

Weak lensing approaches on Dark Matter and Dark Energy distributions

Cyrus Walther

June 24, 2022

Presentation in the Seminar:
Astro-particle physics II



- The missing 95% of the universe and why to investigate them
 - ▶ Dark Energy
 - ▶ Dark Matter

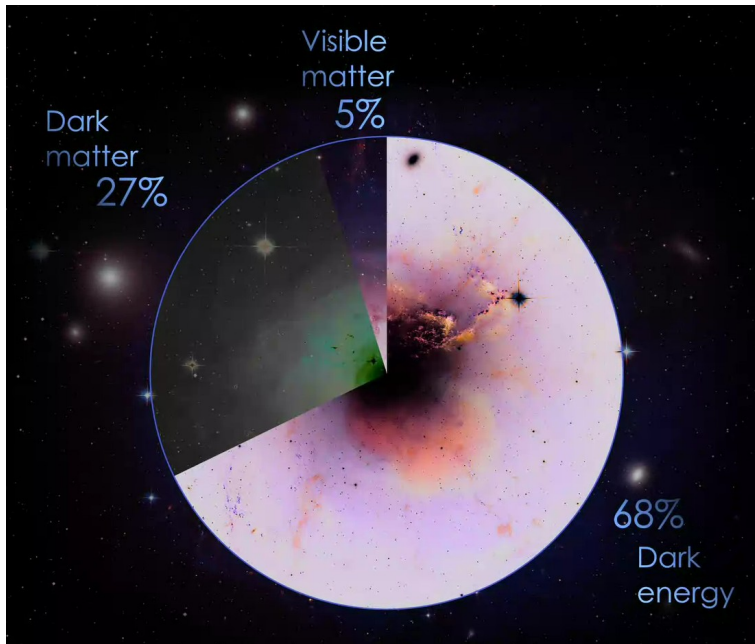
- The missing 95% of the universe and why to investigate them
 - ▶ Dark Energy
 - ▶ Dark Matter

- The concept of gravitational lensing
 - ▶ Conceptual idea
 - ▶ Usage in research

Contents

- The missing 95% of the universe and why to investigate them
 - ▶ Dark Energy
 - ▶ Dark Matter
- The concept of gravitational lensing
 - ▶ Conceptual idea
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- Experimental observation and outlook
 - ▶ Dark Energy Survey
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 - ▶ DES Y3 Results
 - ▶ DES Y3 and the CMB
 - ▶ Conclusions and future projects

The missing 95% of the universe and why to investigate them



¹<https://svs.gsfc.nasa.gov/12307>

Dark Energy:

²https://en.wikipedia.org/wiki/Accelerating_expansion_of_the_universe

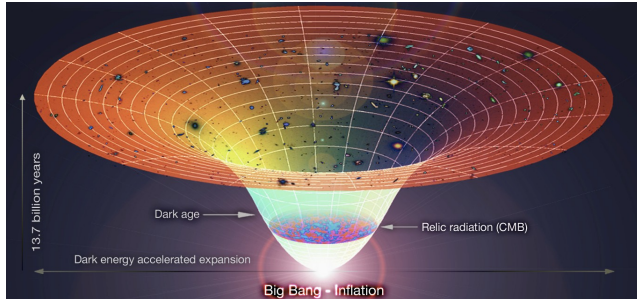
Dark Energy:

- Dark energy is a construct to explain the accelerating expansion of the universe
 - ⇒ Dark energy countervailing the gravitational force of visible matter
- It can be used as an explanation of the inhomogeneous CMB
- One candidate for dark energy is the cosmological constant in general relativity following the Λ -CDM theory (the standard model of cosmology)

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Dark Matter:

³ZWICKY, Fritz. Die rotverschiebung von extragalaktischen nebeln. Helvetica physica acta, 1933, 6. Jg., S. 110-127.

Dark Matter:

■ Dark matter:

- ▶ Interacts gravitationally
- ▶ Does not interact electromagnetically
- ▶ Researchers hope dark matter interacts through the weak interaction
- ▶ Is neither included in the Standard Model of Particle Physics nor in general relativity

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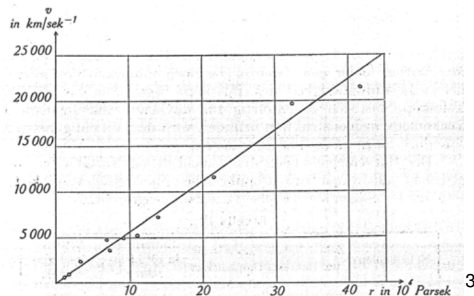
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The concept of gravitational lensing

Conceptual idea

- The gravitational lensing spectrum is divided in strong and weak lensing
 - ⇒ Only weak lensing will be discussed in this presentation

⁴Weak lensing: Dark Matter, Dark Energy and Dark Gravity, arXiv:0911.0350v1

⁵<https://kids.strw.leidenuniv.nl/DR4>

Conceptual idea

- The gravitational lensing spectrum is divided in strong and weak lensing
 - ⇒ Only weak lensing will be discussed in this presentation
- Weak lensing results from inhomogeneous mass distributions like galaxy clusters
- Electromagnetic waves are deflected along the travel path
- The effects are small distortions in the shape, size and brightness of objects
- Due to the signal-to-noise ratio shape distortions called shears are mostly analysed ⁴

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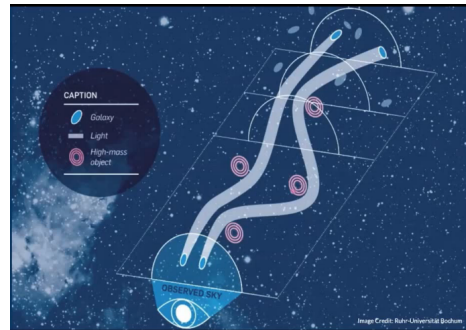
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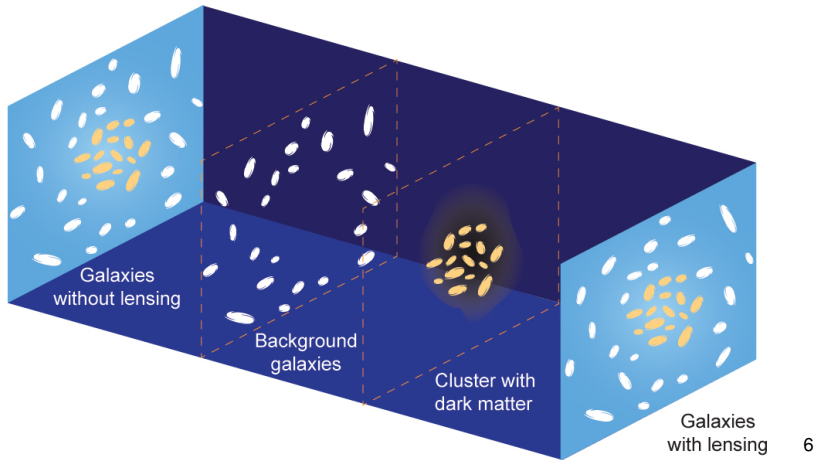
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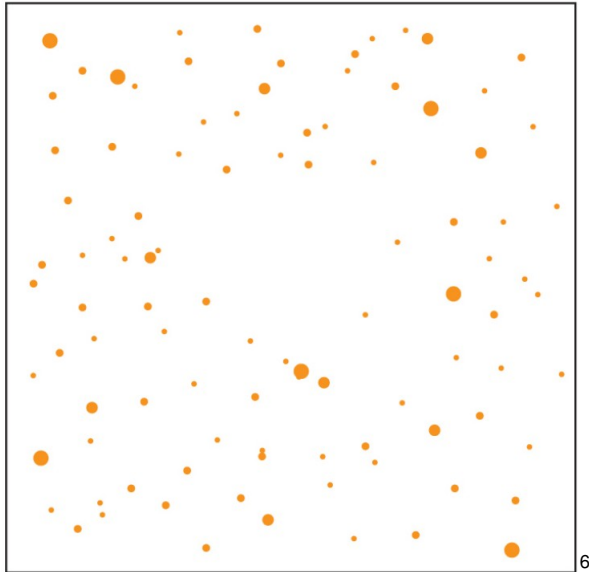
- Single observations will not show enough shear to lead to weak lensing
- Multiple shear measurements around the same lensing source will show a correlation developing an anisotropy in the orientation of the galaxies
- The mass distribution can be investigated using the systematic alignment of the shear measurements
- Weak lensing depends only on the mass distribution not on its dynamical state or composition
⇒ **Measures also dark matter**
- Comparing measured mass distributions to luminous matter draws conclusions about possible dark matter effects

Weak lensing



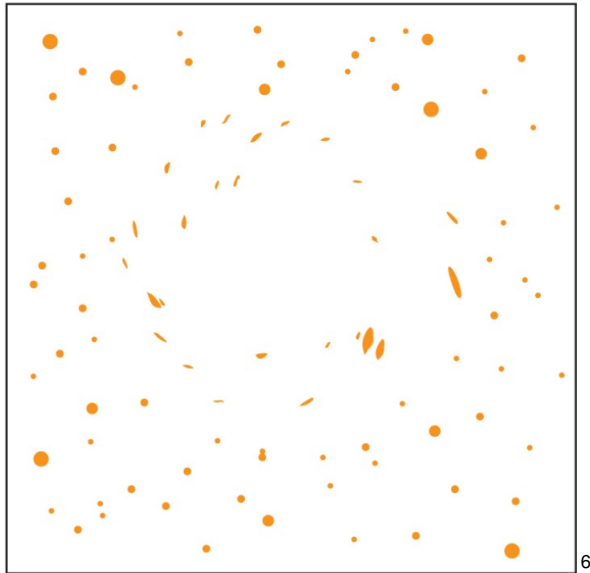
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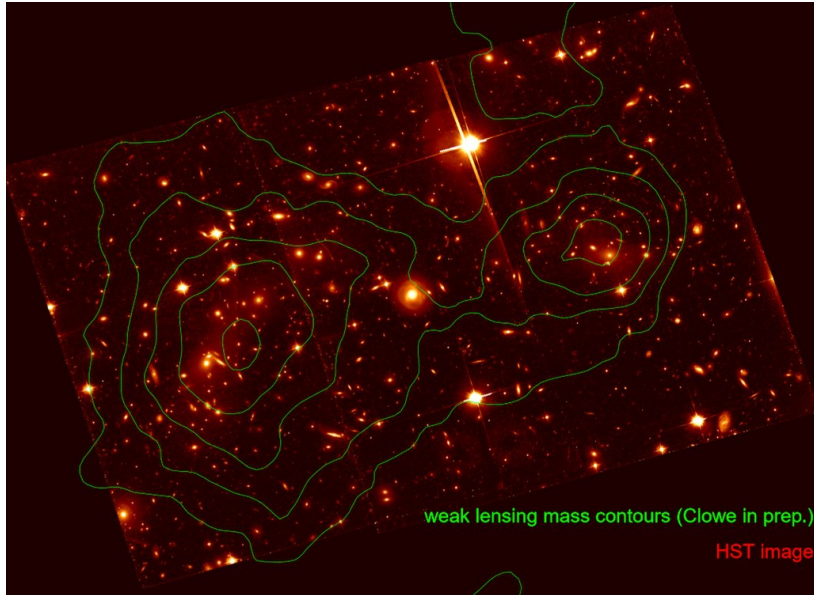


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Usage in research

- The first detection of a cosmic shear (change of shape) was only made in 2000
⇒ Very young field of analysis
- Due to its nature, weak lensing is able to investigate high redshift targets
- Weak lensing requires high quantities of measurements to reduce statistical uncertainties
⇒ Galaxy surveys and sky surveys are used to map major parts of the sky ⇒ Mass mapping
- Dark matter maps can be compared with optical or x-ray maps to find coherence in both distributions

Usage in research



⁷https://en.wikipedia.org/wiki/Weak_gravitational_lensing#/media/File:Bullet_cluster_lensing.jpg

Experimental observation and outlook

Dark Energy Survey (DES)

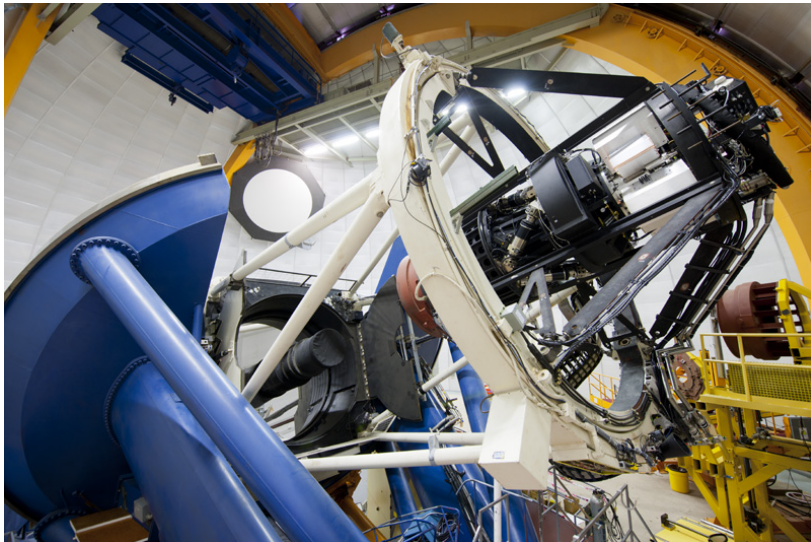
- Phenomena of interest are:
 - ▶ Type Ia supernovae \Rightarrow Usage as standard candles
 - ▶ Baryon acoustic oscillations \Rightarrow Measuring the distribution of galaxies
 - ▶ Gravitational lensing and cosmic shear \Rightarrow Investigate matter distribution in the universe
- In over 6 years (2013-2019), 400 scientists have measured 300 million galaxies in 5000 deg^2 of night sky
- So far, only the one year dataset (Y1) and the three year dataset (Y3) have been analyzed

Data taking

- The experiment is located at the Cerro Tololo Inter-American Observatory in Chile surveying parts of the southern hemisphere
- A highly sensitive 570-Megapixel camera was mounted on the Blanco 4-meter telescope to create the survey
- The telescope features with a 3.3 ft main lense the largest optical corrector component in astronomical use ⁸
- Image acquisition is achieved with five filters with a 62 cm diameter and a spectrum from $\lambda = 400 \text{ nm}$ to $\lambda = 1080 \text{ nm}$
- The Hexapod mechanism assures alignment of the optical elements between exposure times

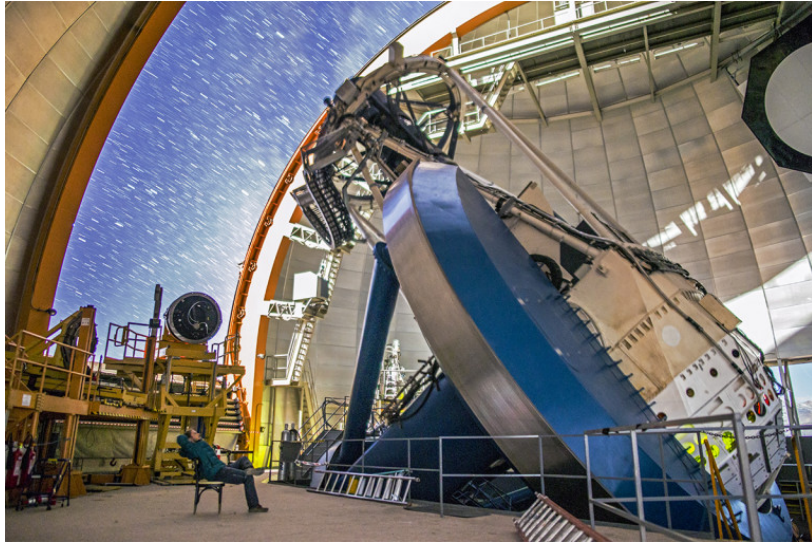
⁸<https://www.darkenergysurvey.org/the-des-project/instrument/>

DECam



⁹<https://www.darkenergysurvey.org/the-des-project/overview/>

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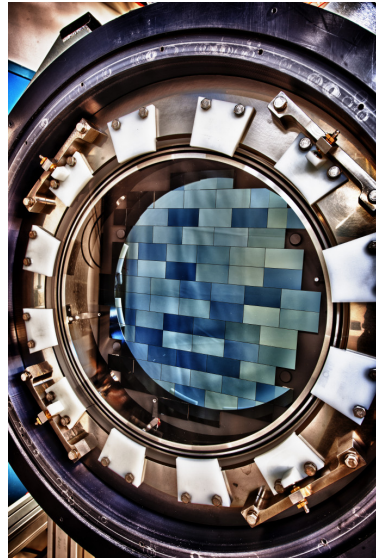
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- The DECam CCDs are specifically designed to observe red shifted light sources
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DES Y3 Results

- In the first 3 years of the DES, an effective area of 4143 deg^2 has been observed
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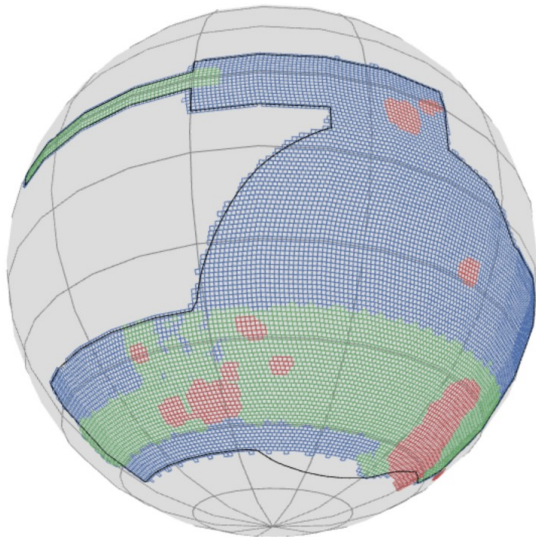
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- Resulting in an average galaxy density of $n_{eff} \approx 5.59 \frac{gal}{r^2}$
- In the observed area the photometric spectrum bands g , r , i , and z have been analyzed
- Only successfully measured objects are considered that were not marked as "anomalous" and that are part of the DES Gold catalogue

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...resulting in a final 326,049,983 objects in the catalogue

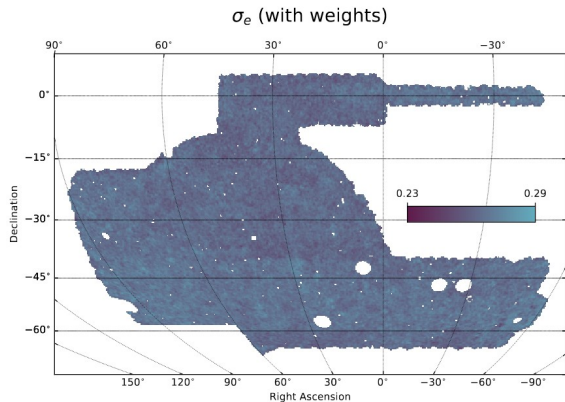
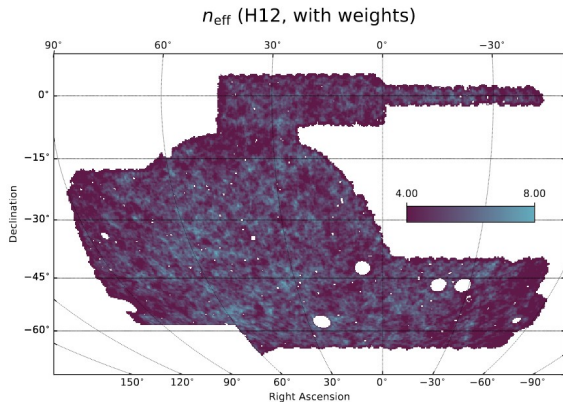
DES Y3 Results



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¹¹Dark Energy Survey Year 3 Results: Weak Lensing Shape Catalogue, arXiv:2011.03408v3, Gatti et al.

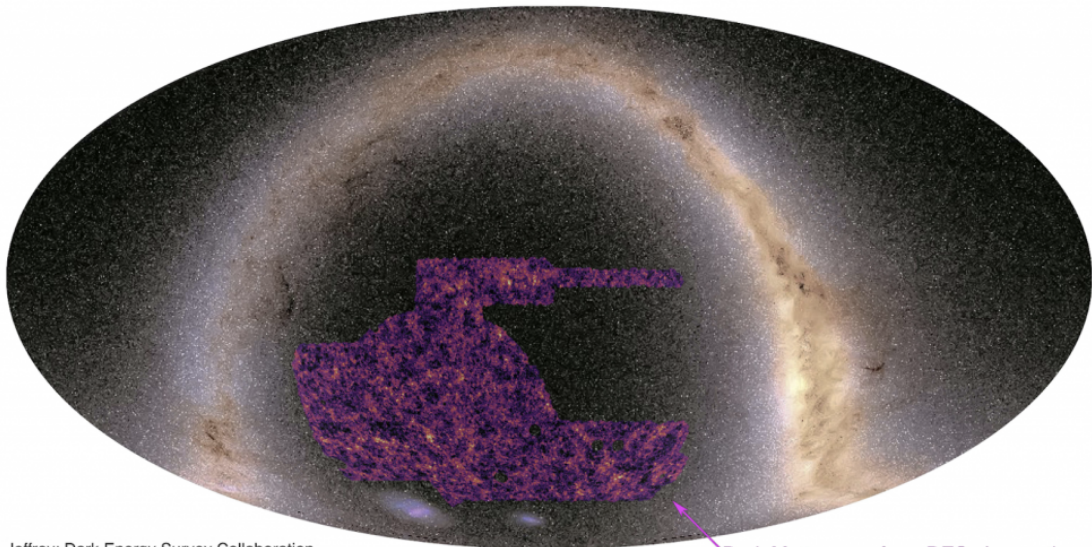
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DES Y3 Results



N. Jeffrey; Dark Energy Survey Collaboration

Dark Matter map from DES observations

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¹²<https://www.darkenergysurvey.org/des-year-3-cosmology-results-papers/>

Idea:

If there are lensing sources in the weak lensing catalog, shouldn't there be the similar lensing sources in the CMB?

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Cross-correlation of weak lensing measurements and lensing in the CMB!

- CMB data sources are the South Pole Telescope(SPT)(2500 deg^2) and the PLANCK(full sky) satellite
- The cross correlation is sensitive to effects of large scale objects
- Results are expected to be robust to systematical uncertainties because of the different analyzed spectra
- CMB lensing objects peak at $z \approx 2$ whereas the weak lensing catalogue peaks at $z \leq 1$
⇒ Combination with the CMB lensing is expected to increase the signal-to-noise ratio

DES Y3 and the CMB:Results

- The comparison of both lensing maps reaches a signal-to-noise ratio of ≈ 20
- The main effect diminishing the signal-to-noise ratio is the uncertainty in modeling nonlinear galaxy bias
 - ⇒ Leads to a removal of small angle correlations
- The cross correlations constraint the cosmic parameter to:¹³

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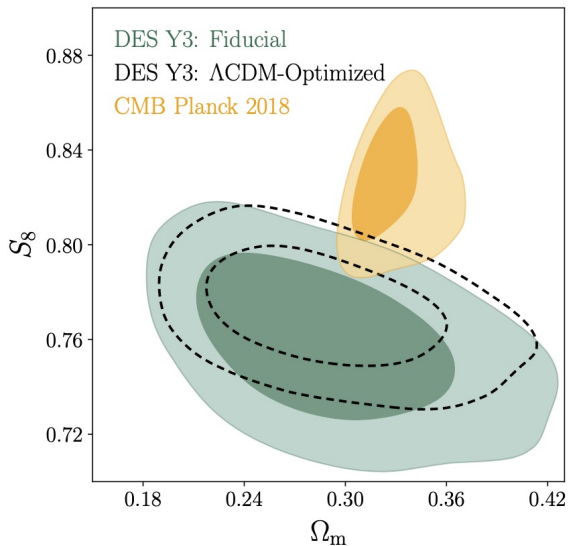
$$\Omega_m = 0.272^{+0.032}_{-0.052}$$

$$S_8 = 0.736^{+0.032}_{-0.028}$$

- Competitive constrains are made only with galaxy-CMB lensing comparison
- An additional comparison with the DES Y3 3x2pt data set is yet to come

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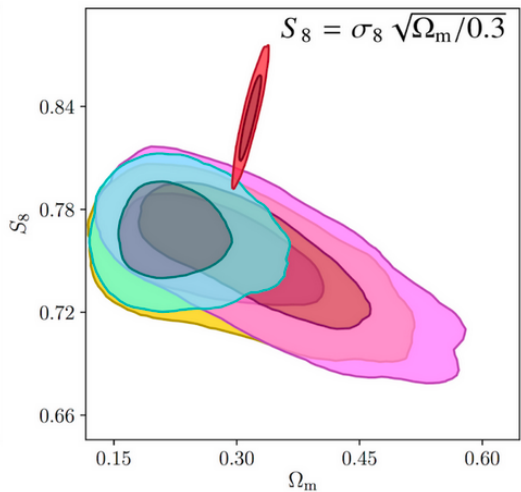
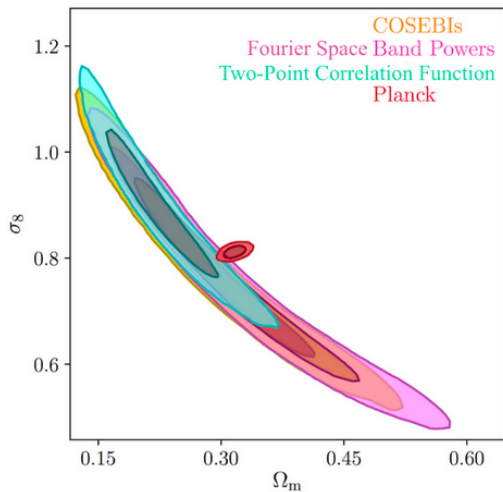
DES Y3 and the CMB: Results



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¹⁴Dark Energy Survey Year 3 Results: Cosmology from Cosmic Shear and Robustness to Data Calibration, arXiv:2105.13543v1, A. Amon et al.

DES Y3 and the CMB: Results



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- The DES was able to create a $\approx 5000 \text{ deg}^2$ weak lensing map measuring competitive constrains
- The analysis of the DES Y6 data set will bring even more detail to the weak lensing map
- There are significant opportunities in CMB lensing comparisons to improve constraints and increase robustness
- It is desirable to measure a complete weak lensing map to allow for an overall comparison with the CMB and to understand the large scale mass and energy distribution of the universe

Thanks for your attention!



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Any Questions?

¹⁵<https://www.darkenergysurvey.org/desendofnights/>