The cosmic microwave background (CMB) 400,000 years after the Big Bang

Image: ESA & the Planck Collaboration
PRECISION COSMOLOGY

Planck Collaboration

WL Cosmology: Challenges & Opportunities

Elisa Chisari
PRECISION COSMOLOGY

- Cosmological constant, $\Lambda$
- Dynamical field, $p = \mathcal{w}c^2\rho$
- Modification of gravity.

Planck Collaboration
PRECISION COSMOLOGY

LARGE-SCALE STRUCTURE

- Afterglow Light Pattern 375,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.
- Big Bang Expansion 13.77 billion years

WL Cosmology: Challenges & Opportunities 3 Elisa Chisari
WEAK GRAVITATIONAL LENSING

- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Afterglow Light Pattern 375,000 yrs.
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.
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Precision cosmology with galaxy surveys

Gravitational lensing
Precision cosmology with galaxy surveys

Gravitational lensing

Theoretical challenges

I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies
Outline

Precision cosmology with galaxy surveys

Gravitational lensing

Theoretical challenges

I. Modelling the distribution of matter
II. Intrinsic alignments of galaxies

New opportunities

Cosmology with intrinsic alignments
GRAVITATIONAL LENSING

Image: NASA/ESA
GRAVITATIONAL LENSING

Growth of matter perturbations
GRAVITATIONAL LENSING

Distance-redshift relation
Growth of matter perturbations
GRAVITATIONAL LENSING

Tomography

Distance-redshift relation

Growth of matter perturbations

Image: NASA/ESA

WL Cosmology: Challenges & Opportunities

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Strong lensing is rare
Weak lensing can be measured statistically

\[ \delta \approx 1\% \]
COSMOLOGY WITH LENSLING SURVEYS

SDSS

Kilo-Degree Survey

Euclid (2021)

LSST (2021)

CFHTLenS

DES

HSC

WFIRST (2025)
**COSMOLOGY WITH LENSING SURVEYS**

\[ w = w_0 + w_a (1 - \alpha) \]

*KiDS-450*

Joudaki+, KiDS collaboration, 2016

see also: DES Y1, 2017

Hikage+, 2018
\( w = w_0 + w_\alpha (1 - \alpha) \)

KiDS-450

Joudaki +, KiDS collaboration, 2016

see also: DES Y1, 2017

Hikage +, 2018

LSST DESC SRD v1

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Combining probes: cross-correlation with CMB lensing

Harnois-Déraps, Troester, Chisari+ (KiDS collaboration, 2017)
I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies
I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies
I. MODELLING THE DISTRIBUTION OF MATTER

Cosmic shear in an LSST-like survey, Eifler+ (2015)
See also Semboloni+ (2011), Huang+ (2018)
COSMOLOGICAL SIMULATIONS

Image: J. Devriendt, Horizon-AGN
**Horizon-AGN**

*(PI Y. Dubois, Co-Is: J. Devriendt & C. Pichon)*

- 6 million CPU hours
- $(100 \text{ Mpc}/h)^3$ comoving volume
- $1024^3$ dark matter particles
- spatial resolution 1 kpc
- stellar mass resolution $10^6 \, M_{\text{Sun}}$
- dark matter mass resolution $10^8 \, M_{\text{Sun}}$
- $\sim 150,000$ galaxies formed by $z=0$
Horizon-AGN
(PI Y. Dubois, Co-Is: J. Devriendt & C. Pichon)

6 million CPU hours

$(100 \text{ Mpc/h})^3$ comoving volume

$1024^3$ dark matter particles

spatial resolution $1 \text{ kpc}$

stellar mass resolution $10^6 \text{ M}_\odot$

dark matter mass resolution $10^8 \text{ M}_\odot$

$\sim 150,000$ galaxies formed by $z=0$

Horizon-noAGN
no energy injection by Active Galactic Nuclei

Horizon-DM
pure dark matter

Image: J. Devriendt, Horizon-AGN
1. MODELLING THE DISTRIBUTION OF MATTER

\[ \delta(x, z) = \frac{\rho(x, z)}{\bar{\rho}(z)} - 1 \]

Density field

\[ P(k) = \langle |\delta_k|^2 \rangle \]

Total matter power spectrum
I. MODELLING THE DISTRIBUTION OF MATTER

$P(k) = \langle |\delta_k|^2 \rangle$

**Requirement**
I. MODELLING THE DISTRIBUTION OF MATTER

$P(k) = \langle |\delta_k|^2 \rangle$

Chisari+ (2018)
1. MODELLING THE DISTRIBUTION OF MATTER

\[ P(k) = \langle |\delta_k|^2 \rangle \]

- Horizon-AGN
- Horizon-noAGN
- OWLS
- Illustris
- Illustris TNG100
- Illustris TNG300
- EAGLE

Impact of baryons (%)

\[ z = 0 \]

\[ k [h/\text{Mpc}] \]

Small scales

Chisari+ (2018)
van Daalen+ (2011)
Vogelsberger+ (2014)
Hellwing+ (2016)
Springel+ (2017)
X-ray/SZ synergies could help us constrain the impact of baryons.

\( f_{\text{gas}} \) vs. \( M_{500} \) for different samples:
- Horizon-AGN
- \( \Omega_b/\Omega_m \)
- Sun+ (2009)

References:
- Chisari+ (2018)
- Schneider+ (2018)
- see also Semoboloni+ (2011/3)
I. MODELLING THE DISTRIBUTION OF MATTER

A model for halos with baryons: stars + gas + DM

- Use constraints from observations
- Do not rely on simulations as priors
- But verify against simulations, ~ few per cent agreement

Schneider+ (2018)
I. MODELLING THE DISTRIBUTION OF MATTER

THE IMPACT ON THE DARK MATTER DISTRIBUTION

Chisari+ (2018)
I. MODELLING THE DISTRIBUTION OF MATTER

REDSHIFT EVOLUTION IN DIFFERENT HYDRO SIMS

Chisari+ (2018)
I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies
II. INTRINSIC ALIGNMENTS

Bias in cosmology due to galaxy alignments

Krause+ (2015)
II. INTRINSIC ALIGNMENTS

Galaxy shapes = Lensing + Intrinsic alignment + Noise

\[ SS = GG + GI + IG + II + \text{Noise} \]
II. INTRINSIC ALIGNMENTS

Galaxy shapes $\sim$ Tidal field of the large-scale structure

Catelan+ (2001)
II. INTRINSIC ALIGNMENTS

Galaxy shapes $\sim$ Tidal field of the large-scale structure

SDSS LOWZ sample - Singh+ (2014)

Catelan+ (2001)
II. INTRINSIC ALIGNMENTS

Galaxy shapes ~ Tidal field of the large-scale structure

Catelan+ (2001)

KiDS + GAMA - Johnston+, incl. EC (2018)
II. INTRINSIC ALIGNMENTS

Galaxy shapes $\sim \left( \text{Tidal field of the large-scale structure} \right)^2$

Catelan+ (2001)
COSMOLOGICAL SIMULATIONS

Horizon-AGN

(PI Y. Dubois, Co-Is: J. Devriendt & C. Pichon)

6 million CPU hours

$(100 \text{ Mpc/h})^3$ comoving volume

$1024^3$ dark matter particles

spatial resolution 1 kpc

stellar mass resolution $10^6 \, M_{\text{Sun}}$

dark matter mass resolution $10^8 \, M_{\text{Sun}}$

$\sim 150,000$ galaxies formed by $z=0$

Image: J. Devriendt, Horizon-AGN
II. INTRINSIC ALIGNMENTS

DISC GALAXIES ALIGN MIMICKING WEAK LENSING

Chisari+ (2015)
II. INTRINSIC ALIGNMENTS

REDSHIFT, COLOR AND LUMINOSITY DEPENDENCE

Chisari+ (2016)
II. INTRINSIC ALIGNMENTS

SPIN SWINGS IN THE COSMIC WEB

Perpendicular

Parallel

$1 + \text{Excess Probability}$

More likely

Less likely

Dubois + (2014)

Codis + (2018)
II. INTRINSIC ALIGNMENTS

MERGERS AS DRIVERS OF SPIN SWINGS

Welker+ (2014)
Dubois+ (2014)

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II. INTRINSIC ALIGNMENTS

GALAXY-HALO ALIGNMENTS ARE MASS-, TYPE- AND REDSHIFT-DEPENDENT

Chisari, Koukoufilippas+ (2017)
I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies
COSMOLOGY WITH INTRINSIC ALIGNMENTS

Galaxy shapes \sim \text{Tidal field of the large-scale structure}

TESTING THEORIES OF INFLATION

\langle \delta(x) g_{ij}(y) \rangle = b_1^I \langle \delta(x) K_{ij}(y) \rangle + \frac{1}{2} b_2^I \langle \delta(x) \delta(y) K_{ij}(y) \rangle

Gaussian \quad \text{Primordial non-Gaussianity}

Chisari+ (2016)
Schmidt, Chisari & Dvorkin (2015)

Spin-2 particles during inflation
Magnetic fields
Solid inflation
COSMOLOGY WITH INTRINSIC ALIGNMENTS

$\tilde{b}^{I}_{NG} A_2 \quad \text{Scale-dependent bias of intrinsic shapes}$

$A_0 \quad \text{Scale-dependent clustering bias}$

Euclid expected – single-tracer

Schmidt, Chisari & Dvorkin (2015)
COSMOLOGY WITH INTRINSIC ALIGNMENTS

Multi-tracer approach

Schmidt, Chisari & Dvorkin (2015)
Chisari+ (2016)
COSMOLOGY WITH INTRINSIC ALIGNMENTS

Euclid expected – single-tracer

Multi-tracer approach

Schmidt, Chisari & Dvorkin (2015)
Chisari+ (2016)
COSMOLOGY WITH INTRINSIC ALIGNMENTS

Euclid expected – multi-tracer

Multi-tracer approach

\[ \tilde{\gamma}_1, A_2 \]

\[ A_0 \]

Schmidt, Chisari & Dvorkin (2015)
Chisari+ (2016)
SUMMARY

Exciting prospects for weak lensing and combined probes come at a PRICE.

The need to understand & model astrophysical systematics:
- the large-scale distribution of matter &
- intrinsic alignments.

An opportunity to learn about inflation & galaxy formation.