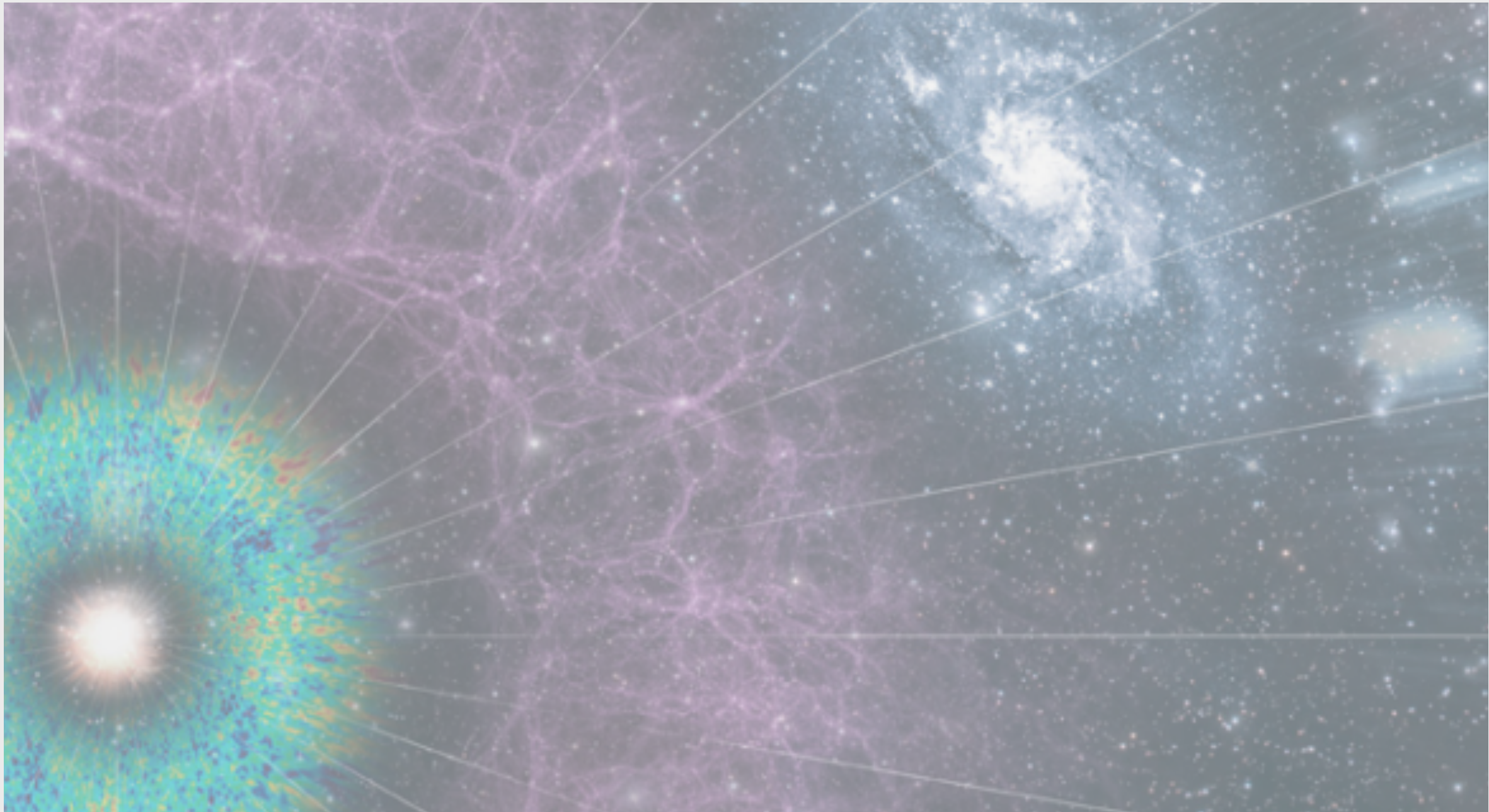


# Integrated approach to cosmology

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Nicola et al., 2016  
arXiv:1607.01014

Andrina Nicola, ETH Zürich  
with Alexandre Refregier and Adam Amara (ETHZ)

21st July 2016, Cairns

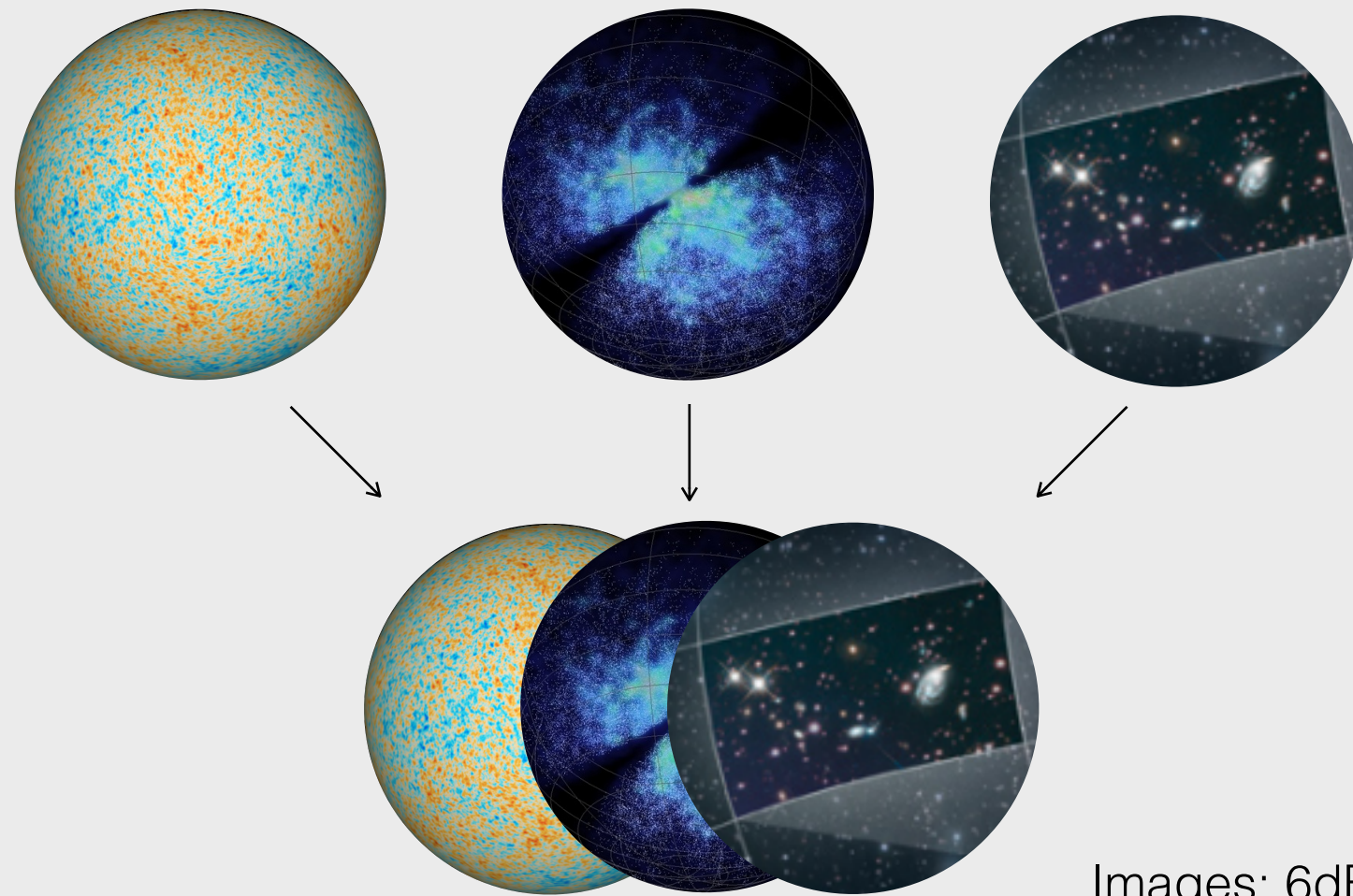
# Cosmological probe combination

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Different cosmological probes are not independent

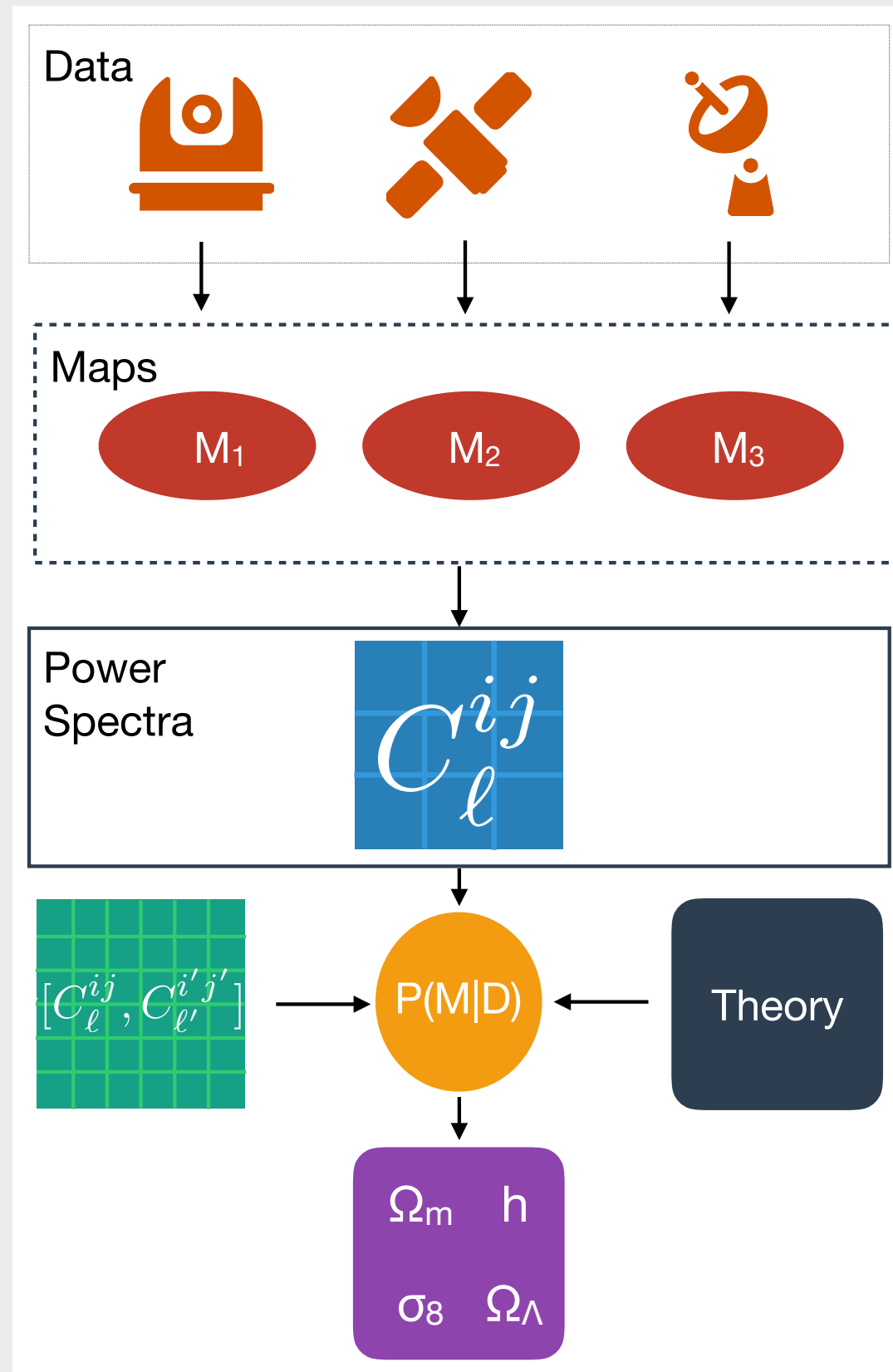
Cross-correlations: systematics identification

Robust tests of cosmological model by comparing consistency of different tracers



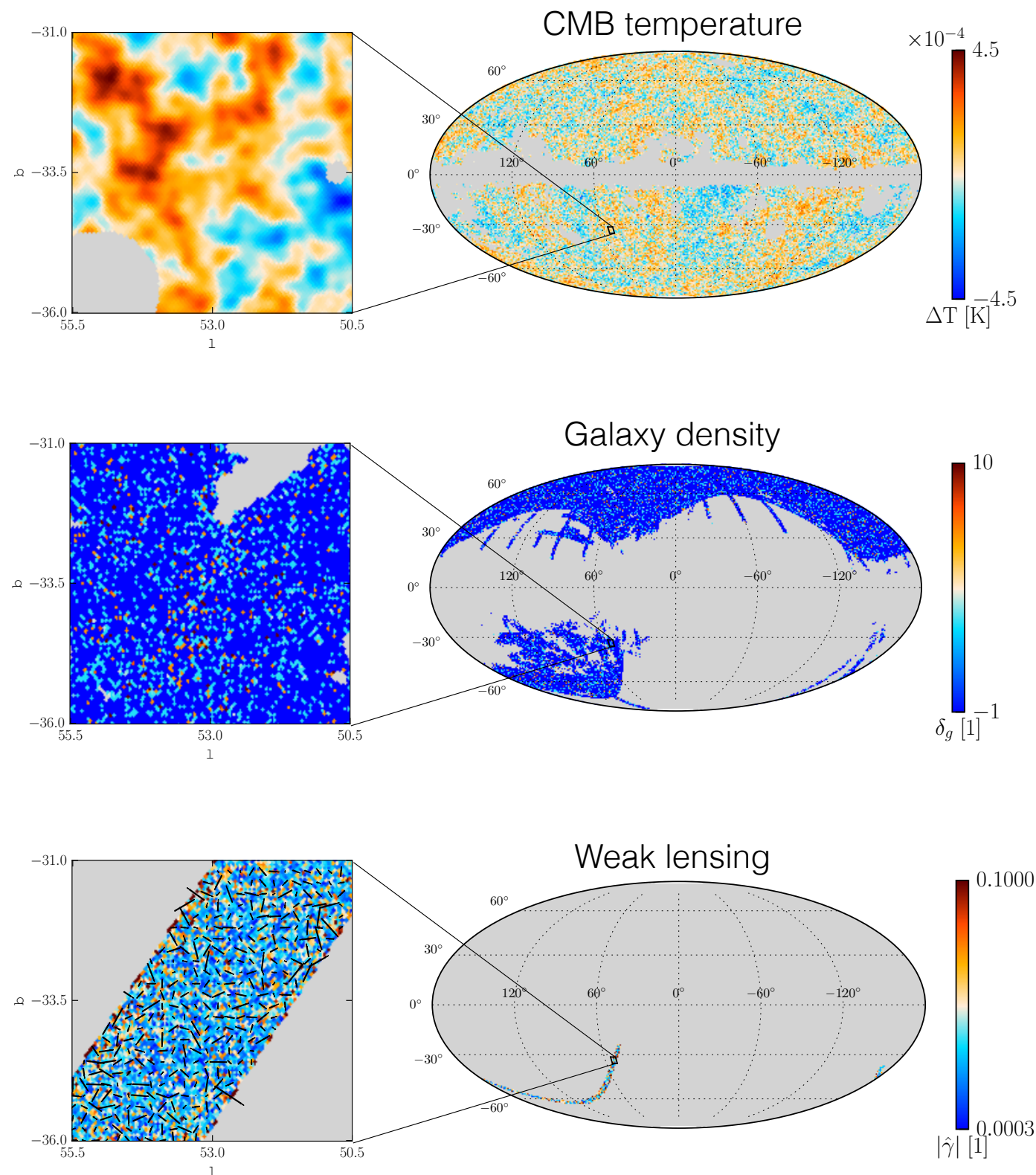
Images: 6dF,  
Planck (Damien P. George)

# Framework





# Maps



CMB:  
Planck 2015  
*Planck Collaboration, 2015*

Galaxy density:  
SDSS DR8 CMASS1-4  
*Aihara et al., 2011,*  
*Ho et al., 2012*

Weak lensing:  
SDSS Stripe 82 co-add  
*Annis et al., 2014,*  
*Lin et al., 2012*

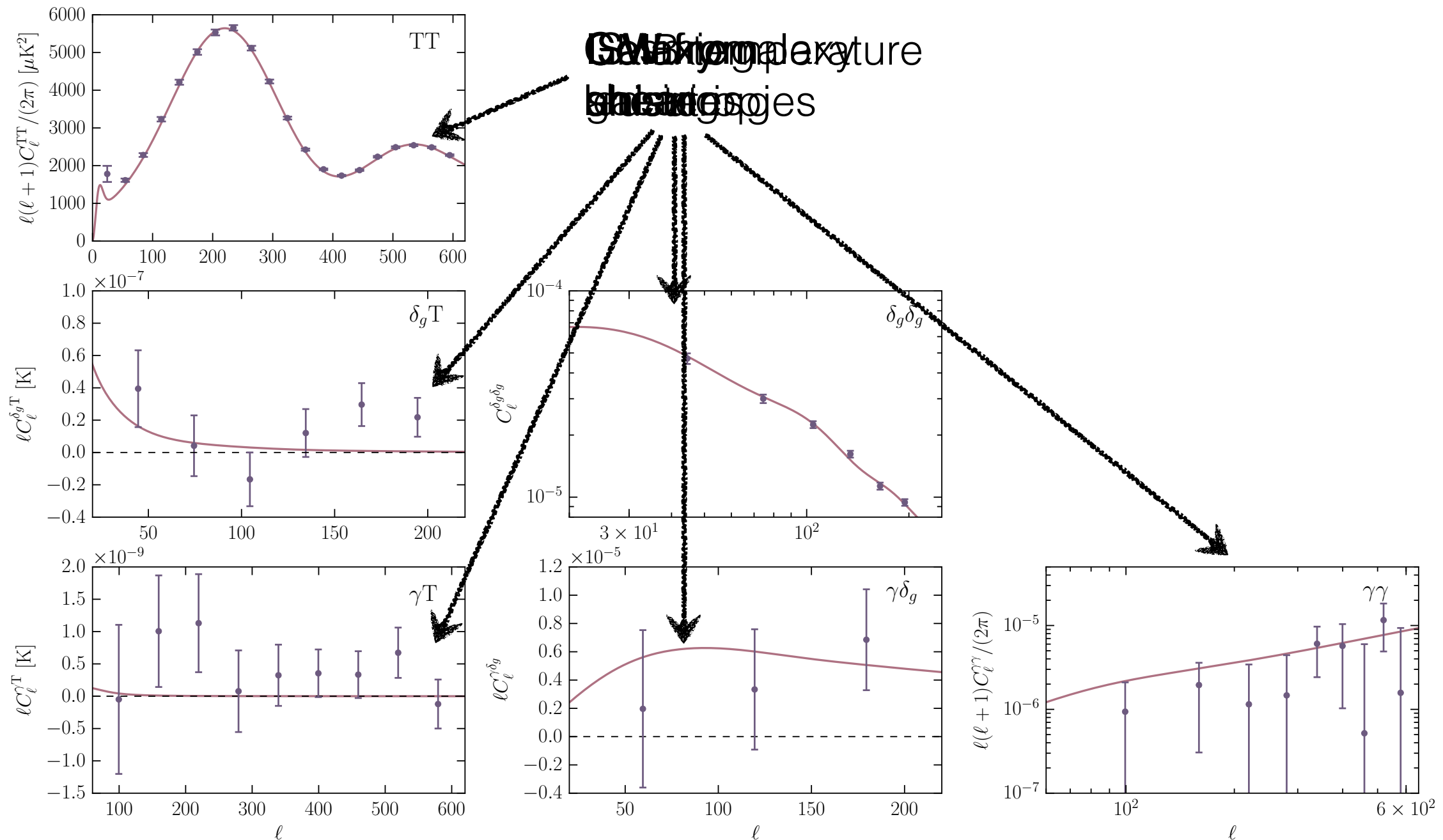
Maps

M<sub>1</sub>

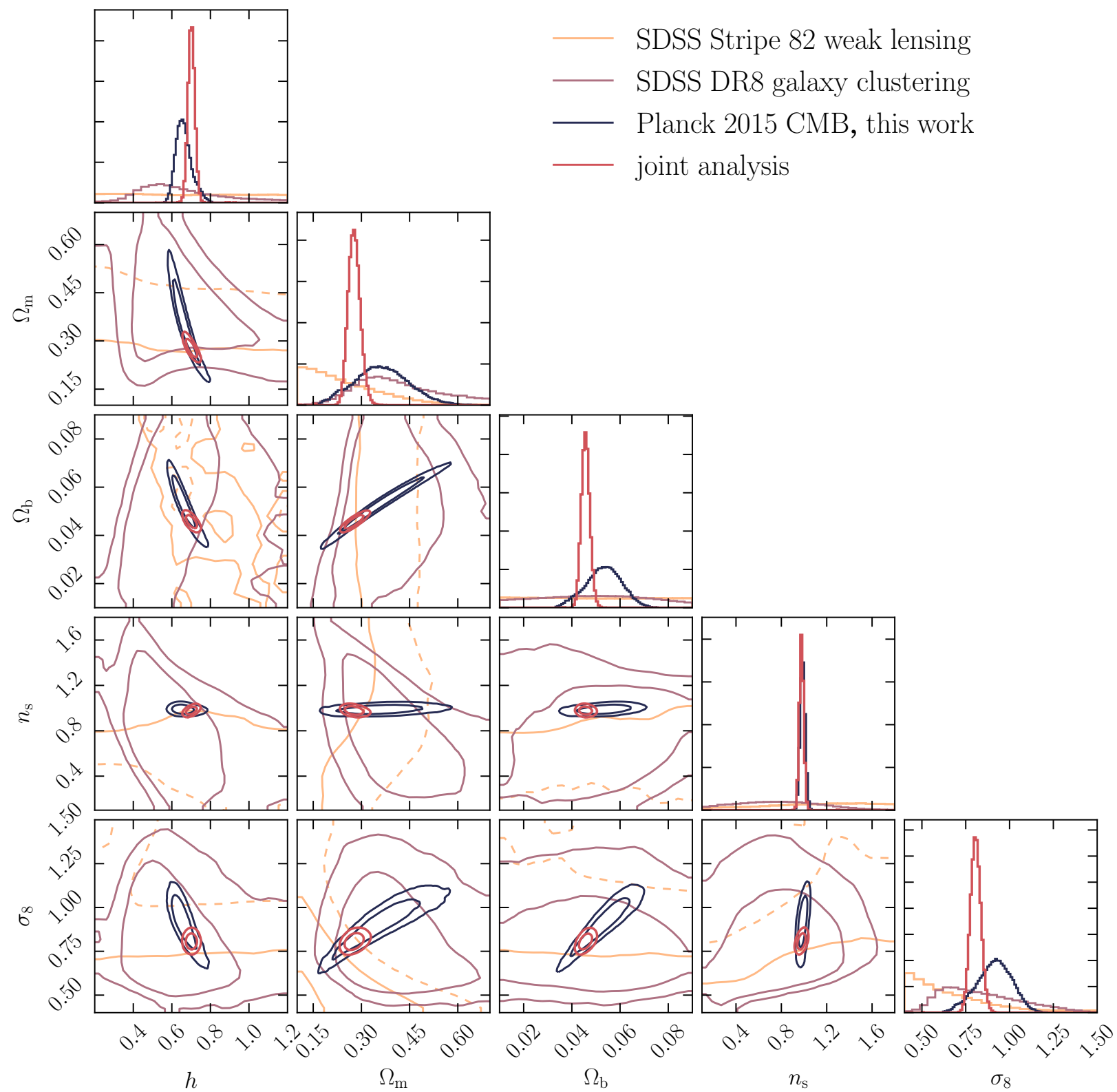
M<sub>2</sub>

M<sub>3</sub>

# Spherical harmonic power spectra



# Cosmological constraints

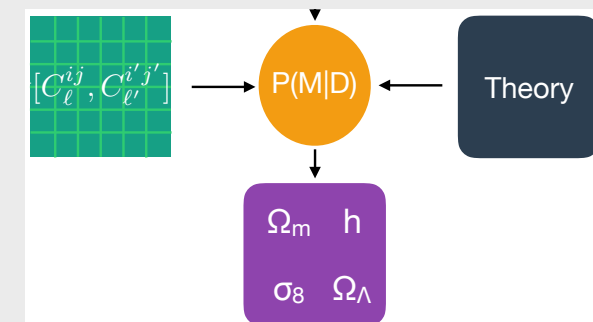


## Additional parameters

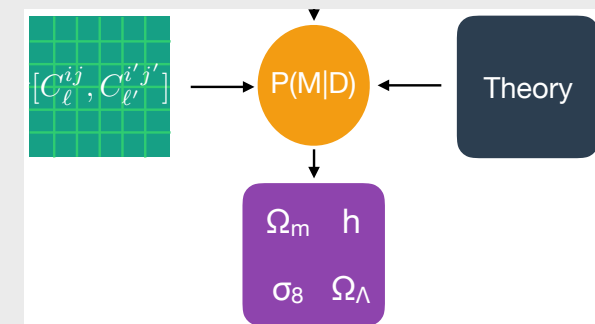
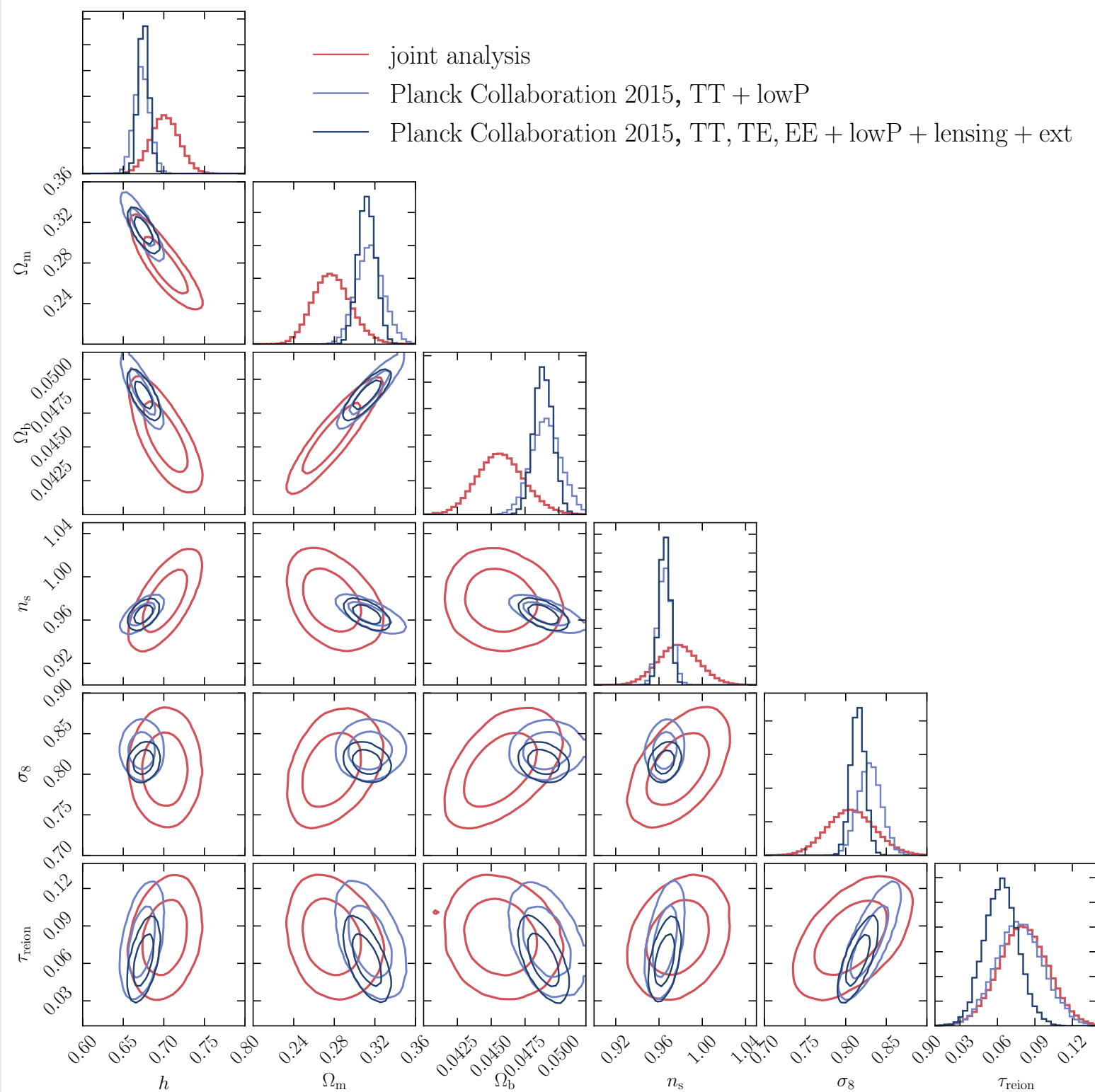
$$\tau_{\text{reion}} = 0.0807^{+0.0198}_{-0.0196}$$

$$b = 2.12 \pm 0.06$$

$$m = -0.160 \pm 0.082$$



# Cosmological constraints



# Conclusions

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Implementation of probe combination framework

First application to CMB, galaxy clustering and weak lensing

Consider all power spectra (3 auto- and 3 cross-spectra)

Conservative cuts and simplifying approximations

Consistent with existing constraints but more conservative

Highlight tensions appearing in joint analysis

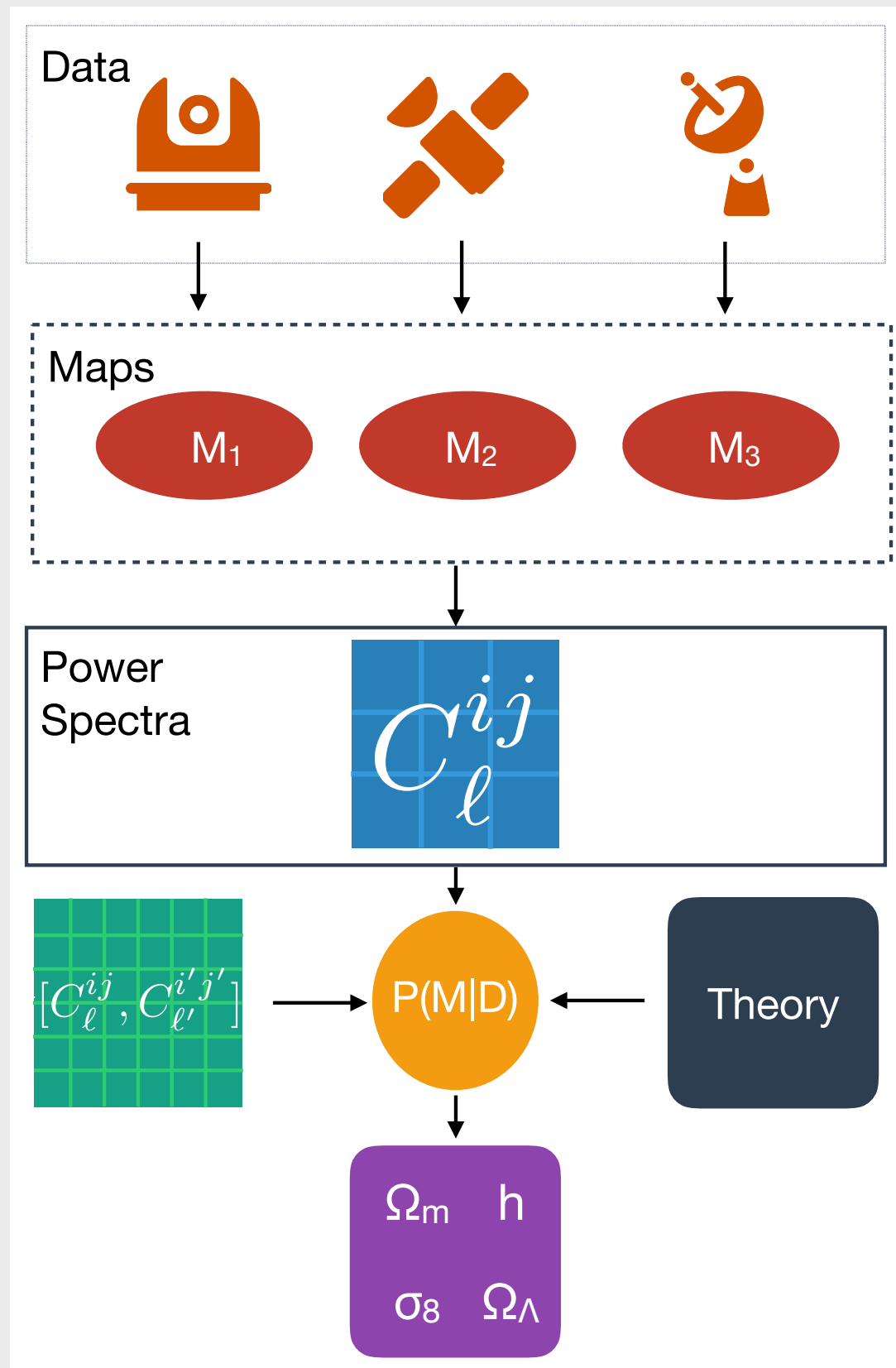
Future work: relax approximations, add cosmological probes, investigate models beyond  $\Lambda$ CDM



# Backup

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# Framework



Data collection

CMB: Planck 2015

Galaxy density: SDSS DR8

Weak lensing: SDSS Stripe 82

HEALPix maps

CMB auto power spectrum: NSIDE = 2048

Rest: NSIDE = 1024

Foreground reduction, PSF correction

Compute the 6 power spectra

using PolSpice (*Szapudi et al., 2001*,  
*Chon et al., 2004*)

3 auto-, 3 cross power spectra

Compute cosmological parameter constraints

Covariance matrix: from Gaussian simulations of  
correlated realisations of the 3 probes

Dimensions: 6x6

Cosmological parameters:  $\{h, \Omega_m, \Omega_b, n_s, \sigma_8\}$

Additional parameters:  $\{\tau_{\text{reion}}, b, m\}$

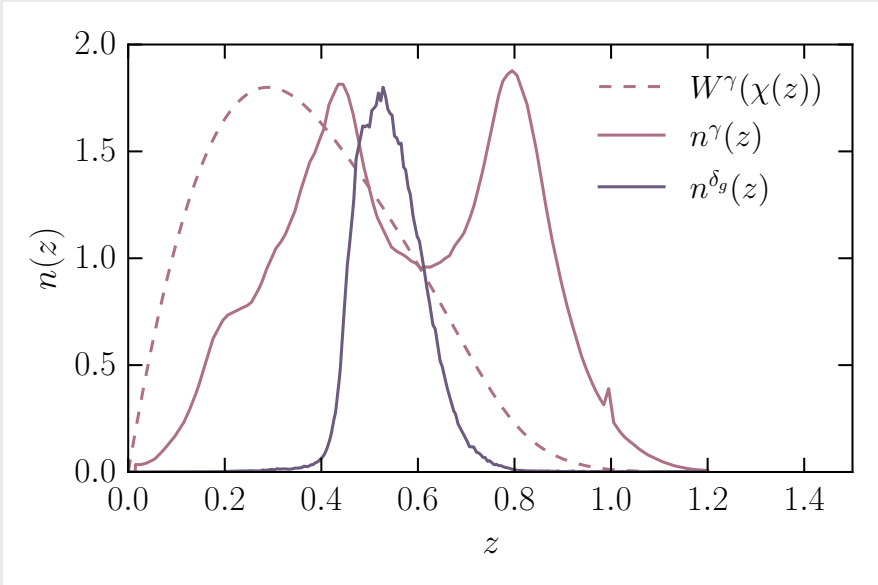
MCMC: CosmoHammer (*Akeret et al., 2013*)

Theory predictions: CLASS (*Lesgourgues et al., 2011*),

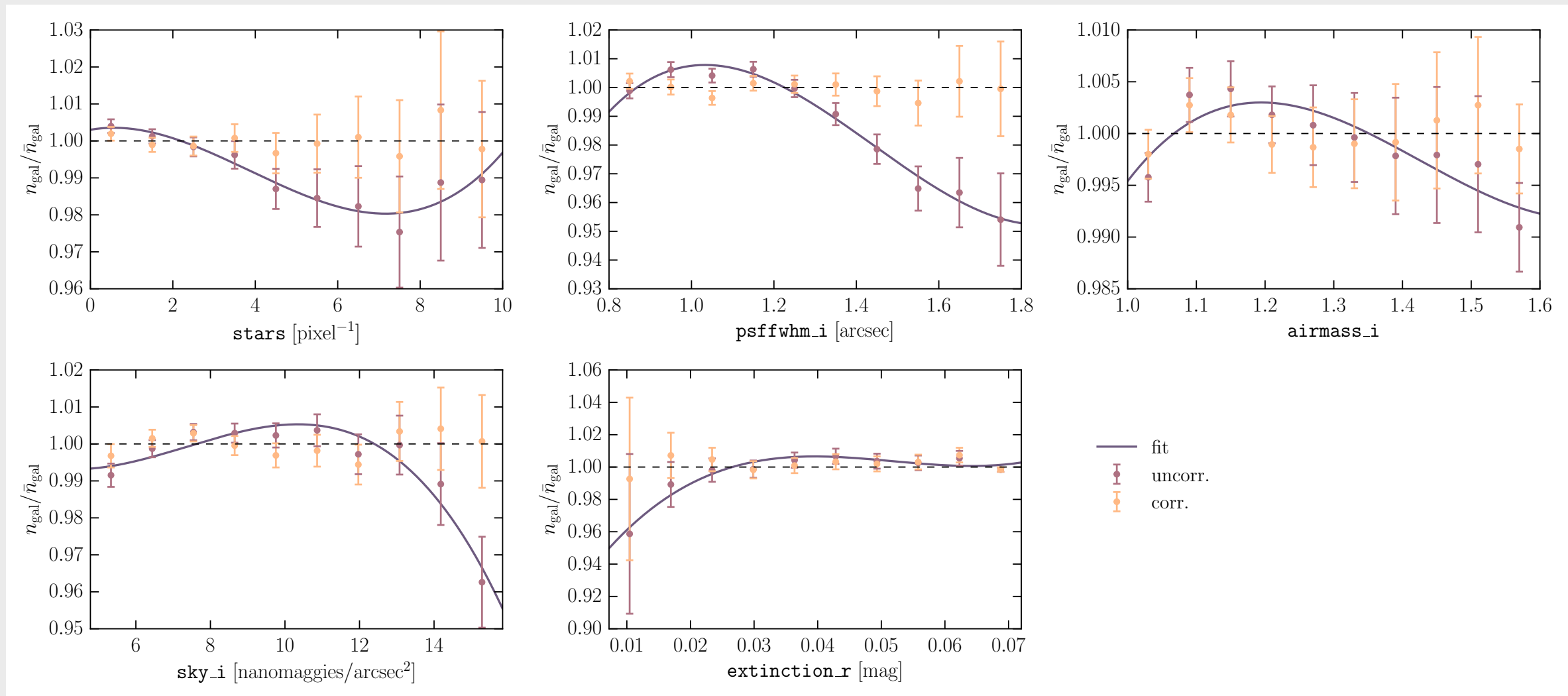
PyCosmo (*Refregier et al., in prep.*)

# Data description

CMB temperature anisotropies	Survey: Planck 2015 Fiducial foreground-reduced map: <b>Commander</b> Sky coverage: $f_{\text{sky}} = 0.776$
galaxy overdensity	Survey: SDSS DR8 Sky coverage: $f_{\text{sky}} = 0.27$ Galaxy sample: CMASS1-4 Number of galaxies: $N_{\text{gal}} = 853\,420$ Photometric redshift range $0.45 \leq z_{\text{phot}} < 0.65$
weak lensing	Survey: SDSS Stripe 82 co-add Sky coverage: $f_{\text{sky}} = 0.0069$ Number of galaxies: $N_{\text{gal}} = 3\,322\,915$ Photometric redshift range: $0.1 \lesssim z_{\text{phot}} \lesssim 1.1$ r.m.s. ellipticity per component: $\sigma_e \sim 0.43$



# Correction for systematic uncertainties in galaxy data



Maps

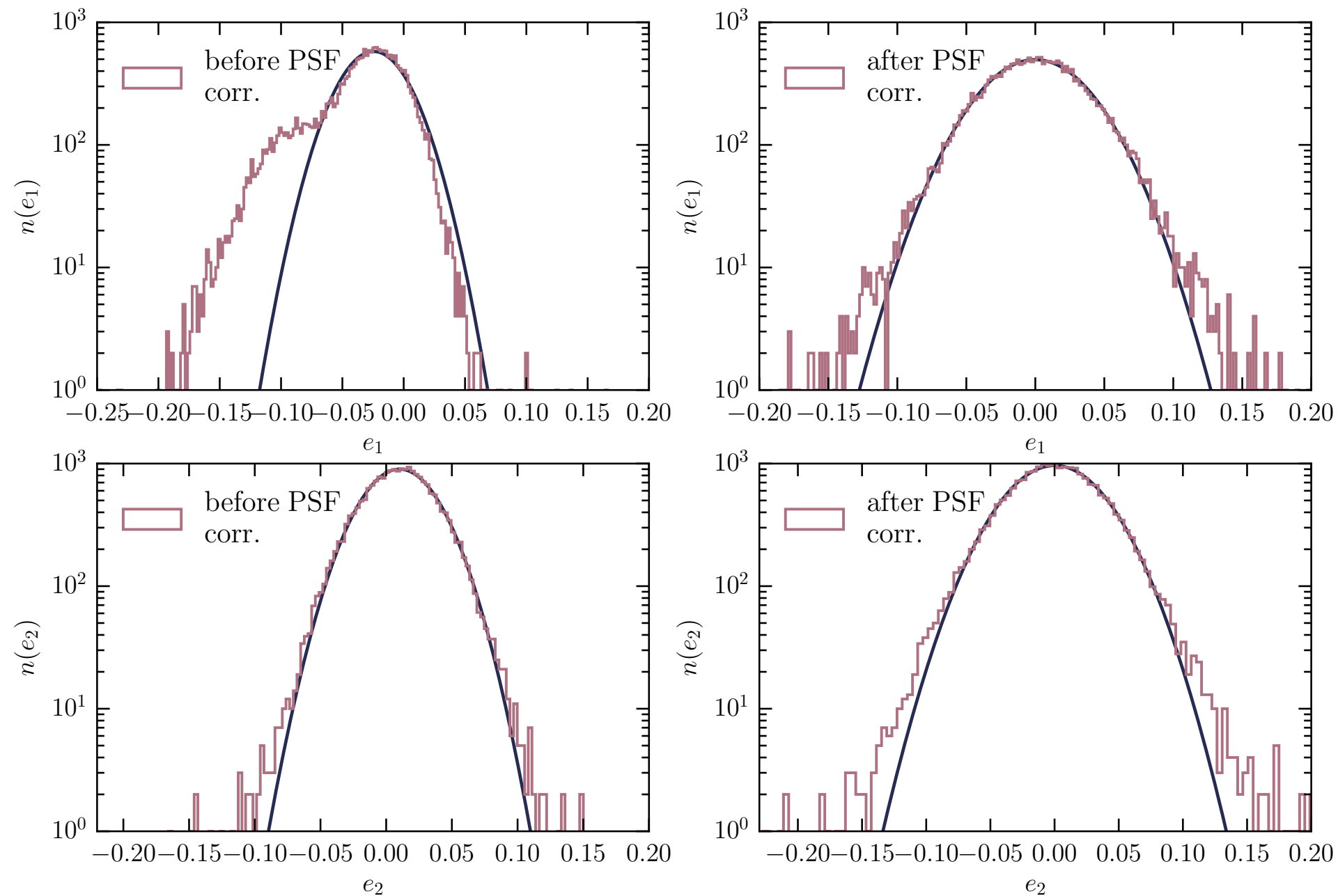
M<sub>1</sub>

M<sub>2</sub>

M<sub>3</sub>



# PSF correction for weak lensing



Linear PSF correction (Hirata & Seljak, 2003)

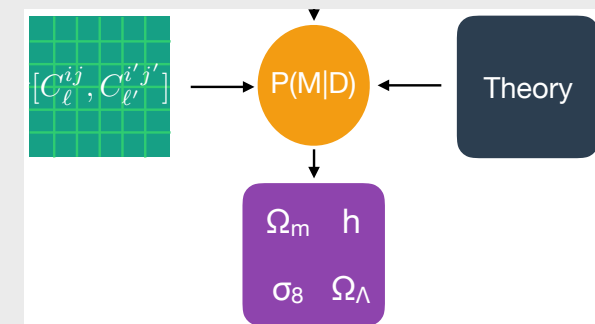
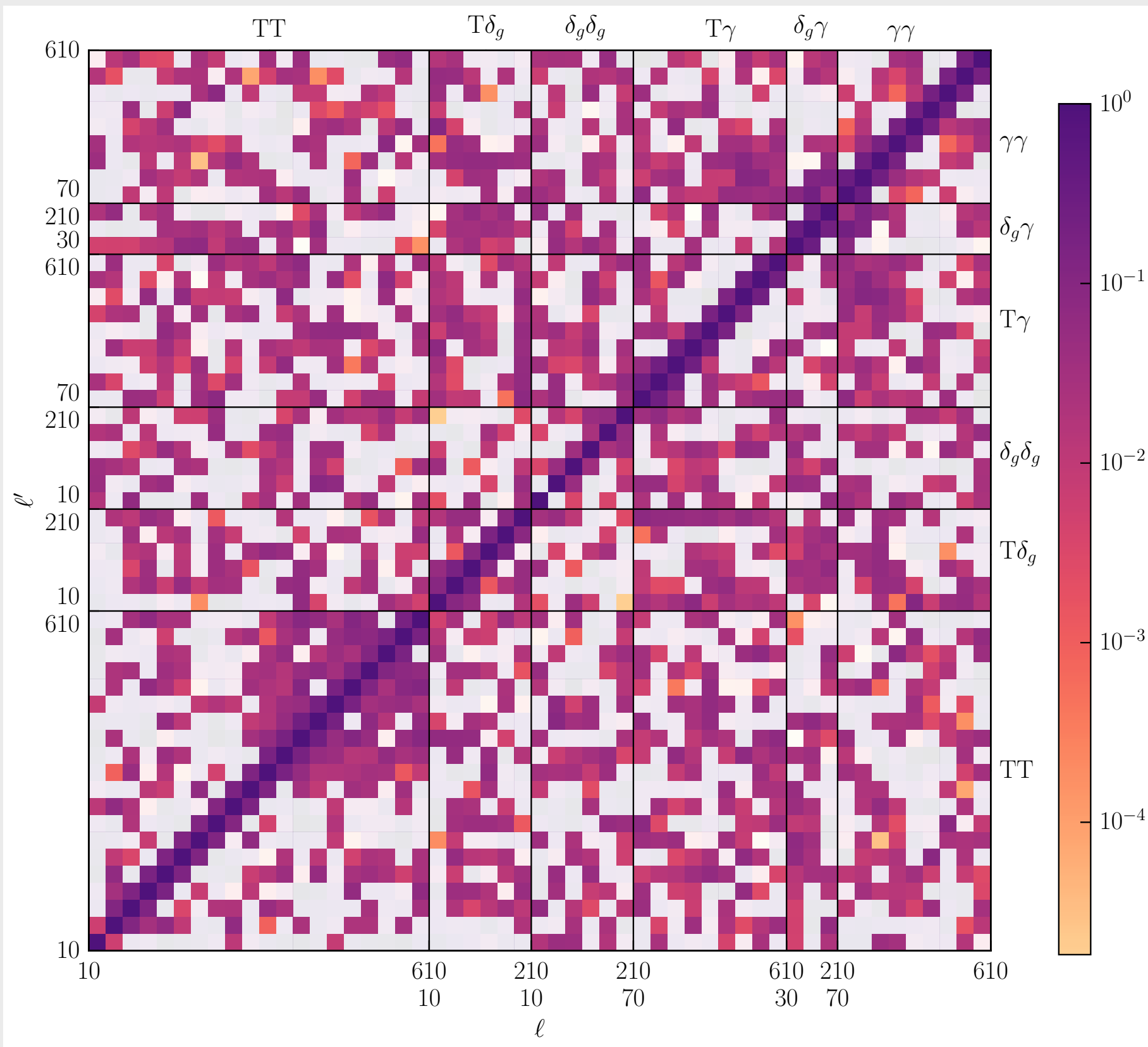
Maps

M<sub>1</sub>

M<sub>2</sub>

M<sub>3</sub>

# Covariance matrix



# Likelihood

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$$\mathcal{L}(D|\theta) \propto e^{-\frac{1}{2}(\mathbf{C}_\ell^{\text{obs}} - \mathbf{C}_\ell^{\text{theor}})^T C_G^{-1} (\mathbf{C}_\ell^{\text{obs}} - \mathbf{C}_\ell^{\text{theor}})}$$

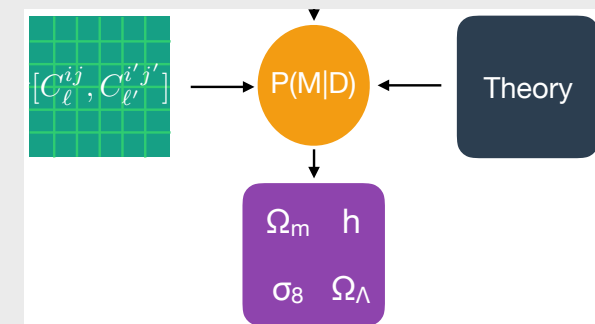
Covariance matrix from Gaussian simulations

Theoretical predictions computed using Limber approximation

MCMC using CosmoHammer (Akeret et al., 2013)

Cosmological parameters:  $\{h, \Omega_m, \Omega_b, n_s, \sigma_8\}$

Additional parameters:  $\{\tau_{\text{reion}}, b, m\}$



# Cosmological parameter constraints

Parameter	Prior	Posterior mean
$h$	flat $\in [0.2, 1.2]$	$0.702^{+0.017}_{-0.018}$
$\Omega_m$	flat $\in [0.1, 0.7]$	$0.278 \pm 0.019$
$\Omega_b$	flat $\in [0.01, 0.09]$	$0.0457 \pm 0.0017$
$n_s$	flat $\in [0.1, 1.8]$	$0.978 \pm 0.019$
$\sigma_8$	flat $\in [0.4, 1.5]$	$0.807 \pm 0.030$
$\tau_{\text{reion}}$	Gaussian with $\mu = 0.089, \sigma = 0.02$	$0.0807^{+0.0198}_{-0.0196}$
$b$	flat $\in [1., 3.]$	$2.12 \pm 0.06$
$m$	Gaussian with $\mu = 0.0, \sigma = 0.1$	$-0.160 \pm 0.082$

