Weak lensing emulators

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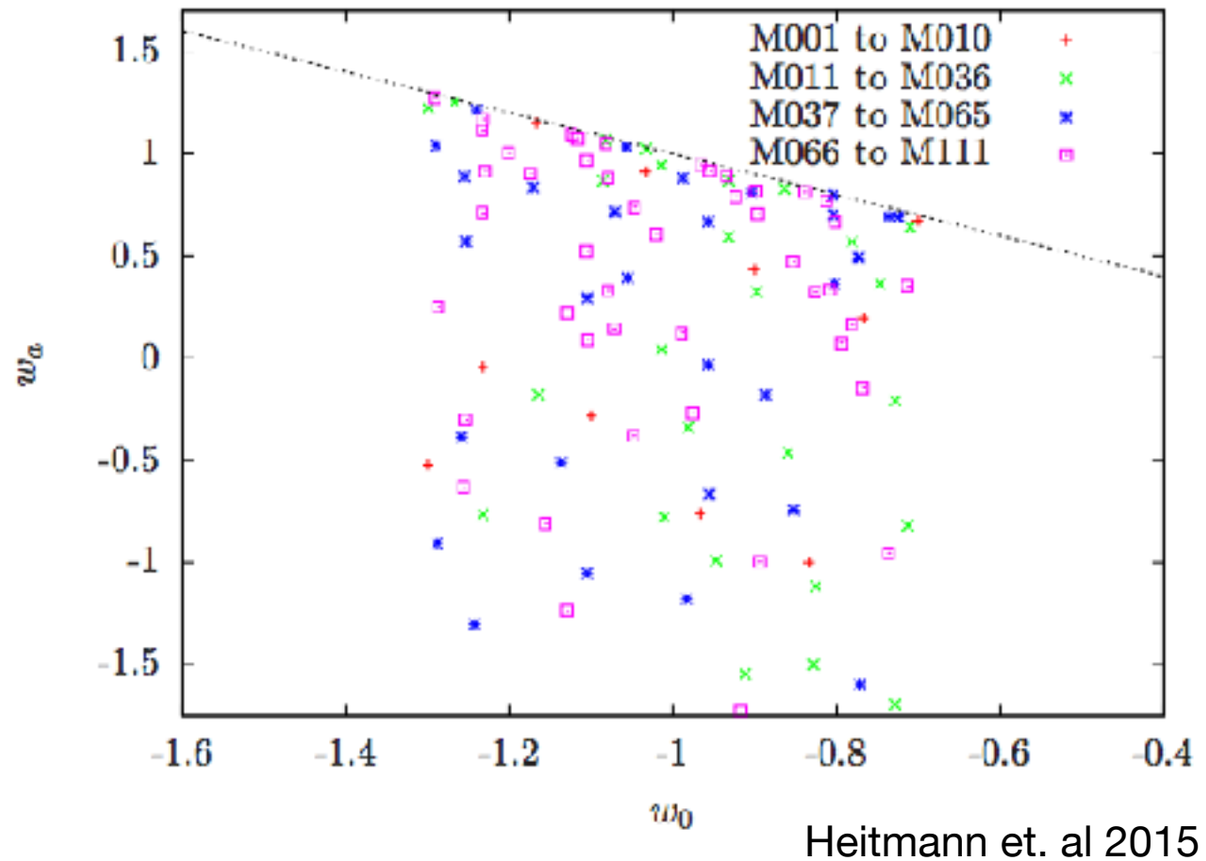
Credit: Nayantara Mudur, Mira-Titan collaboration, CPAC group

Mira-Titan Universe

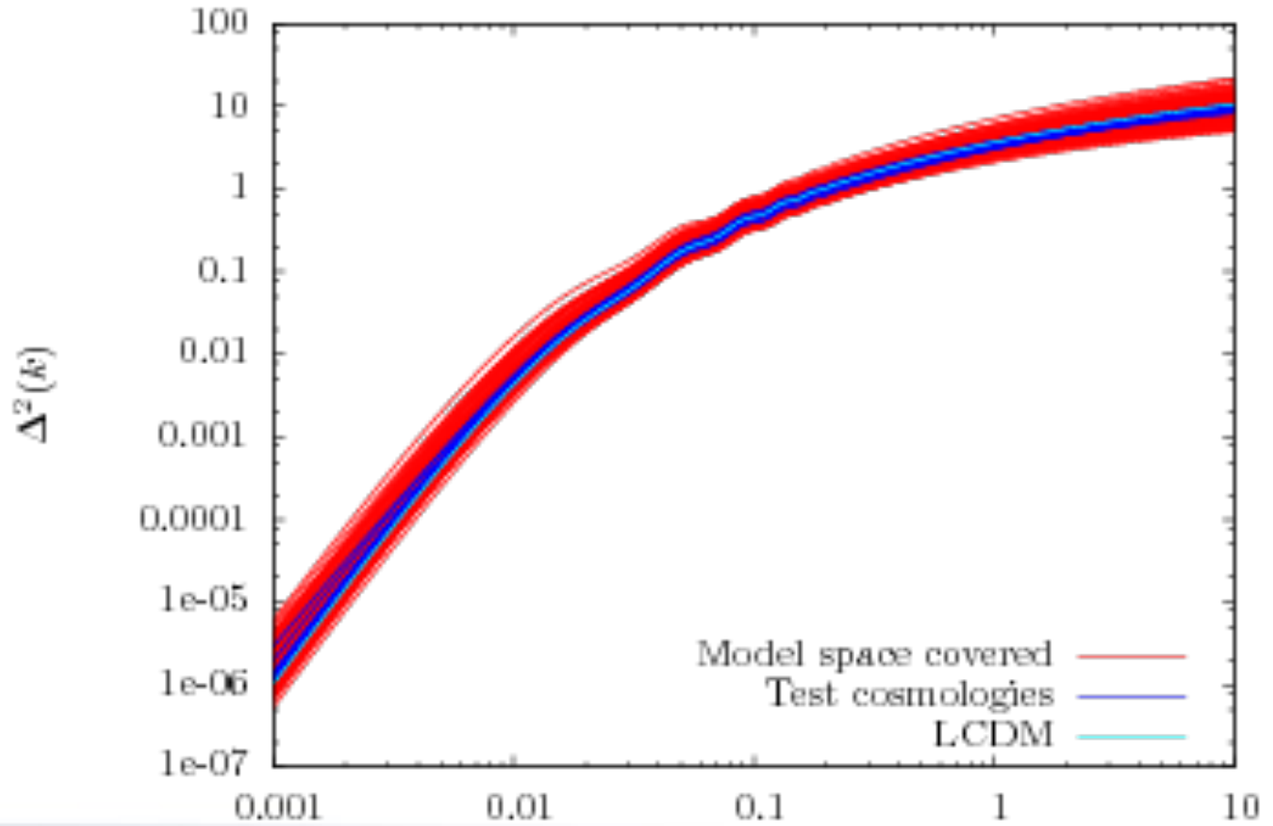
Heitmann et. al 2015

Lawrence et. al 2017

- 8 parameter cosmologies including time-evolving dark energy and massive neutrinos
- Model space is progressively covered with a space-filling tessellation
- Low resolution runs augment the parameter space



Heitmann et. al 2015



Heitmann et. al 2015

Emulators (cosmicEmu)

- High-dimensional interpolator to make predictions from set of output simulation data

- cosmicEmu quickly computes power spectra at any given cosmology within range

- Emulators built on MT Universe can be accurate to <1%

$$0.12 \leq \omega_m \leq 0.155,$$
$$0.0215 \leq \omega_b \leq 0.0235,$$
$$0.7 \leq \sigma_8 \leq 0.9,$$
$$0.55 \leq h \leq 0.85,$$
$$0.85 \leq n_s \leq 1.05,$$
$$-1.3 \leq w_0 \leq -0.7,$$
$$-1.73 \leq w_a \leq 1.28,$$
$$0.0 \leq \omega_\nu \leq 0.01.$$

Heitmann et. al 2015

See http://www.hep.anl.gov/cosmology/CosmicEmu/index.html

Emulators

- Emulators can give accurate, fast predictions from a suite of simulations
- For more implementation details of Mira-Titan based emulators, see Heitmann et. al 2015, Lawrence et. al 2017 and associated papers, and cosmicEmu website: http://www.hep.anl.gov/cosmology/CosmicEmu/index.html
- For implementation details of weak-lensing emulators discussed in this talk see poster by N. Ramachandra

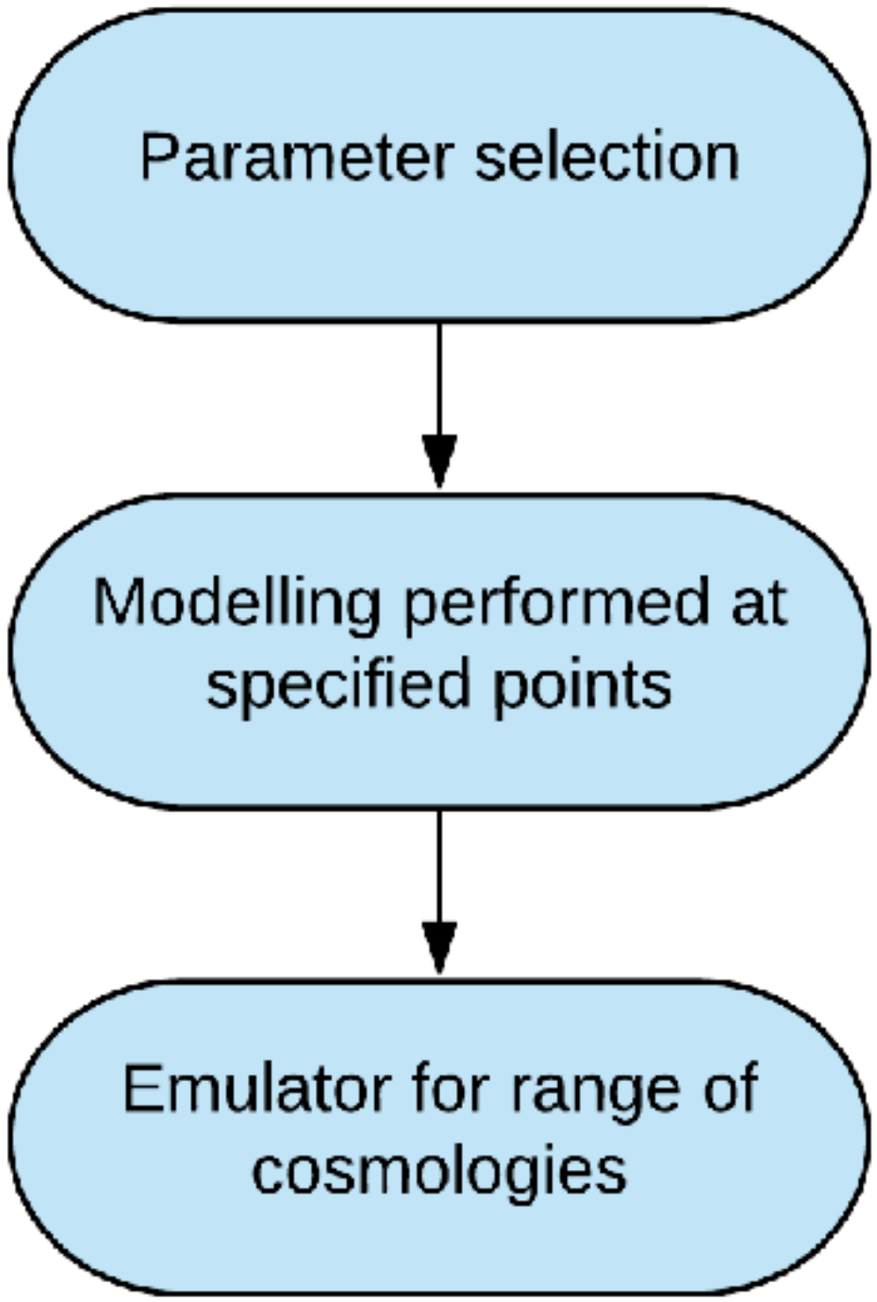
COSMIC EMULATORS FOR NEXT GENERATION SURVEYS

Fast Generation of Weak Lensing Power Spectra using Gaussian Processes

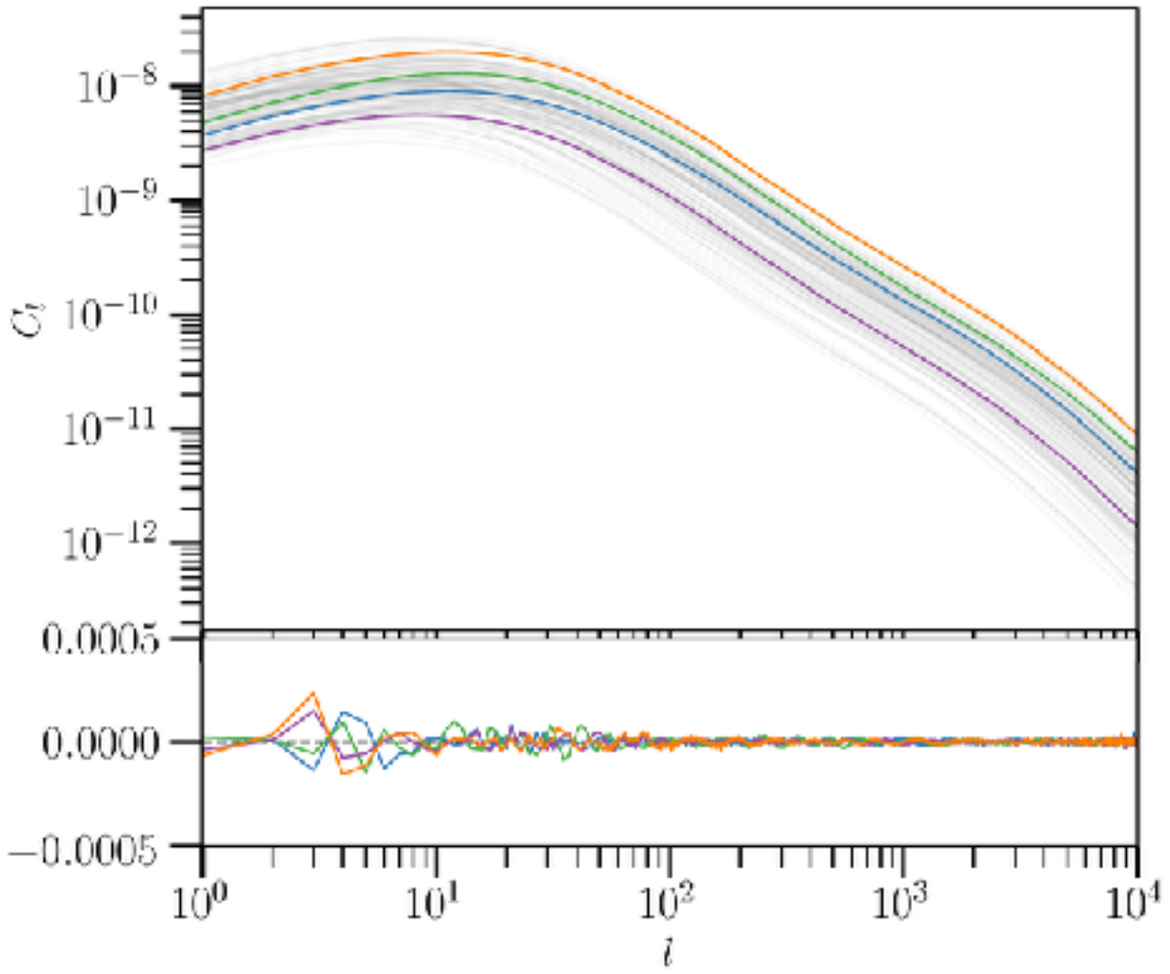
Nesar Ramachandra on behalf of Cosmological Physics and Advanced Computing Group, Argonne National Laboratory.

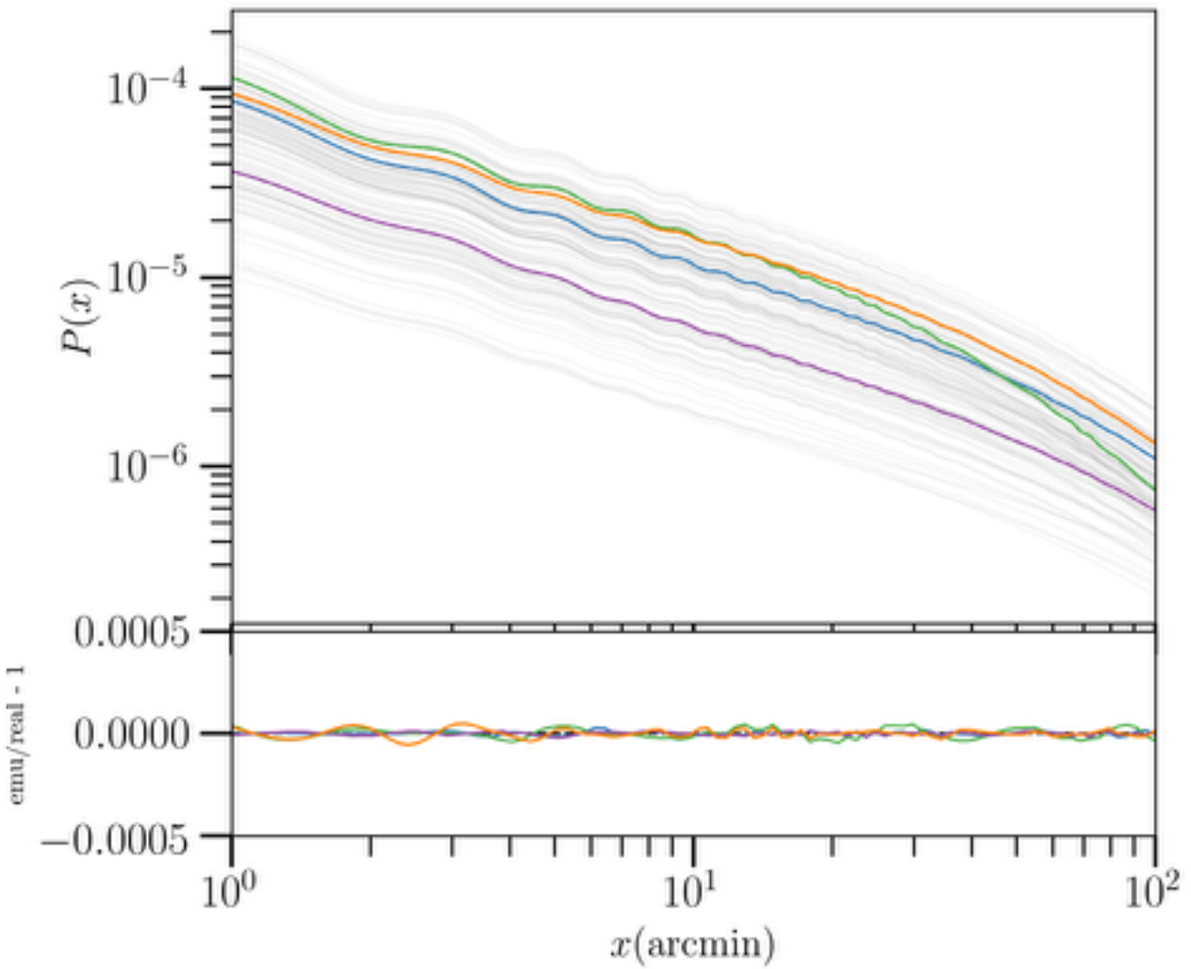
Emulators for lensing applications

- Current work: theory and modelling
- Perform computations at limited points in parameter-space
- Can obtain speed and accuracy simultaneously



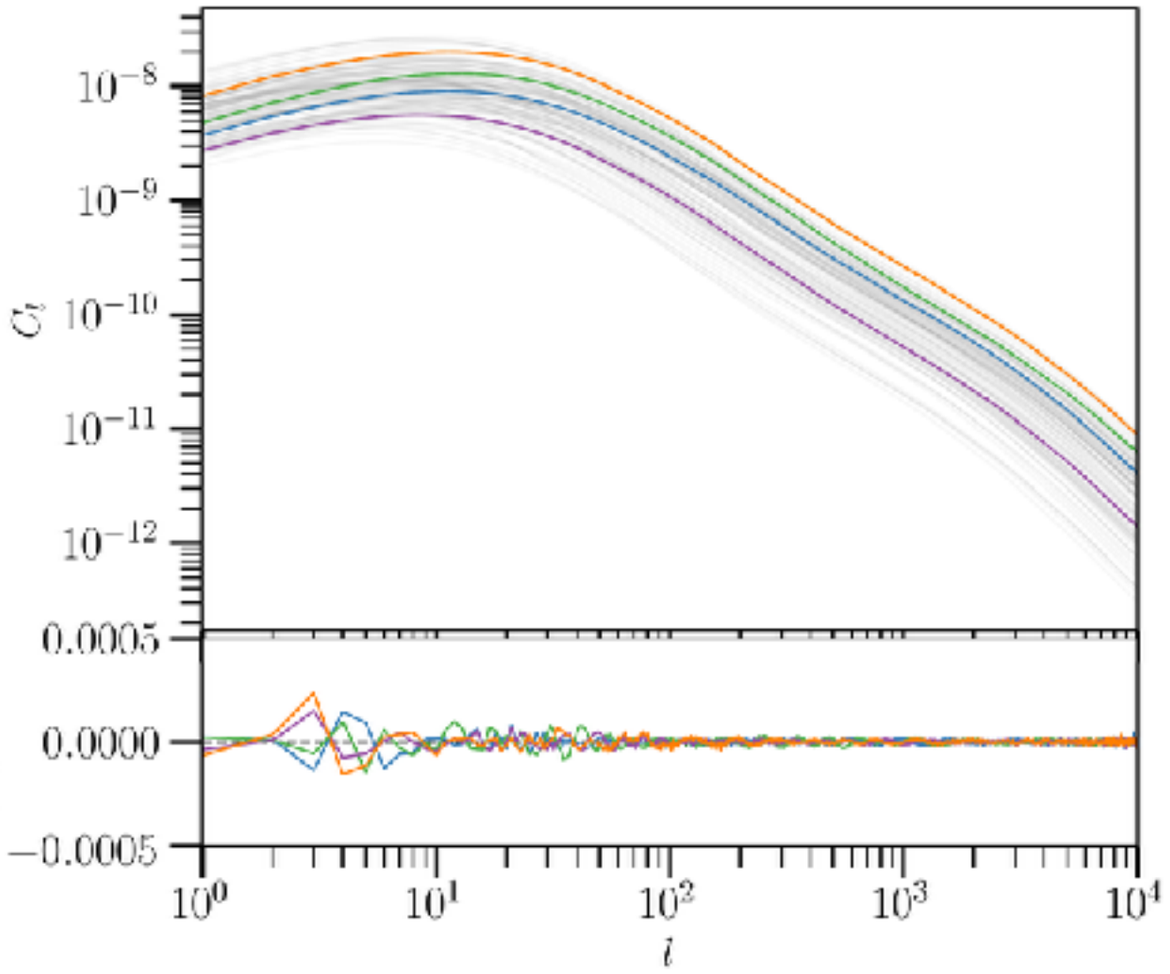
Current work: theory emulator

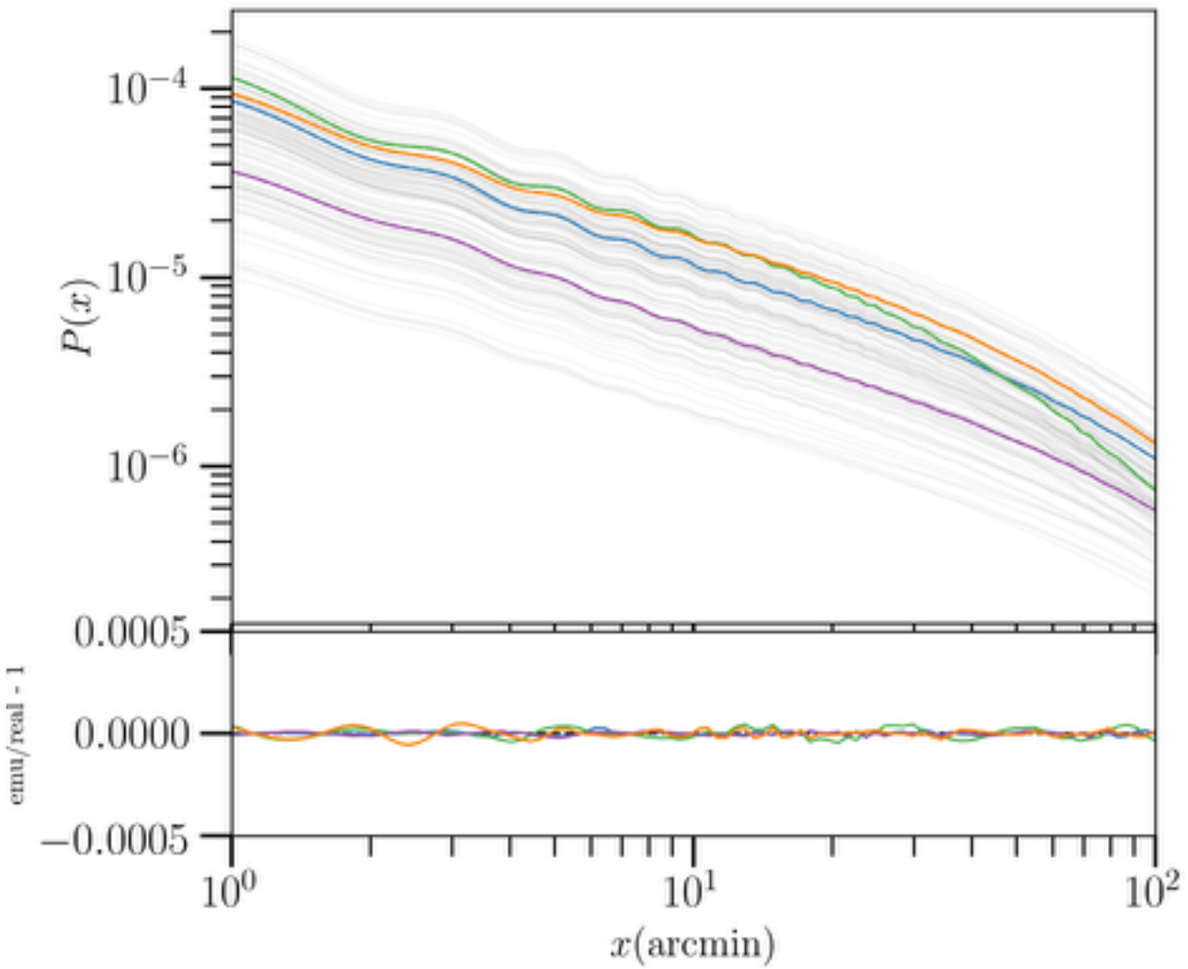




- Weak lensing power spectrum emulator in real and harmonic space, built off Franken-Emu matter power spectrum
- Emulated over two parameter Gaussian n(z) or created for arbitrary input n(z)

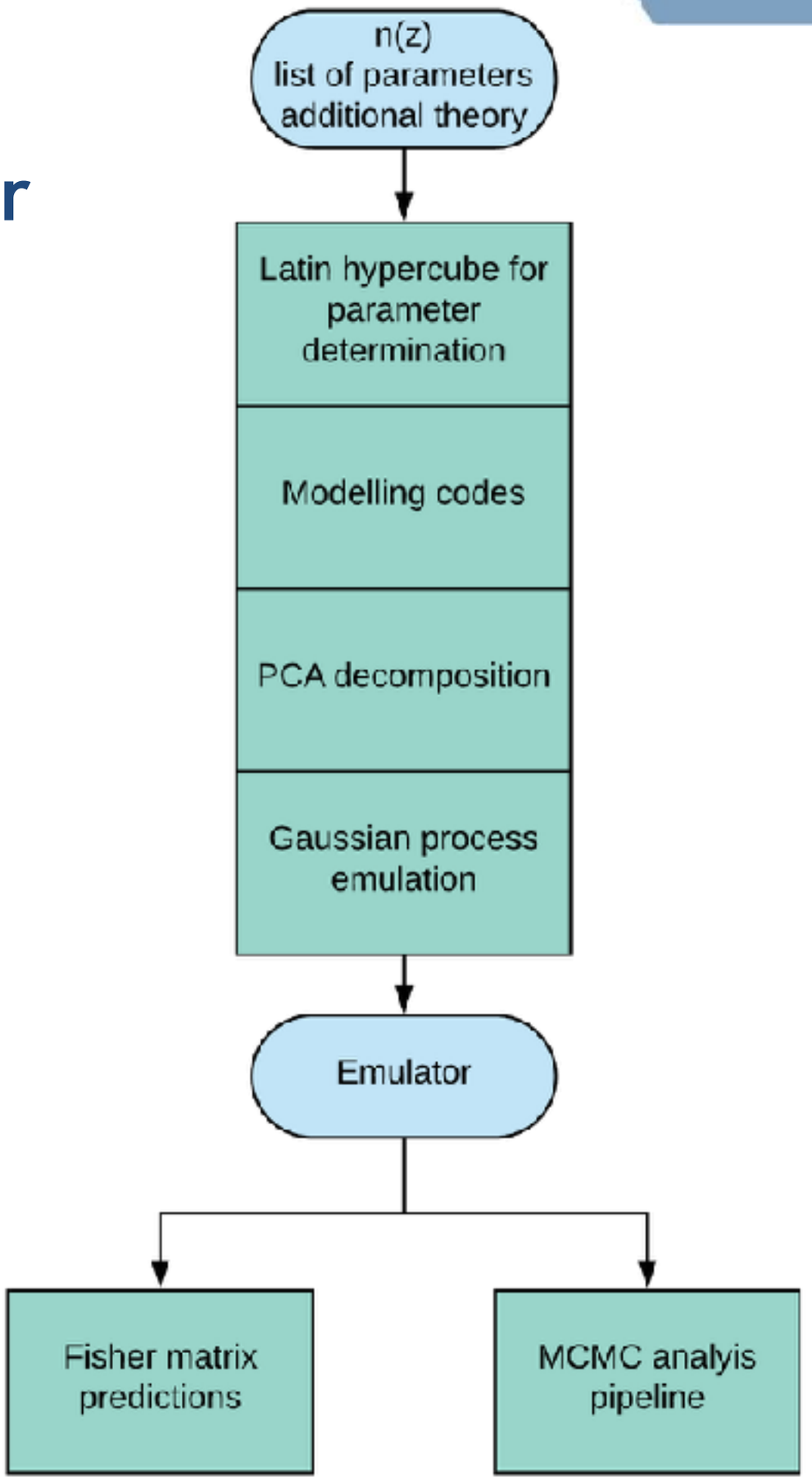
Current work: theory emulator





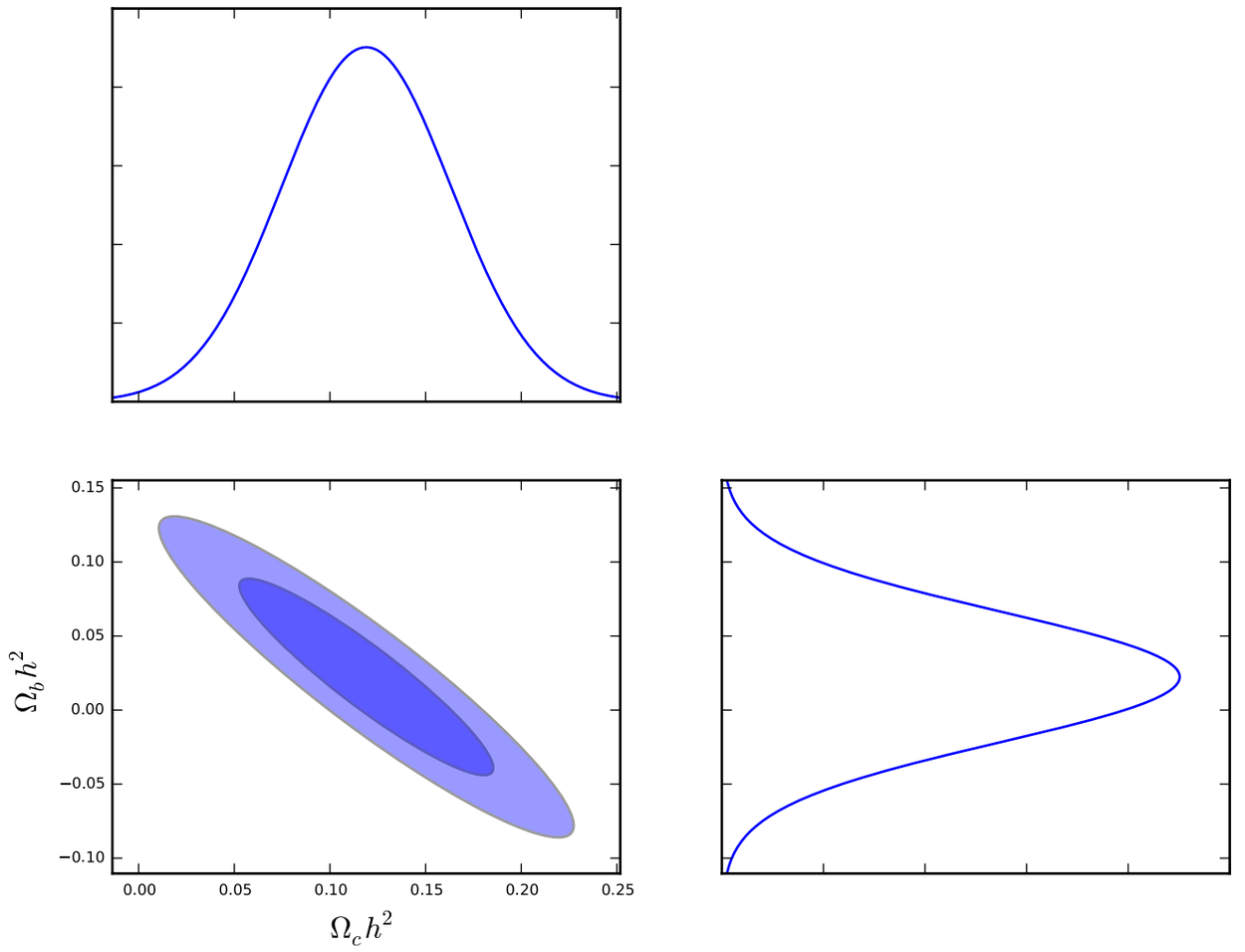
- Extrapolate to high k using Pade approximants
- Shot noise characterisation
- Optimized theory codes to create emulator

Current work: theory emulator



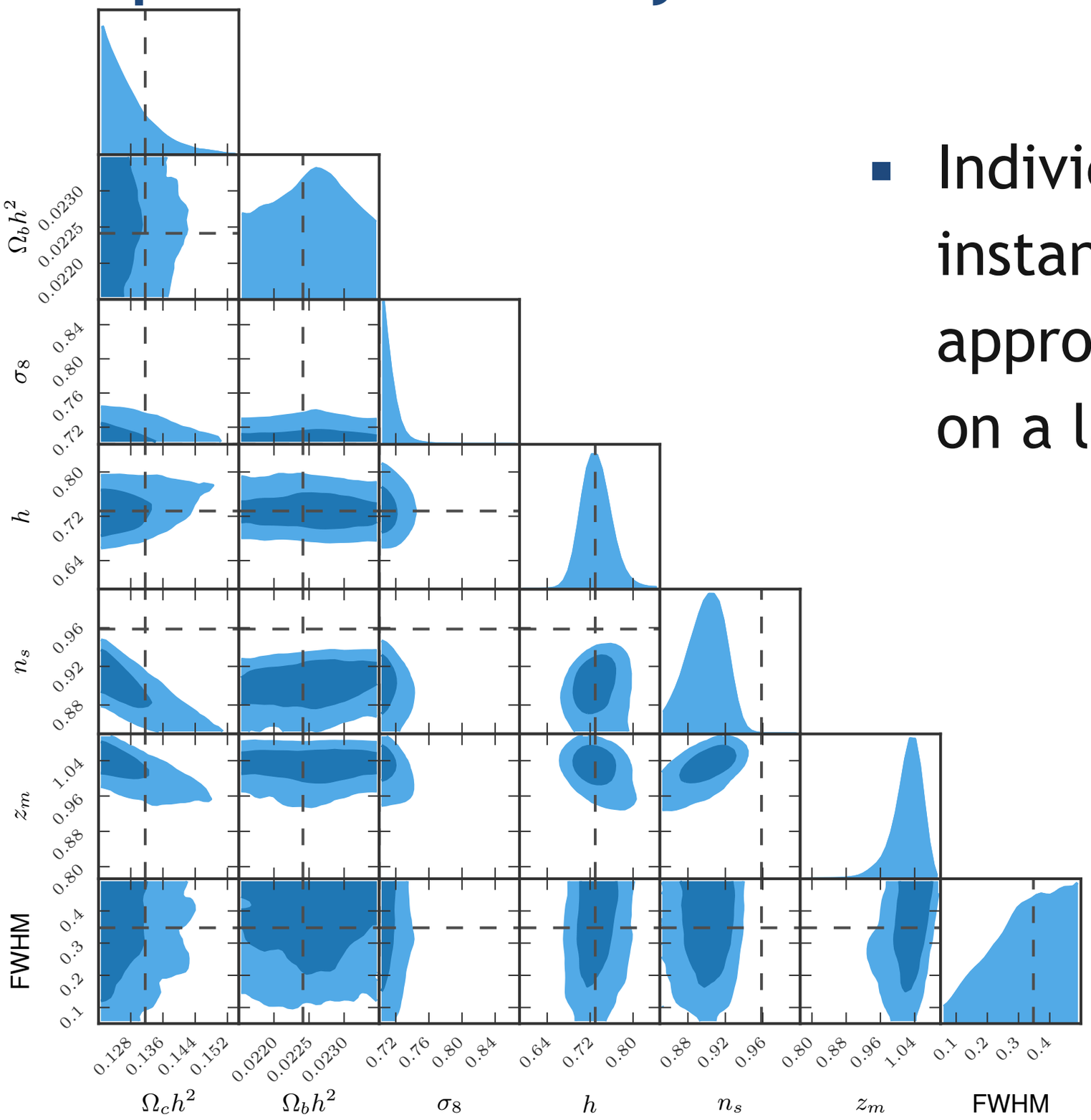
See poster by N. Ramachandra

Example 1: Fisher matrix computation



- Easy to obtain cosmology dependence and derivatives (e.g. Holsclaw et. al 2010)
- Hold-out tests show emulation error subdominant to accuracy of input points

Example 2: MCMC analyses



- Individual emulation instance takes approximately 0.02-0.04s on a laptop

Plotting credit: pyGTC

Planned work: theory emulator

- Provide framework to build emulators on top of specified redshift distribution
- Allow for input arbitrary numbers of nuisance parameters and custom theory codes

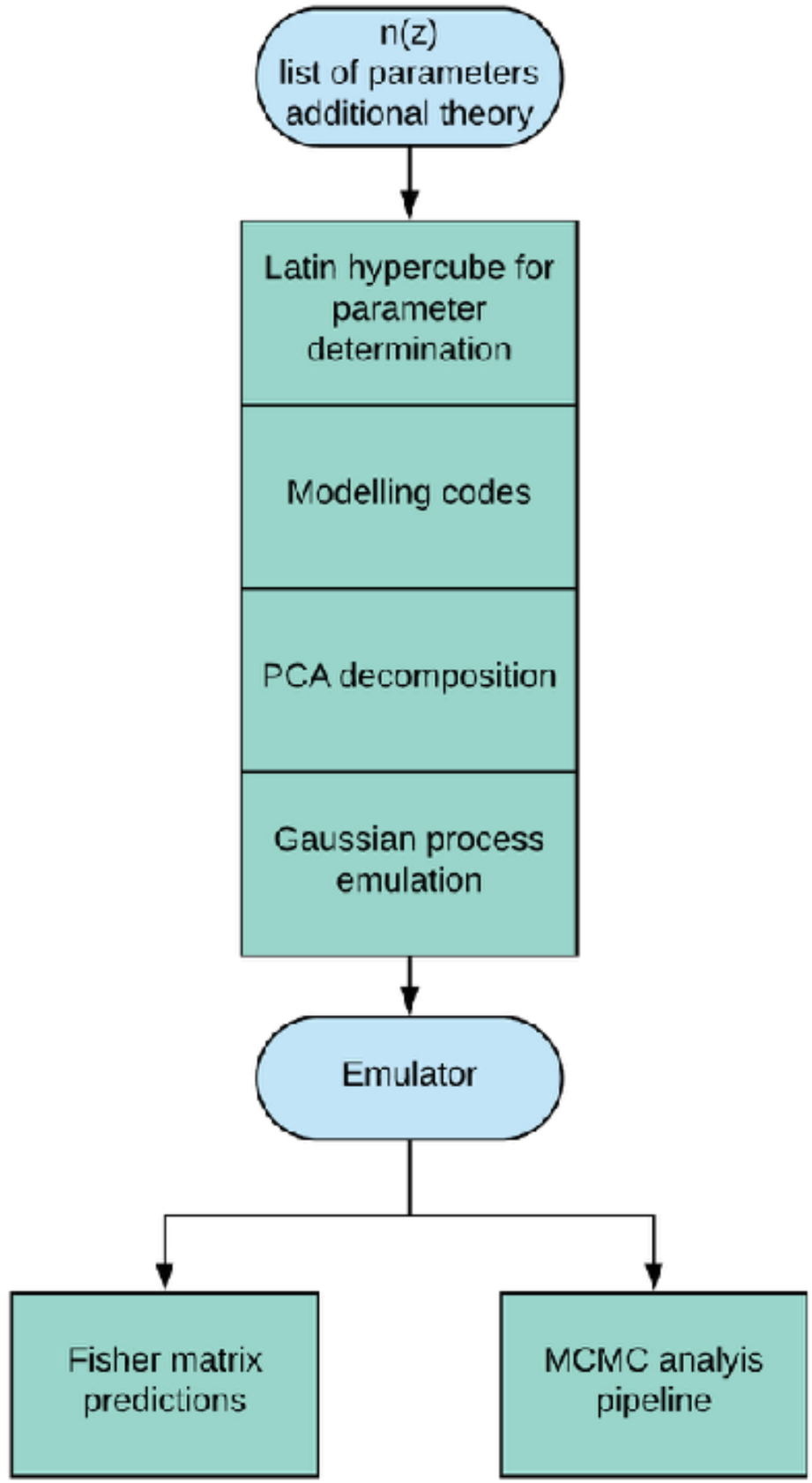
Parameter	Prior
Cosmology	
Ω_m	flat (0.1, 0.9)
A_s	flat $(5 \times 10^{-10}, 5 \times 10^{-9})$
n_s	flat (0.87, 1.07)
Ω_b	flat (0.03, 0.07)
h	flat (0.55, 0.91)
$\Omega_\nu h^2$	flat$(5 \times 10^{-4}, 10^{-2})$
w	flat $(-2, -0.33)$
Lens Galaxy Bias	
$b_i (i = 1, 5)$	flat (0.8, 3.0)
Intrinsic Alignment	
$A_{\rm IA}(z) = A_{\rm IA}[(1+z)/1.62]^{\eta_{\rm IA}}$	
$A_{\rm IA}$	flat $(-5, 5)$
$\eta_{\rm IA}$	flat $(-5, 5)$
Lens photo-z shift (red sequence)	
Δz_l^1	Gauss (0.001, 0.008)
Δz_l^2	Gauss (0.002, 0.007)
Δz_l^3	Gauss (0.001, 0.007)
Δz_l^4	Gauss (0.003, 0.01)
Δz_l^5	Gauss (0.0, 0.01)
Source photo-z shift	
Δz_s^1	Gauss $(-0.001, 0.016)$
Δz_s^2	Gauss $(-0.019, 0.013)$
Δz_s^3	Gauss $(+0.009, 0.011)$
Δz_s^4	Gauss $(-0.018, 0.022)$
Shear calibration	
$m^i_{\rm METACALIBRATION} (i = 1, 4)$	Gauss (0.012, 0.023)
$m^i_{\rm IM3SHAPE} (i = 1, 4)$	Gauss (0.0, 0.035)

Dark Energy Survey Collaboration 2017

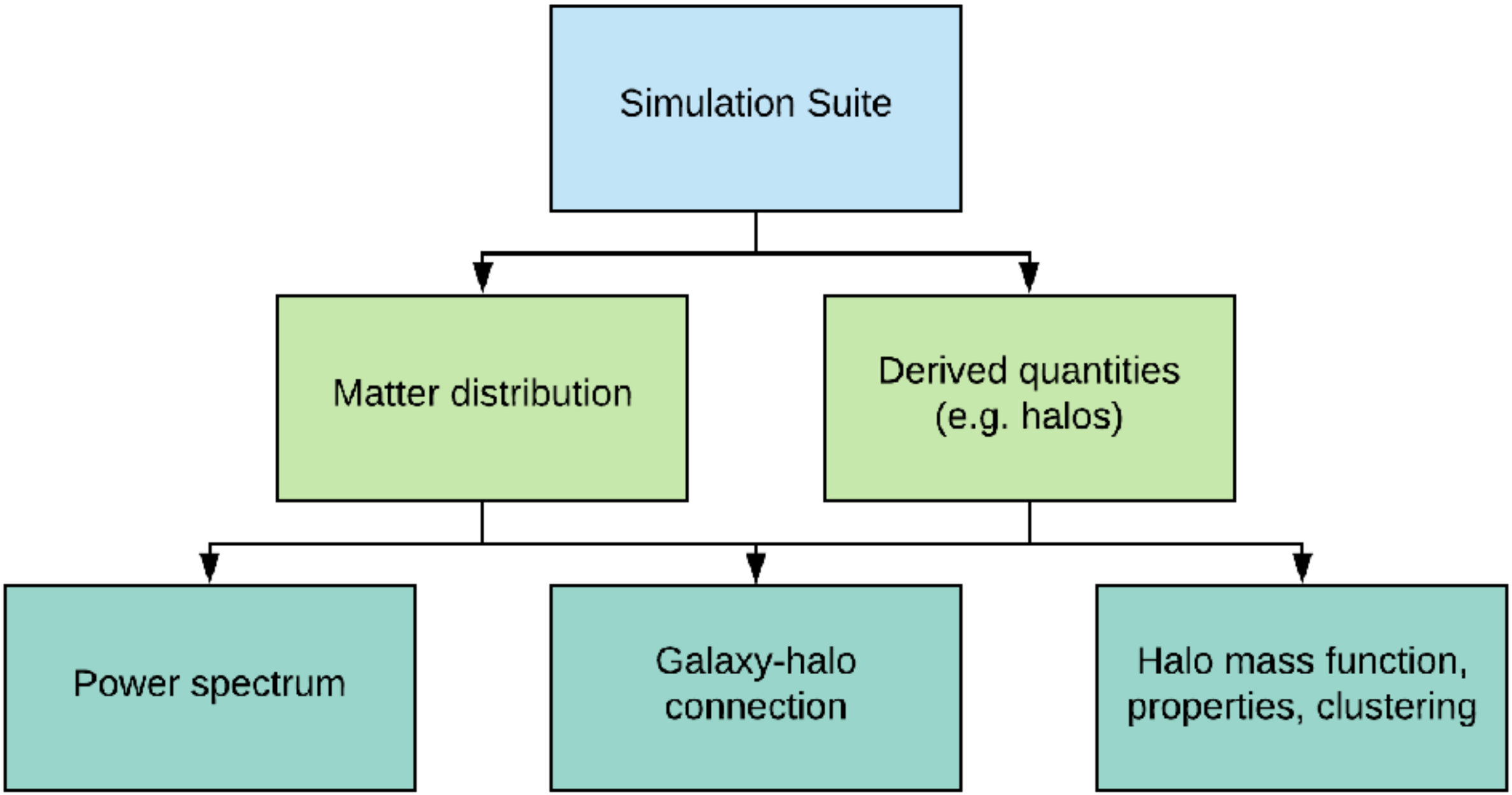
Planned work: theory emulator

- Provide framework to build emulators on top of specified redshift distribution

- Allow for input arbitrary numbers of nuisance parameters and custom theory codes



Emulators for lensing applications



Planned work: simulations

- Can build an emulator off higher-level simulation measurements
- Dark-matter simulation outputs or galaxies painted on using additional parameters
- Existing example: halo mass function emulator

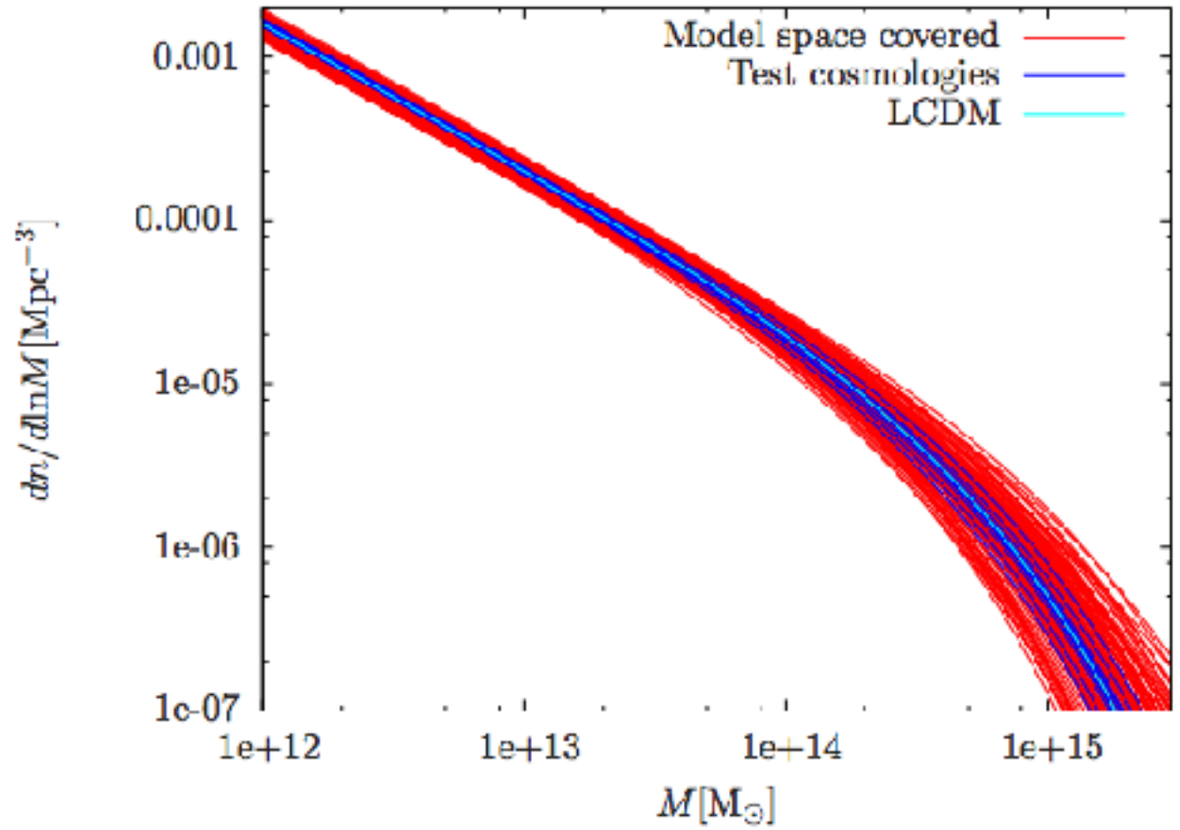


FIG. 11.— Coverage of mass function model space with the simulation design described in this paper at $z = 0$ (red). The dark blue lines show the test models and the light blue line the fiducial ΛCDM mass function. All models are based on assuming universality is valid over the full parameter range. This assumption is valid at the $\sim 10\%$ level of accuracy.

Heitmann et. al 2015

Planned work: simulations

- Example: Lensing profiles
- Example: Halo clustering
- Example: 3x2pt measurement

- See recent paper by Nishimichi et. al 2018, previous talks in this meeting.

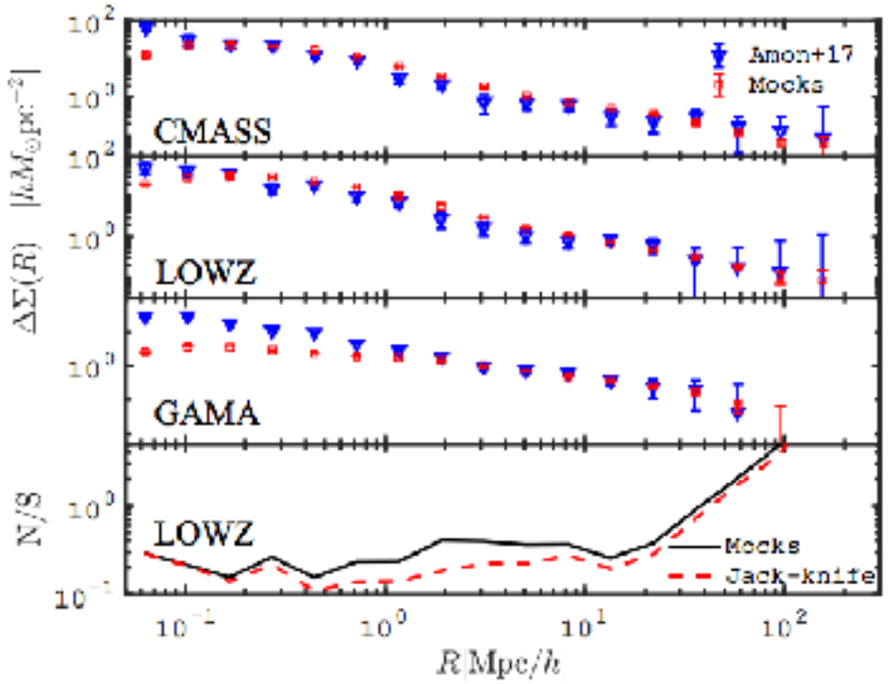
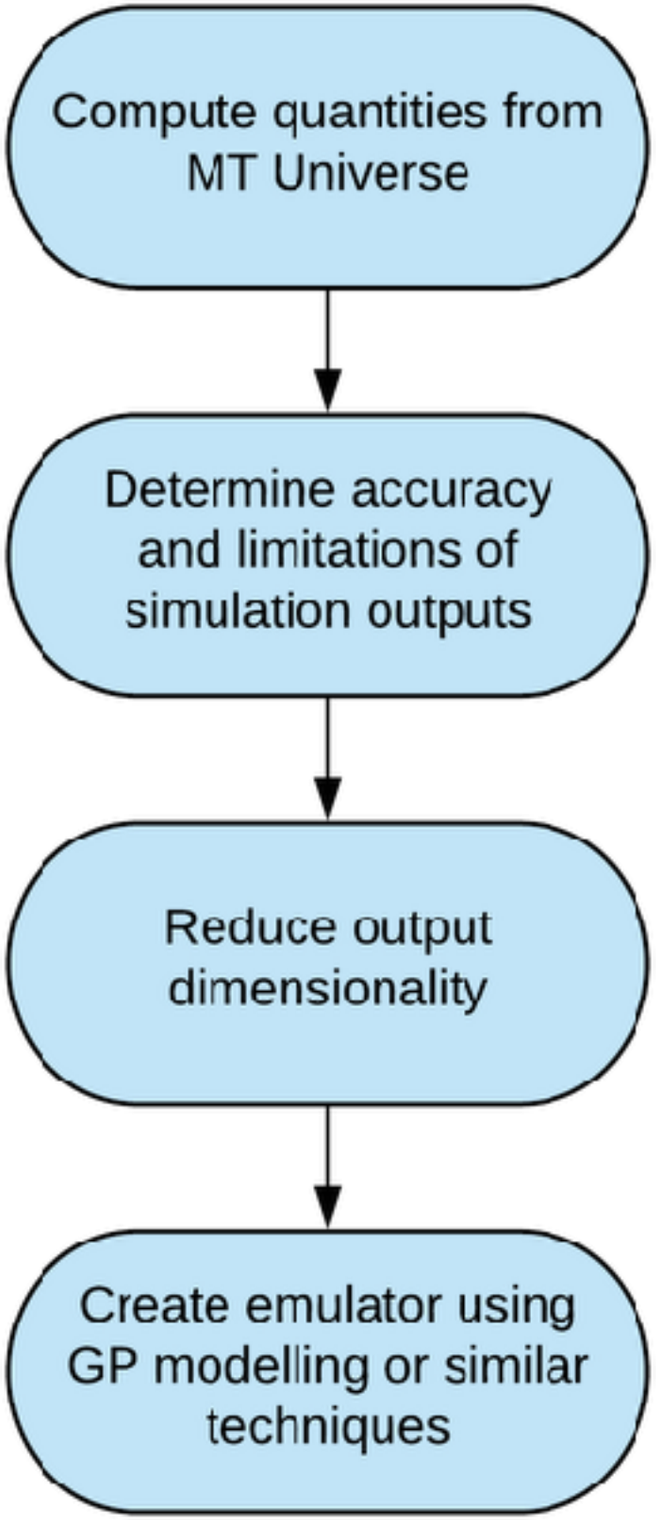


Figure 16. (*upper three panels:*) Differential surface mass density, $\Delta\Sigma$, as measured in the KiDS-450 and CMASS/LOWZ/GAMA mocks, and compared to the measurement from the data by Amon et al. (2017). The error bars on the mocks are on the mean, while that on data are from the mocks, scaled to the overlapping survey areas. (*lowest panel:*) Comparison between the error obtained from the mock covariance about the LOWZ × KiDS-450 measurement, and the jack-knife estimate from the data.

Harnois-Deraps et. al 2018

Planned work: simulations

- Compute quantities from Mira-Titan Universe
- Determine accuracy and limitations of these outputs
- Different output types including biases and noise properties



Long-term opportunities

- Emulators can be built off any simulation suite, input parameters do not have to be cosmology

- Suite of hydro simulations with different sub-grid parameters to fit for baryonic effects, can also incorporate gas-related outputs such as tSZ and kSZ effects

- Halo shapes, parameterised prescriptions for adding, orienting galaxies.

Conclusions

- Emulators can achieve the high levels of modelling accuracy required for future analyses

- We have created a customisable weak lensing power spectrum emulator

- We are planning more weak lensing related emulators from the Mira-Titan Universe

- If you have comments/suggestions/want to use these emulators, come and talk to us!