LUTH meeting recap

The emulators

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What is an emulator ?

- Large survey (Euclid, DESI, LSST) will probe clustering of matter over an unprecedented range of scale and redshift
    - requires theoretical predictions to account for non-linear gravitational effects at late time and at small scales
        - require the use of large volume high-resolution *N*-body simulations -> obtained for 1 given set of parameter -> large computational cost !
- Two different approaches developed in past
    - semi-analytical methods : combination of theoretical modelling and calibration to simulations
        - compute non-linear matter power spectrum or halo mass function
        - provides predictions at negligible computational costs
    - approximate numerical schemes: perform simplified fast numerical simulations
    - **both methods have limited accuracy and uncertainties not straightforward to propagate**
- Emulators: based on machine-learning technics, have proven to be very promising
    - can be arbitrarily precise and incorporate as many effects as training dataset provides -> higher computational cost to generate the training dataset (done once) **but emulator itself becomes very fast and accurate**

E-mantis emulator

- Emulator for Multiple observable ANalysis in extended cosmological TheorIeS
- **Emulator of halo mass function (HMF)**
- Compared to other emulators, E-mantis is designed to:
    1. better capture the cosmological dependence of the HMF (not a predefined functional form like Tinker)
    2. larger coverture of parameters)
    3. Supports multiple dark matter halo definitions :
        - SOD 200c, 500c/200c, 1100c/200c, mfof with d=0.2 (ratio of SOD masses are sparsities)
    4. provide and propagate errors on interpolation
    5. wCDM model (w varying) + f(R) models
- Assume flat geometry (like all other emulators)

E-mantis

- Emulator do interpolation but no extrapolation -> defined for a given redshift and mass range
  - m>10^13 Mo/h, redshift<1.5
- Prediction of emulator limited to the range of parameter initially selected (very difficult to extend/add parameters). But too large range lead to lower density of training points ->degrade final accuracy of emulator
- 100 simulations performed with an optimized set of value for the 6 parameters

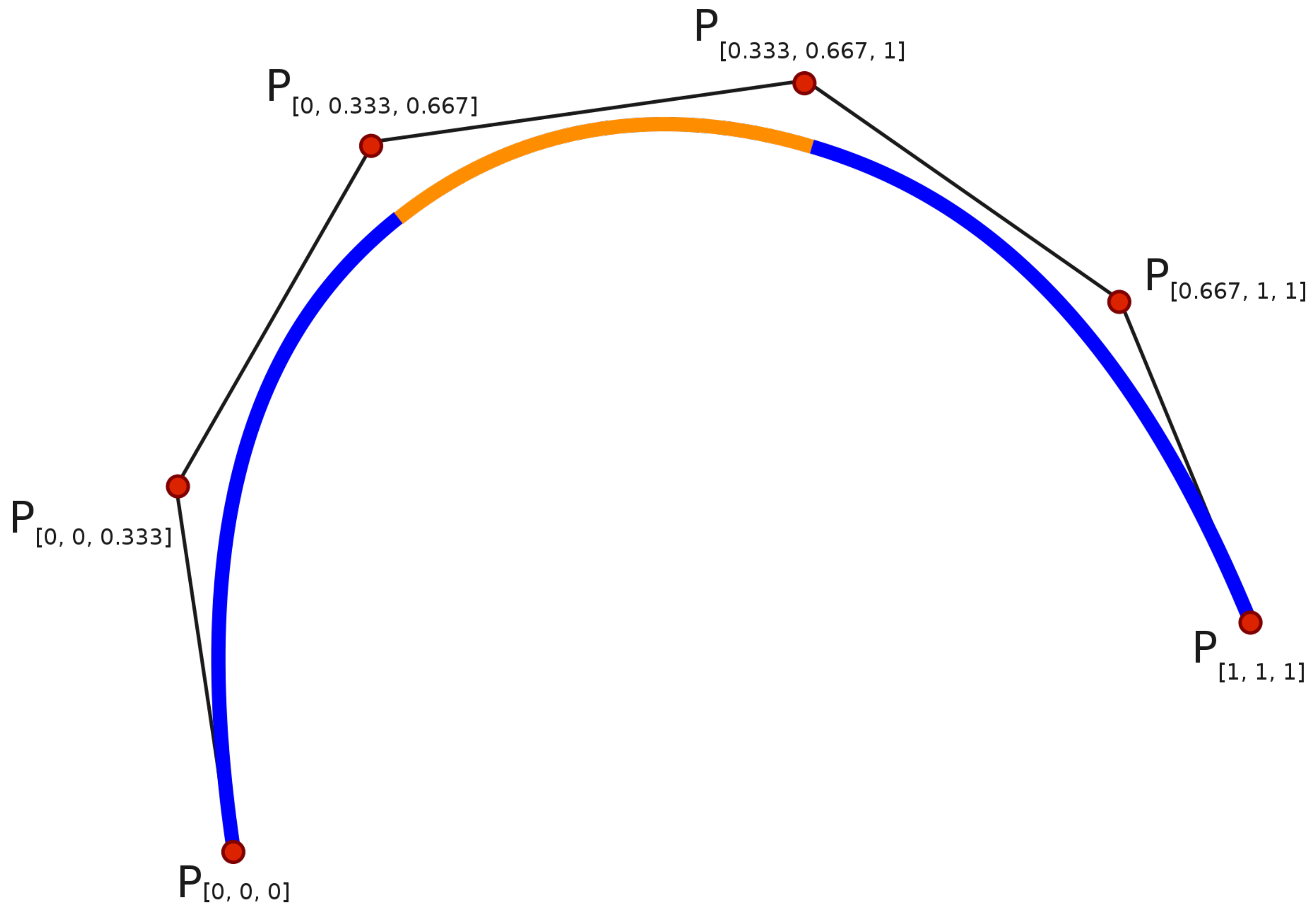
Table 1: Ranges of the cosmological parameters supported by the emulator, and values of the cosmological parameters for some reference models. Model is the cosmology, w the equation of state of dark energy, f_{R_0} the derivative of the scalar function with respect to the Ricci scalar at $z = 0$, Ω_m the matter density parameter, σ_8^{GR} the amplitude of linear matter density fluctuations on the $8\,h^{-1}$Mpc scale assuming GR, h the normalized hubble constant, n_s the slope of the primordial power spectrum, Ω_b the baryon density parameter.

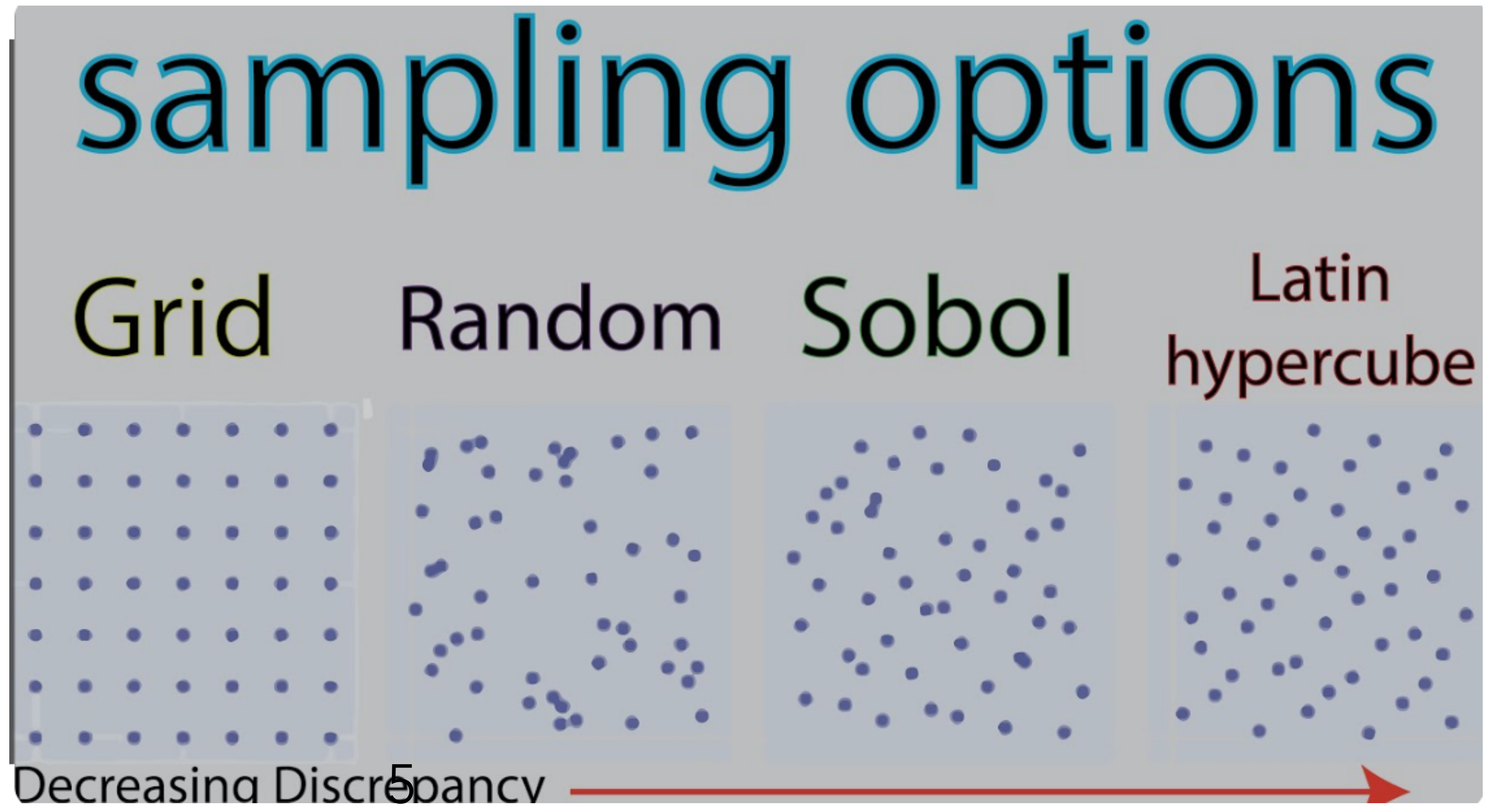
wider ranges than any other emulator !

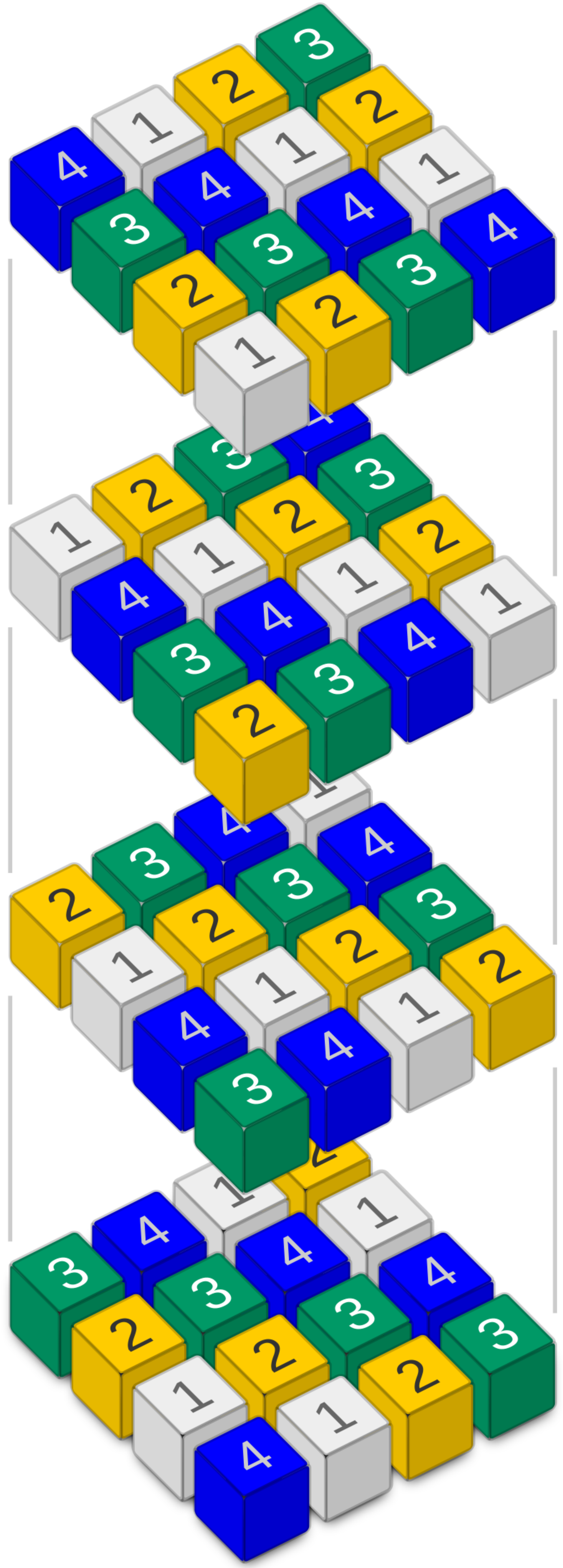
Model	w	$\log_{10} \lvert f_{R_0} \rvert$	Ω_m	σ_8^{GR}	h	n_s	Ω_b
wCDM	$[-1.5, -0.5]$	-	$[0.155, 0.465]$	$[0.6083, 1.014]$	$[0.55, 0.85]$	$[0.72, 1.2]$	$[0.037, 0.062]$
$f(R)$CDM	-	$[-7, -4]$	$[0.155, 0.465]$	$[0.6083, 1.014]$	$[0.55, 0.85]$	$[0.72, 1.2]$	$[0.037, 0.062]$
P18	-1	-	0.3071	0.8224	0.6803	0.96641	0.048446
w12	-1.2	-	0.3071	0.8224	0.6803	0.96641	0.048446
F5	-	-5	0.3071	0.8224	0.6803	0.96641	0.048446
F6	-	-6	0.3071	0.8224	0.6803	0.96641	0.048446

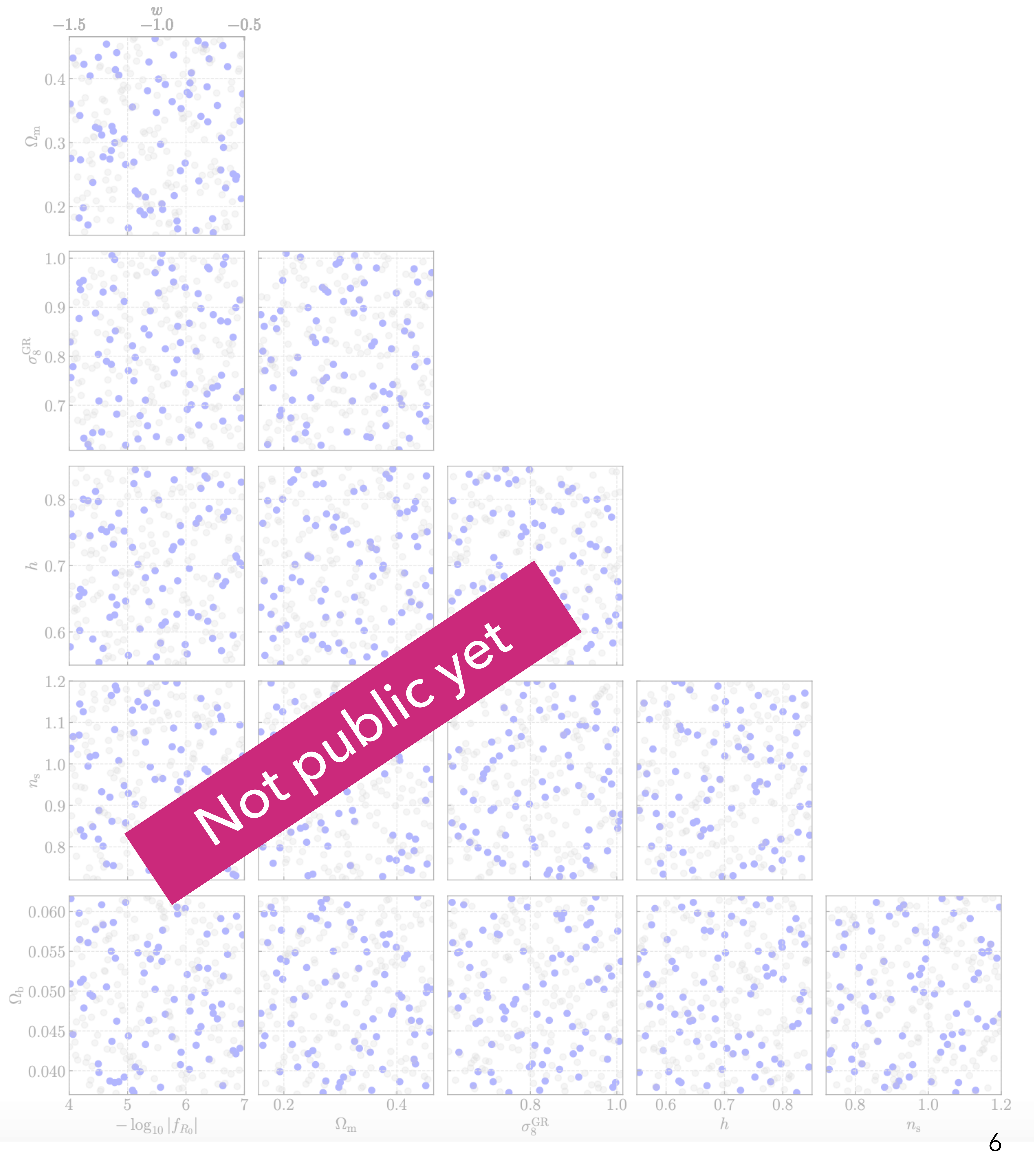
Interpolation

- Spline interpolation
  - fits low-degree polynomials to small subsets of the values instead of high-degree polynomial to larger set of values
- The grid is adapted as a function of the parameters we want to map
  - Latin HyperCube Sampling (LHS) to optimise the interpolation at 6 dim
    - stat method to generate near-random sample of values from a multidimensional distribution
- If we want to add a parameter, the full grid need to be re-optimised





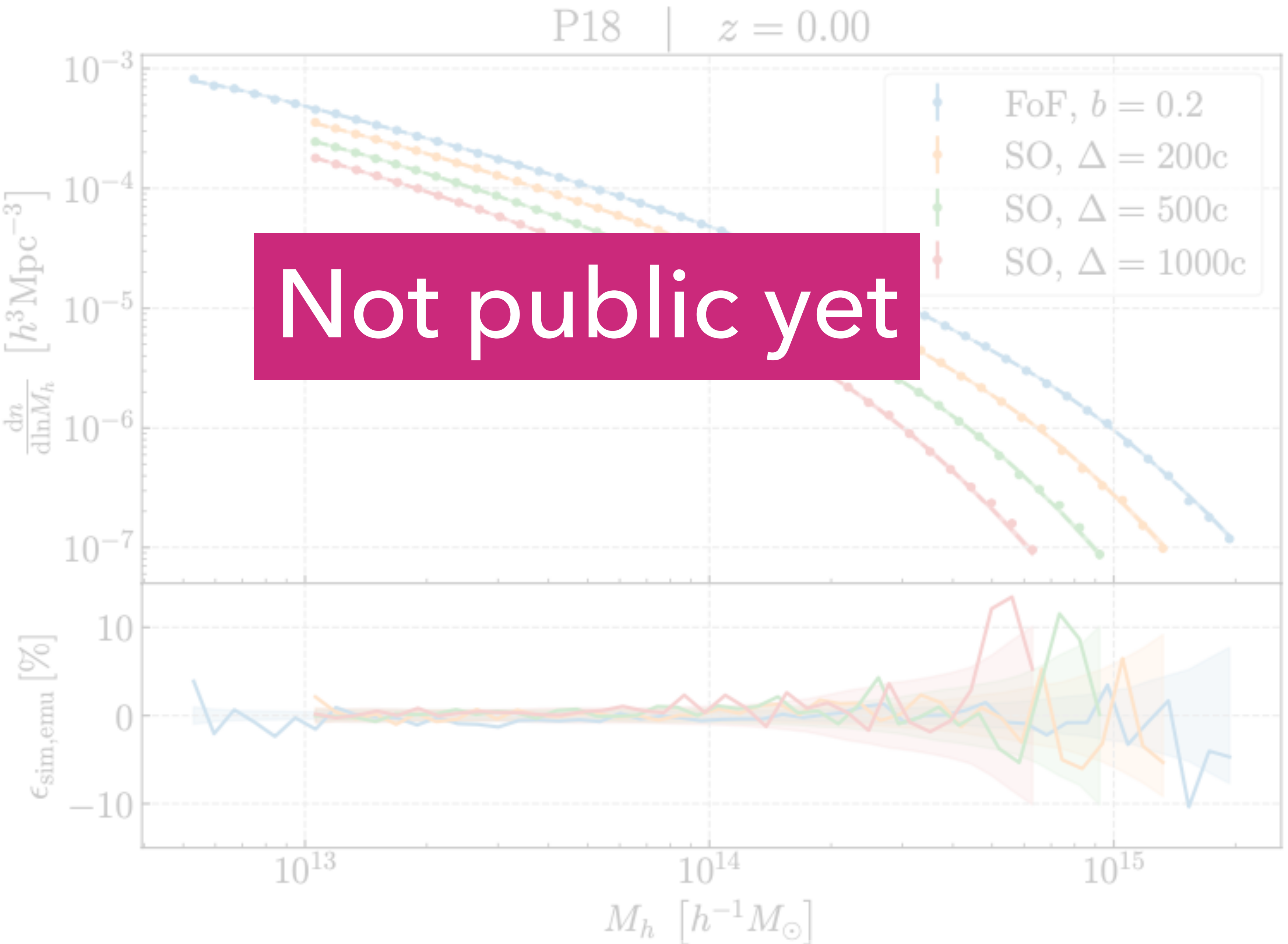


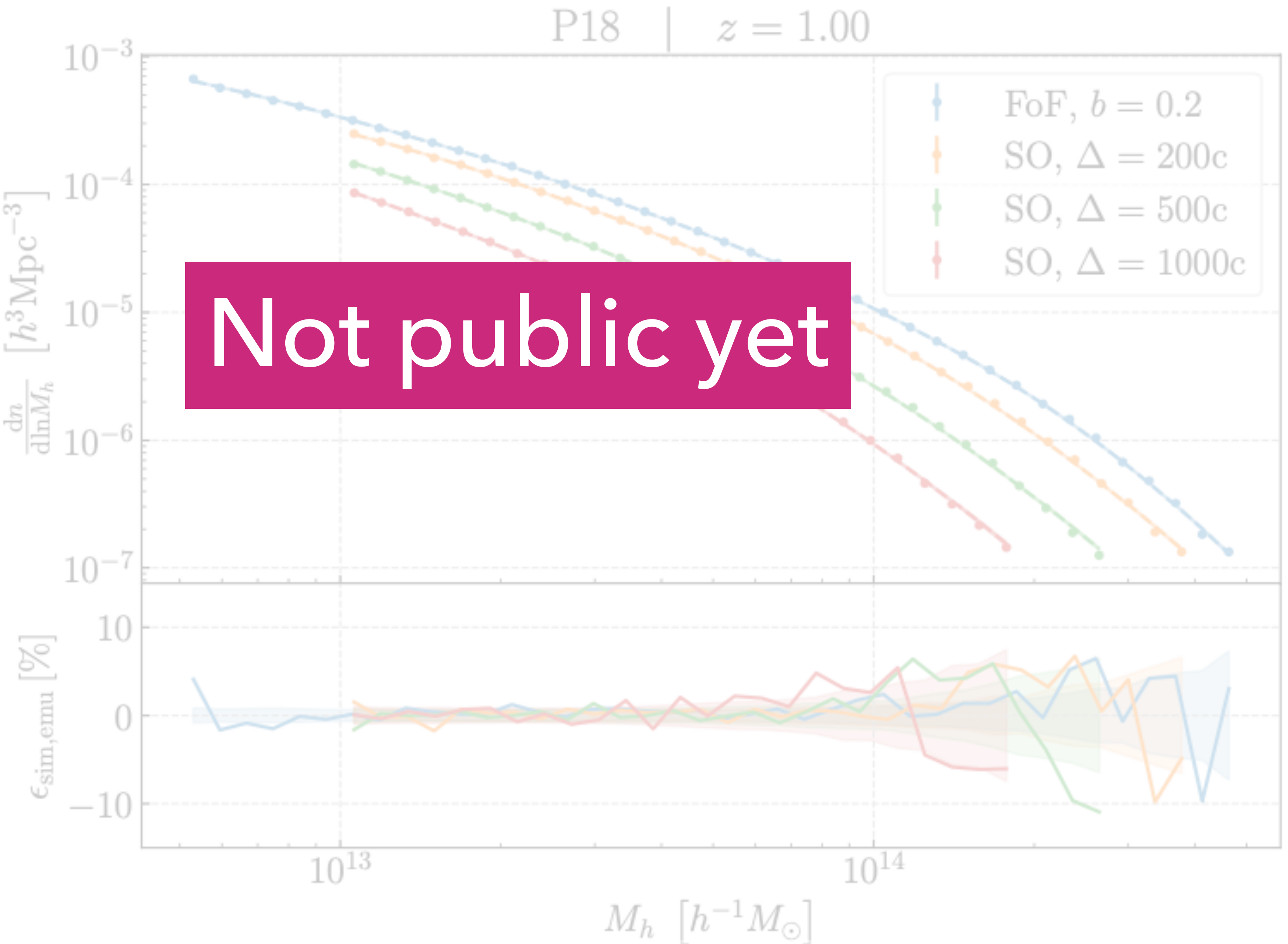


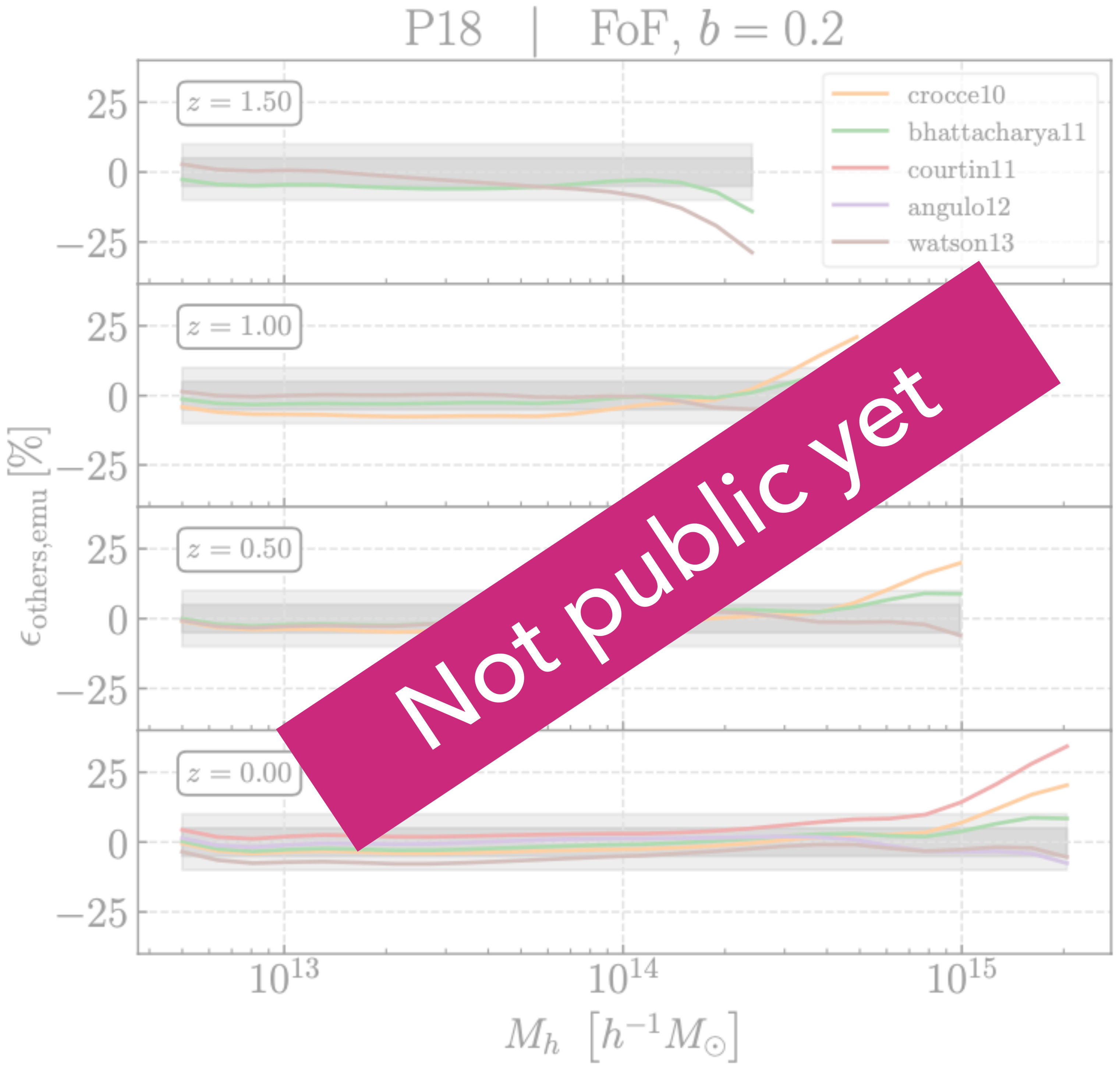
w
−1.5
−1.0
−0.5
Ω_m
0.2
0.3
0.4
σ_8^{GR}
0.7
0.8
0.9
1.0
h
0.6
0.7
0.8
n_s
0.8
0.9
1.0
1.1
1.2
Ω_b
0.040
0.045
0.050
0.055
0.060
4
5
6
7
$-\log_{10}|f_{R_0}|$
0.2
0.4
Ω_m
0.8
1.0
σ_8^{GR}
0.6
0.7
0.8
h
0.8
1.0
1.2
n_s
Not public yet

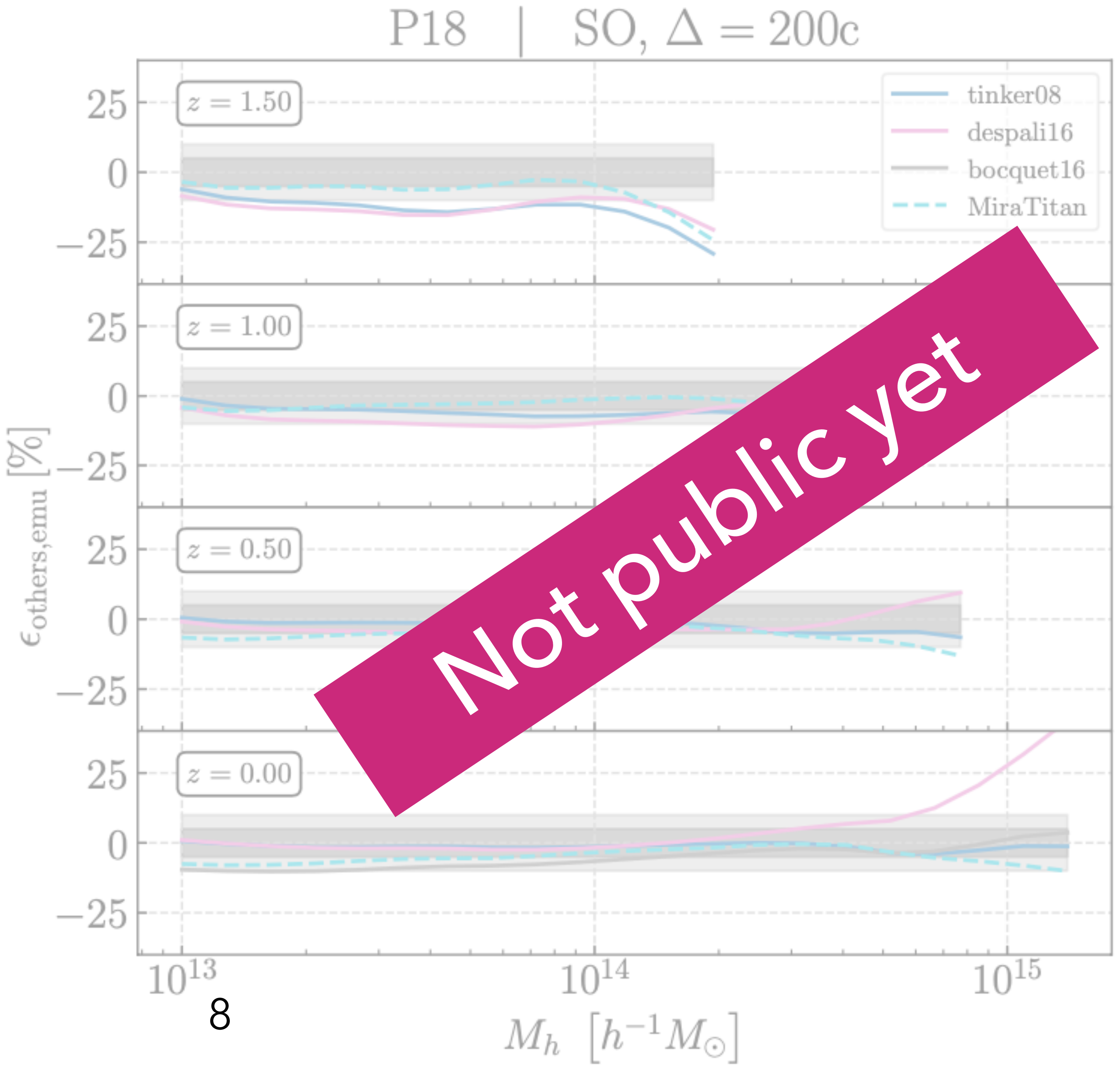
Errors on E-mantis emulator

- Cosmic variance: statistical fluctuation on the simulation (redo several times the simulation)
- Spline interpolation : error on interpolation of mass function for a given cosmo (coef a,b, c,d)
- Error from difference between a emulated prediction for a given set of parameters and the real simulation
- At large masses, Halo Mass Function (HMF) error dominated by stat (shot noise), at small masses (<2e14), error dominated by interpolation (1.5%)
- Error on emulator also provided as a function of cosmo parameter, halo mass, redshift









more rigid functional form of the fitting function for Despali, making it difficult to accurately capture the shape of the HMF at large masses