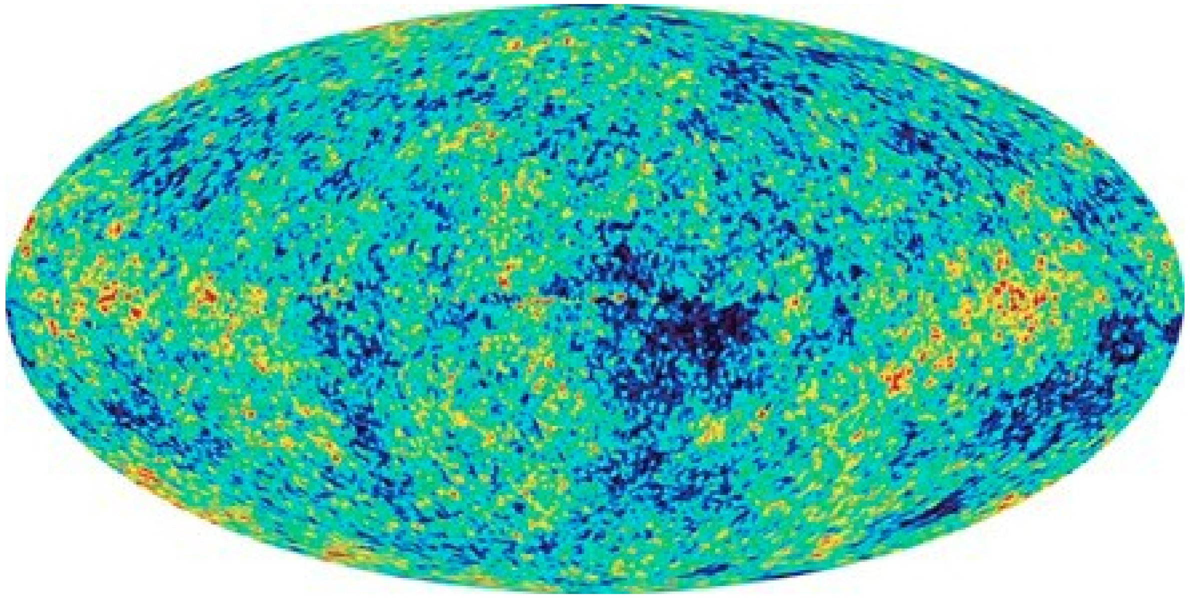
Euclid Cosmological Simulations Requirements and Implementation Plan

Alina Kiessling
Jet Propulsion Laboratory / CalTech

Euclid Weak Lensing Kick-Off Meeting, Edinburgh, 2012

The Cosmological Setting

Primordial fluctuations + Gravitational Instability



z~1100

z~0

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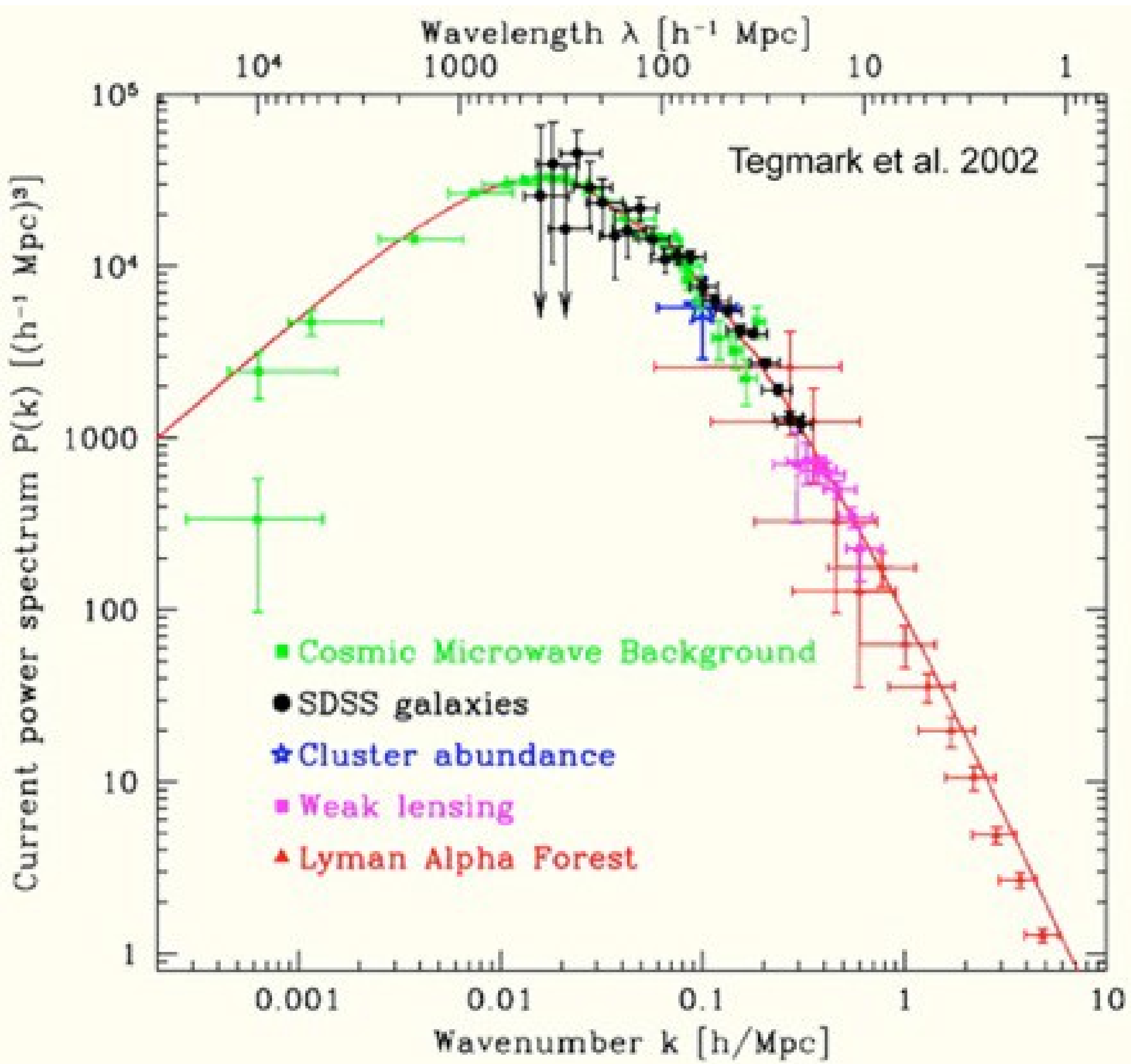
The Matter Density Power Spectrum



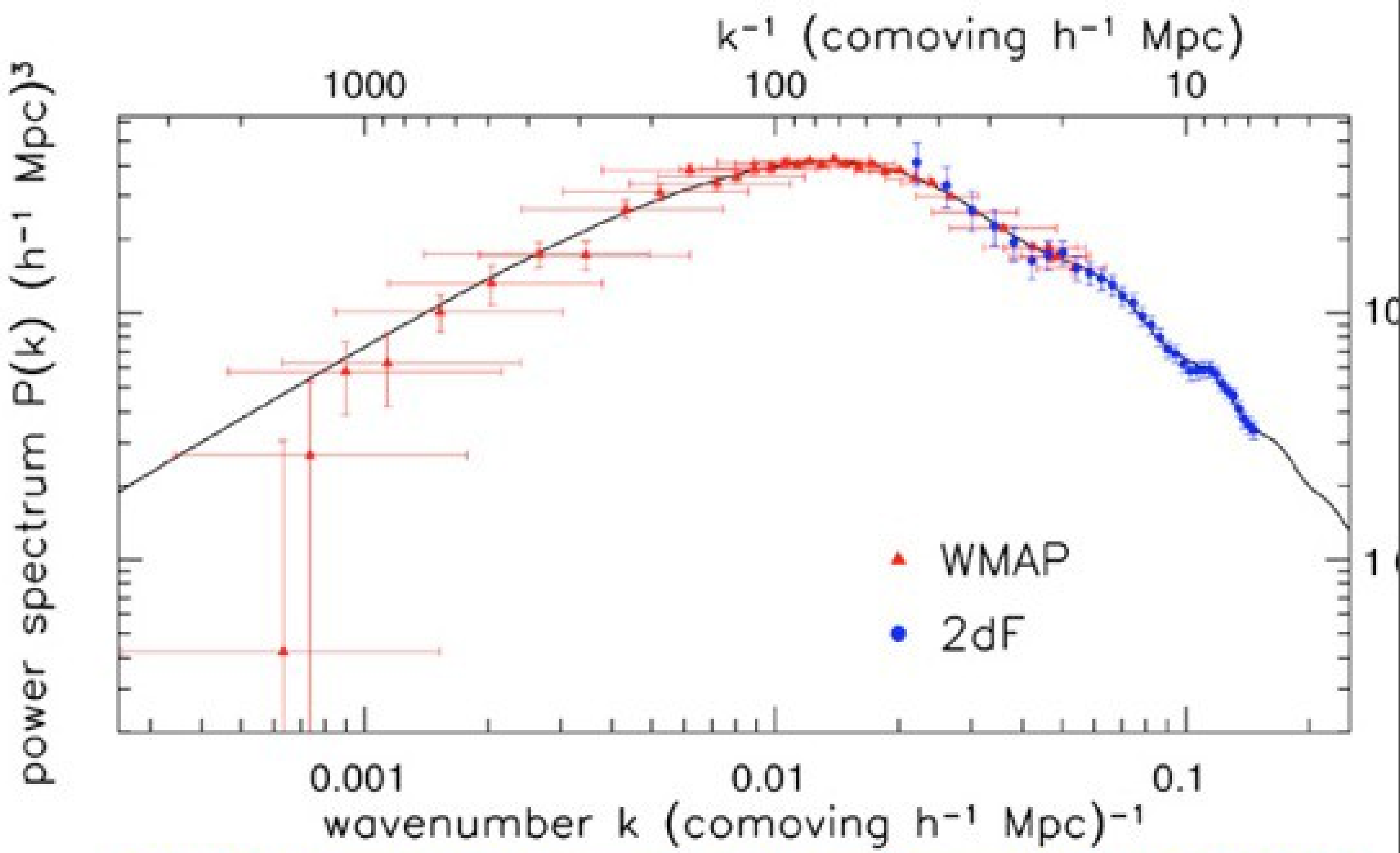
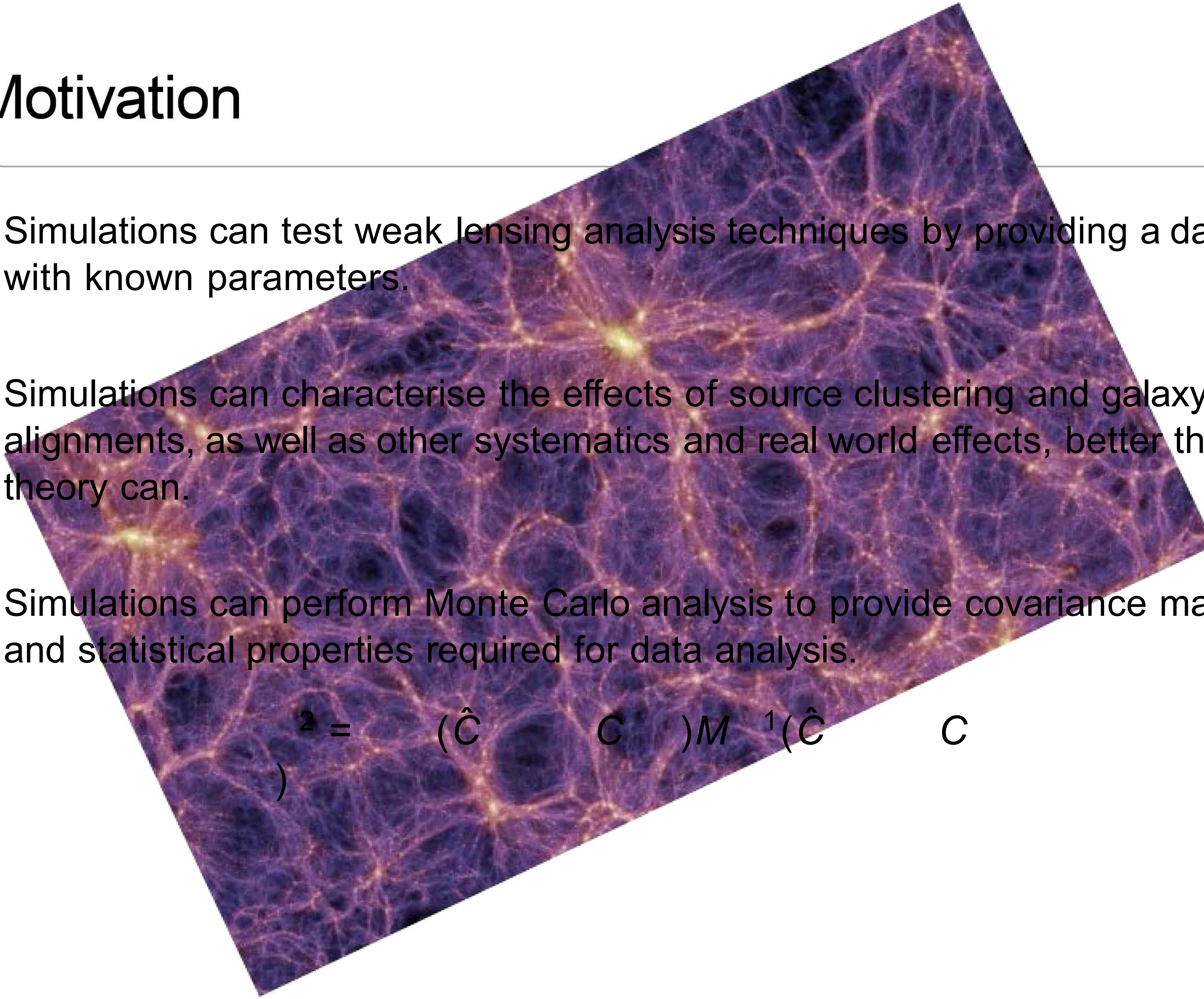


Fig 8.17 (A. Sanchez) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Our theoretical expectation of the matter density power spectrum is matched over a huge range of scales by using many different observations.

Motivation



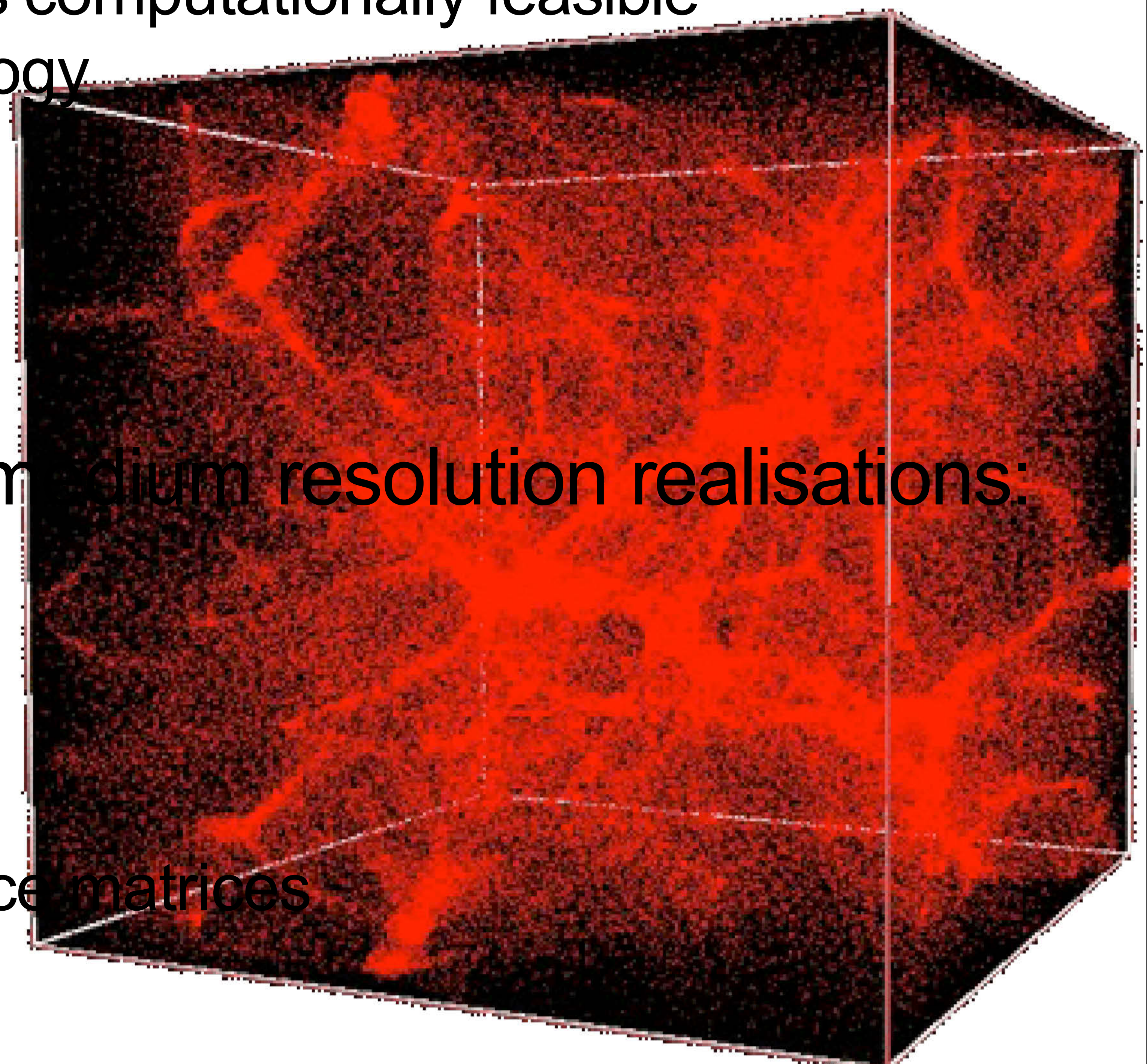
- Simulations can test weak lensing analysis techniques by providing a data set with known parameters.
- Simulations can characterise the effects of source clustering and galaxy alignments, as well as other systematics and real world effects, better than theory can.
- Simulations can perform Monte Carlo analysis to provide covariance matrices and statistical properties required for data analysis.

$$\chi^2 = (\hat{C} \quad C)M^{-1}(\hat{C} \quad C)$$

Large, high resolution single realisations:

- Pushes the limits of what is computationally feasible
- Currently favoured cosmology

  - Halo properties
  - Galaxy formation



Multiple, Monte Carlo, medium resolution realisations:

- Computationally cheap
- Any cosmology

  - Testing of methods
  - Generation of covariance matrices

Draft Lensing Simulation Requirements

- The dark matter only power spectrum P(k,z) should have a standard deviation of 1% from $0.0 \; z \; 4.0$ and between $0.001\ h\ \mathrm{Mpc}^{-1}\ k\ 50\ h\ \mathrm{Mpc}^{-1}$

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- Mock galaxy shear catalogues that include shear, convergence, position, redshift, photo-z errors, catastrophic failures, magnitudes, intrinsic alignments, bulge/disk ratios, bulge/disk ellipticities, morphology, colour and size. The suite of catalogues should provide shear power covariance matrices with errors (TBD)%

Draft Lensing Simulation Requirements

- Additional requirement for IA: A suite of high resolution hydro simulations of clusters and their environment with a spatial resolution down to 10pc

Simulation Implementation Plan - DM Only

Questions:

- Do we need a hierarchy of simulations to achieve a power spectrum P(k,z) with a standard deviation of 1% from 0.0 z 4.0 and between 0.001 h Mpc^{-1} k 50 h Mpc^{-1}, or can this be achieved in a single box?

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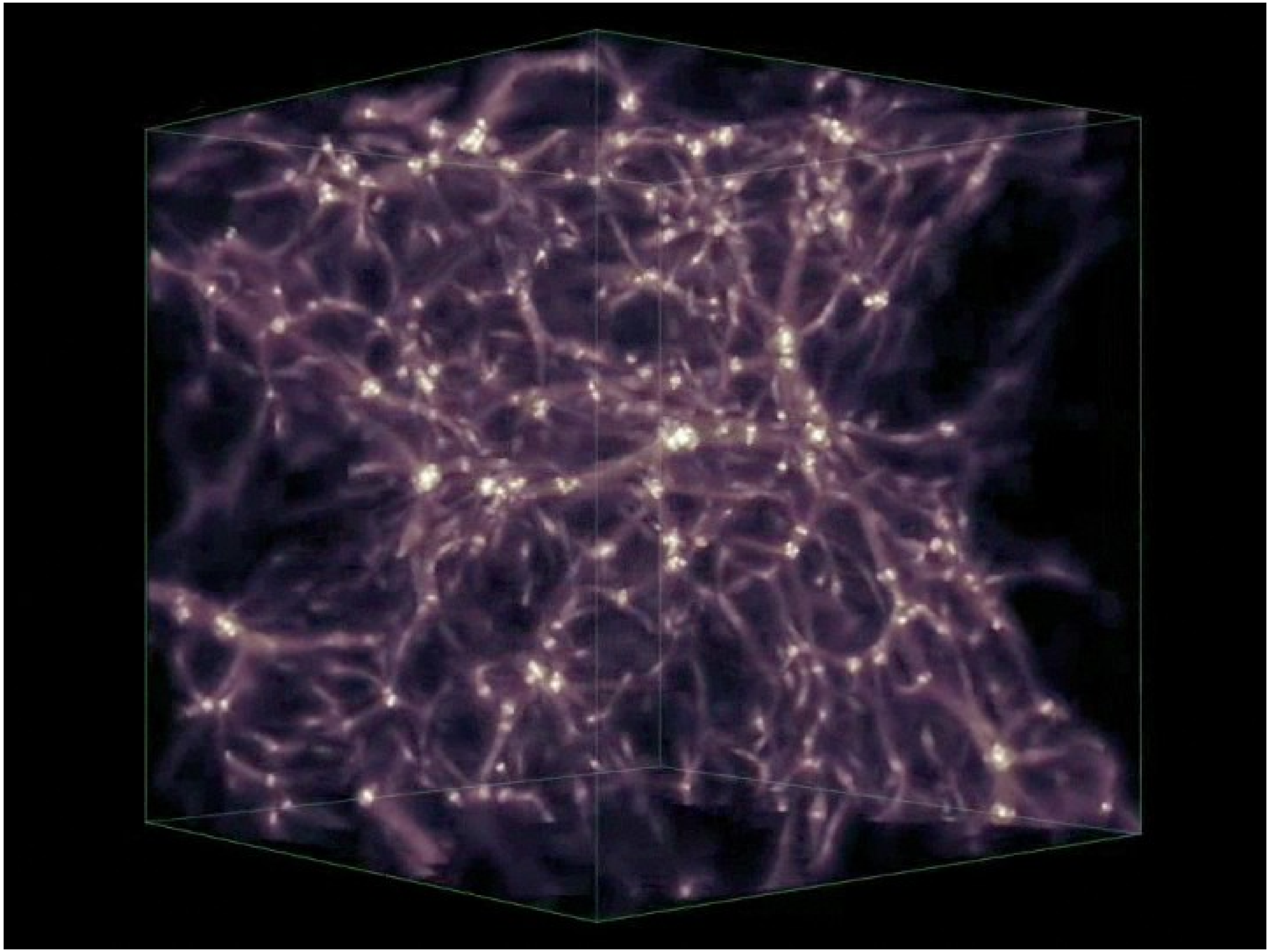
GADGET, RAMSES, ENZO?



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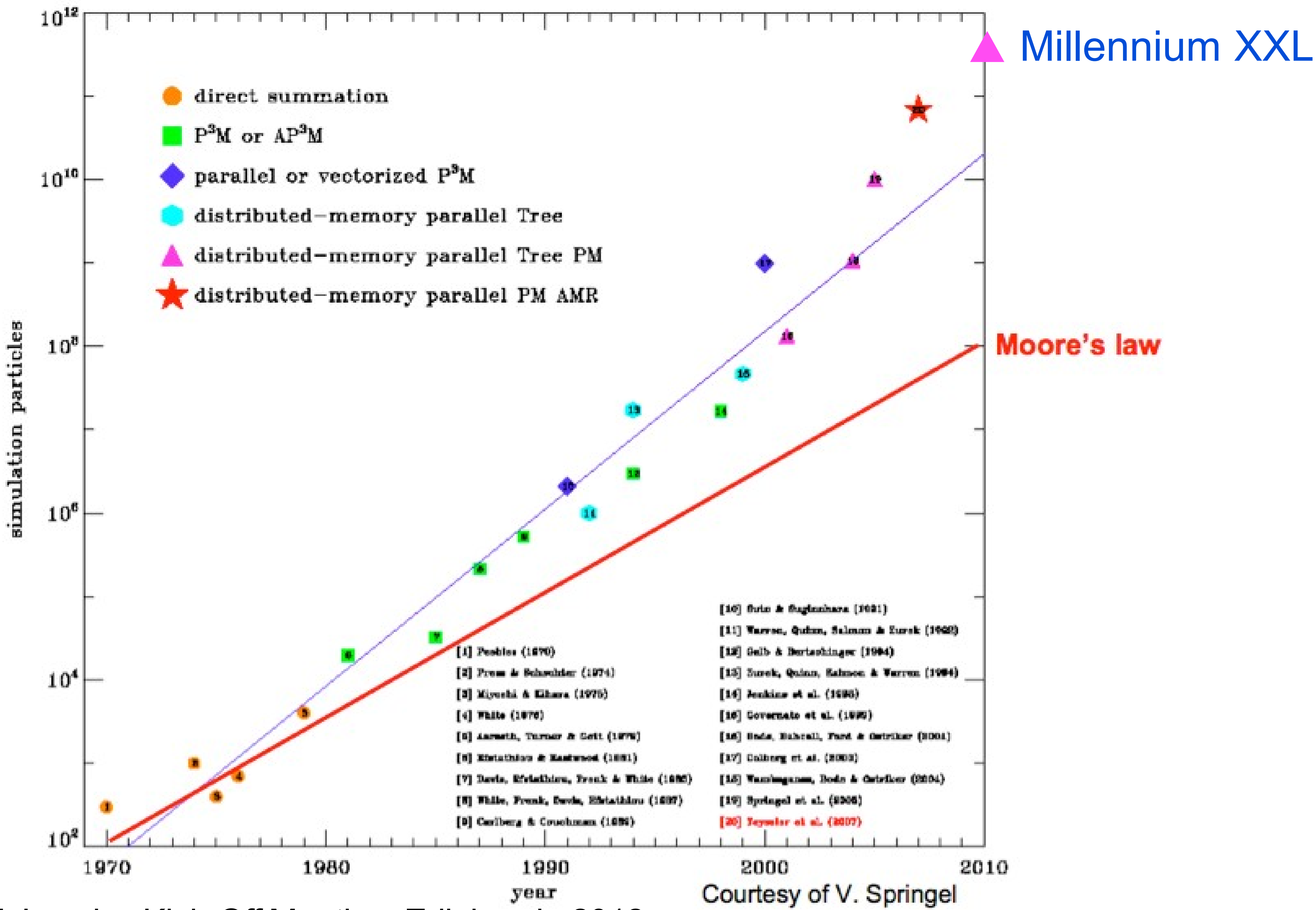
- How much parameter space do we need to sample and what additional resources are required to achieve this requirement over a large parameter space?

Moore’s Law for Simulations



Courtesy of V. Springel

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Simulation Implementation Plan - Hydro

Questions:

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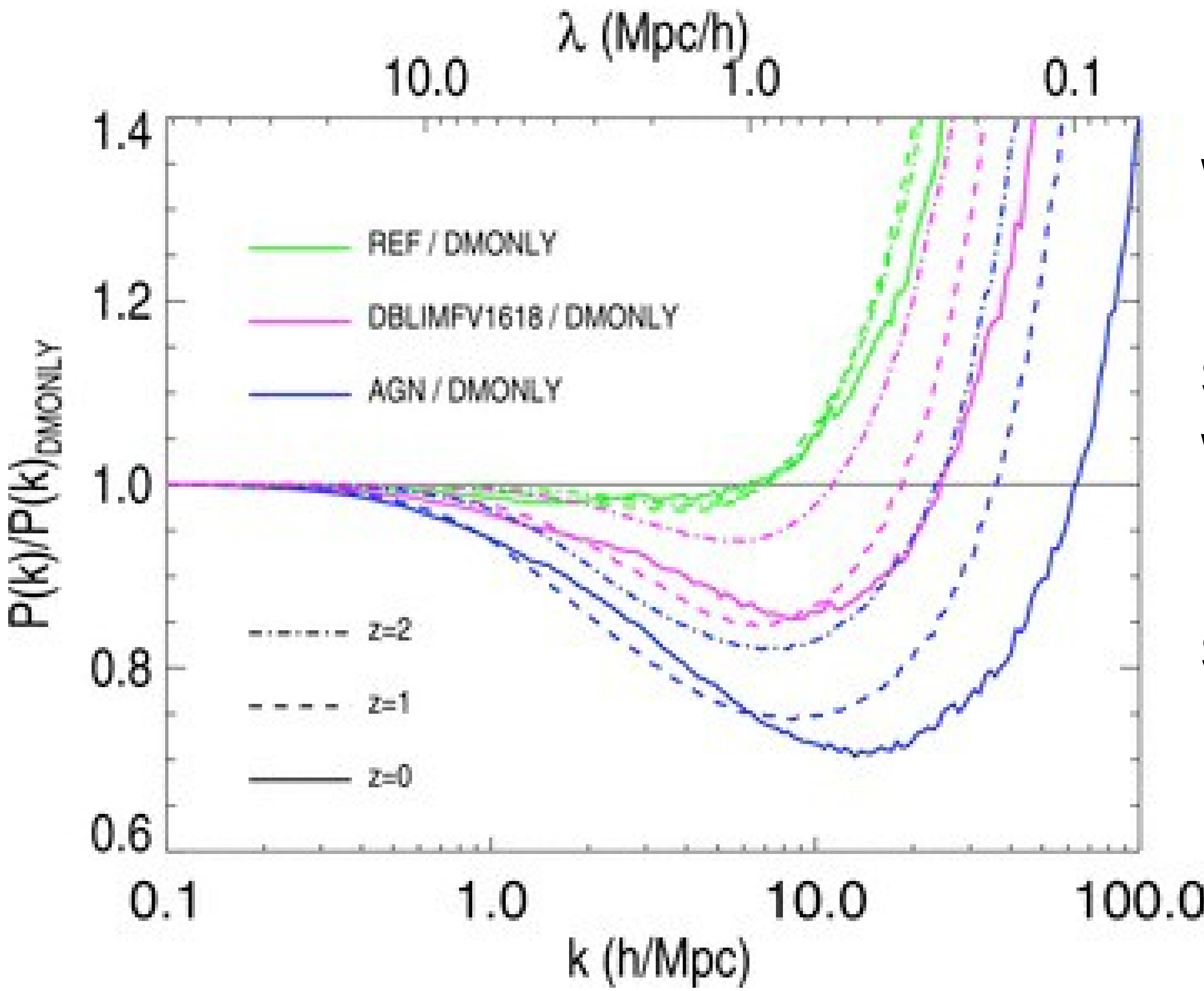
Scientifically, we don't yet know how to do this. Significant effort needs to be put in to understanding how to simulate baryons.

Baryons



Semboloni et al, 2011

We do not currently know how to accurately simulate baryons.
We need to quantify the uncertainty in the simulations and marginalise over it.

Simulation Implementation Plan - Medium

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- Is a single specification sufficient for Euclid WL requirements or will several different sets of simulations be required?

Simulation Implementation Plan - Catalogues

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- How difficult will it be to include flexion and strong lensing in the catalogues?

The SUNGLASS pipeline

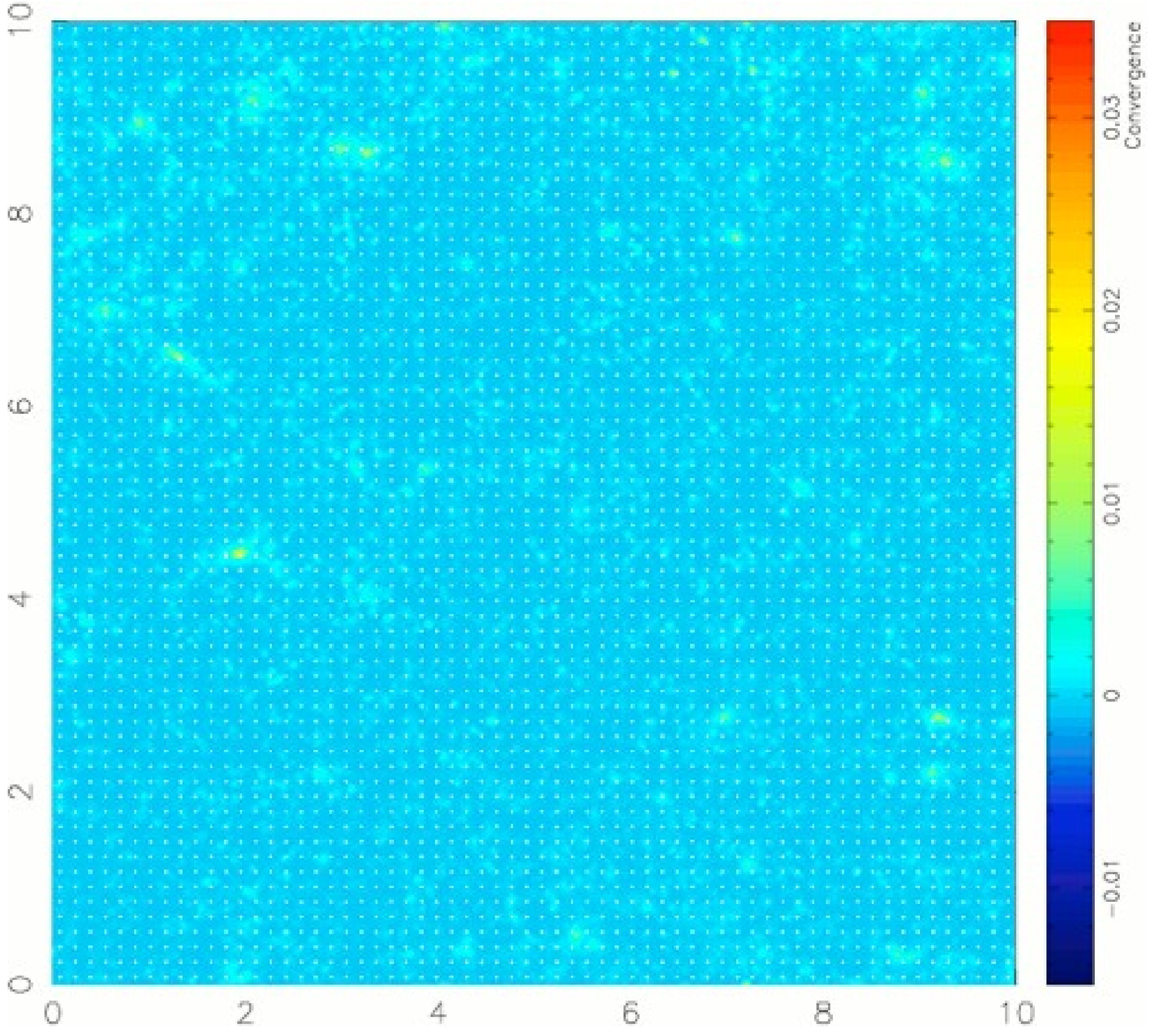
SUNGLASS -

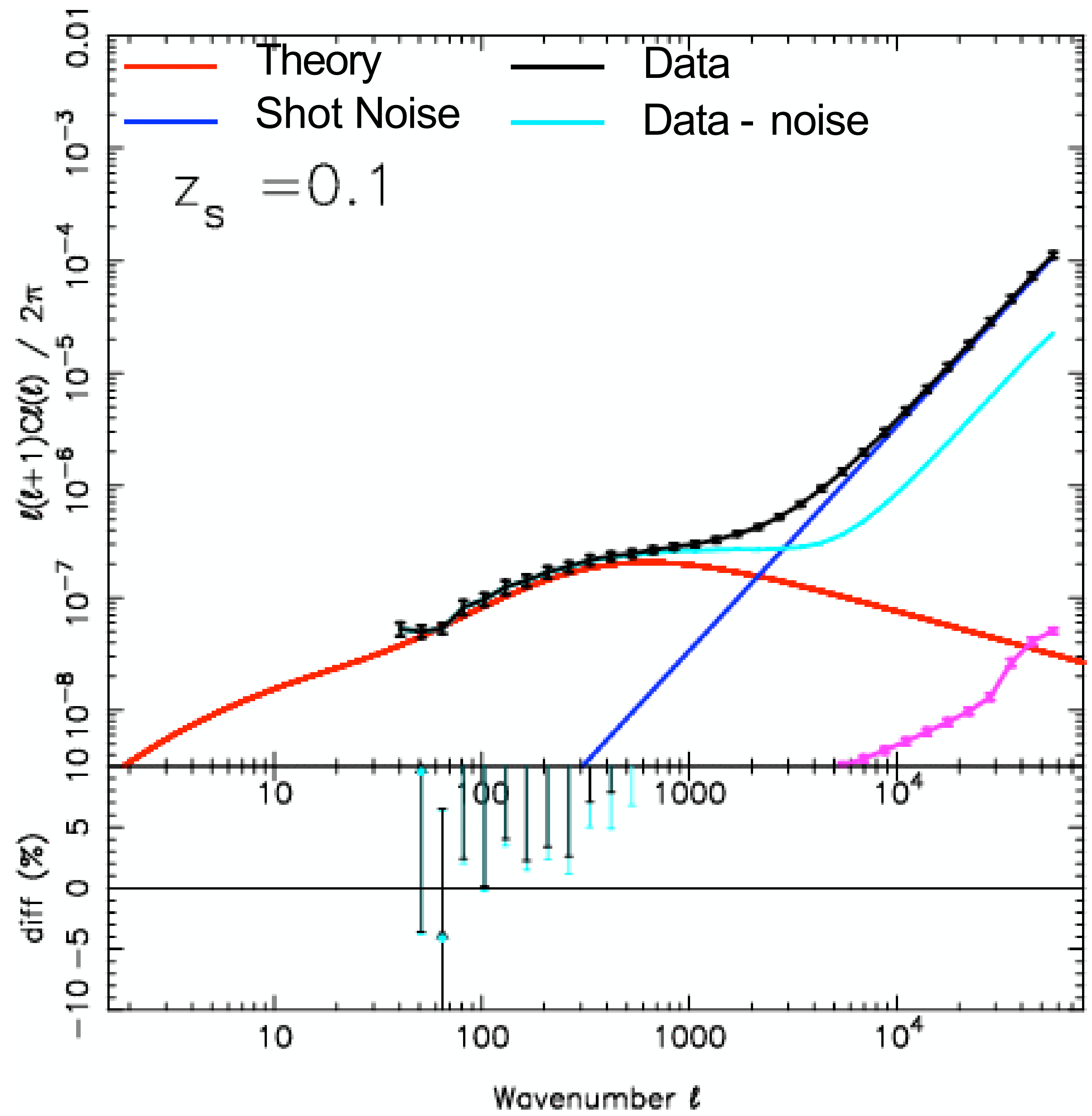
Simulated UNiverses for Gravitational Lensing Analysis and Shear Surveys

A pipeline that rapidly generates Monte Carlo simulated universes for weak lensing and cosmic shear analysis

Kiessling et al 2011, MNRAS, 414, 2235

Source redshift evolution





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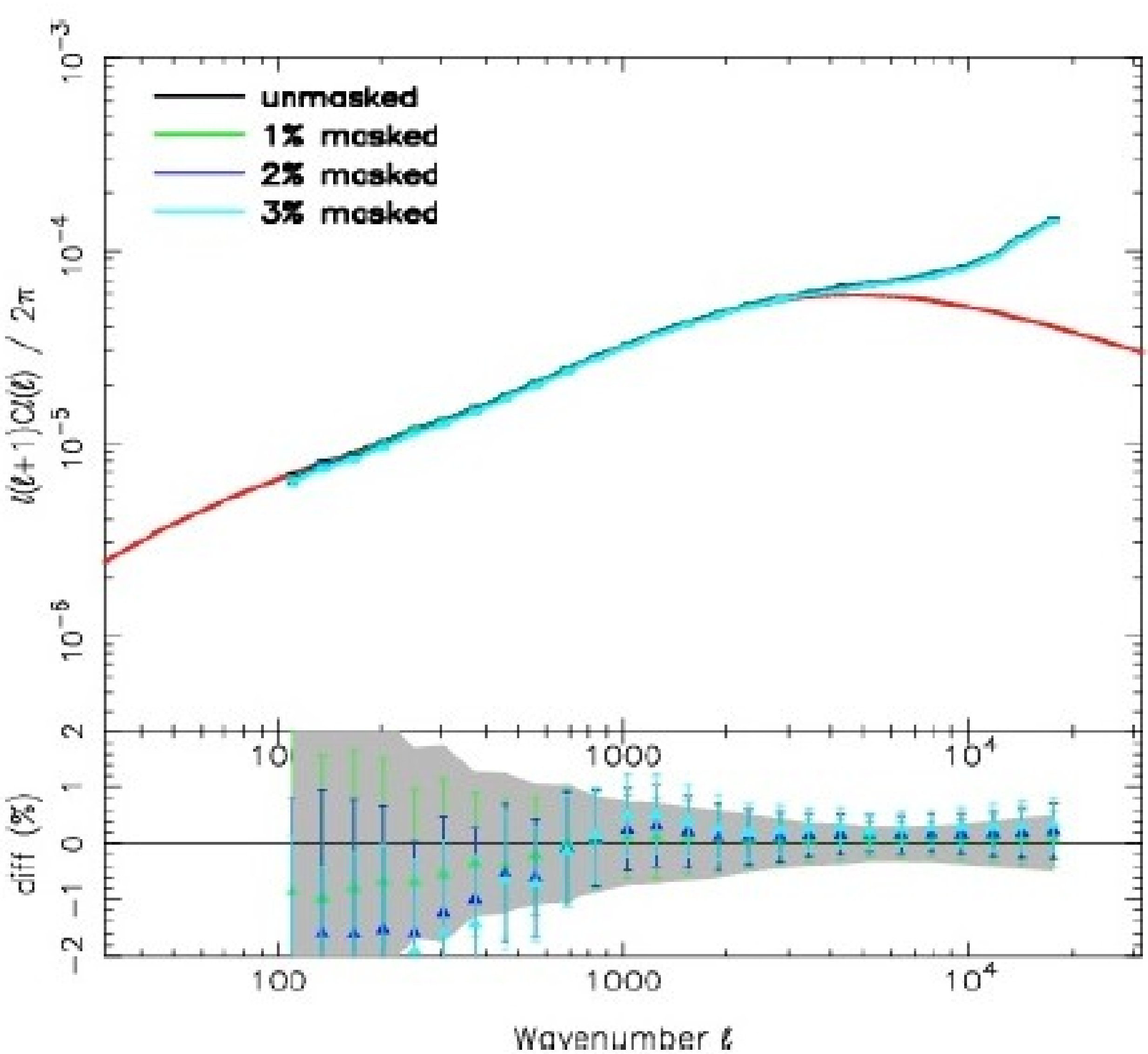
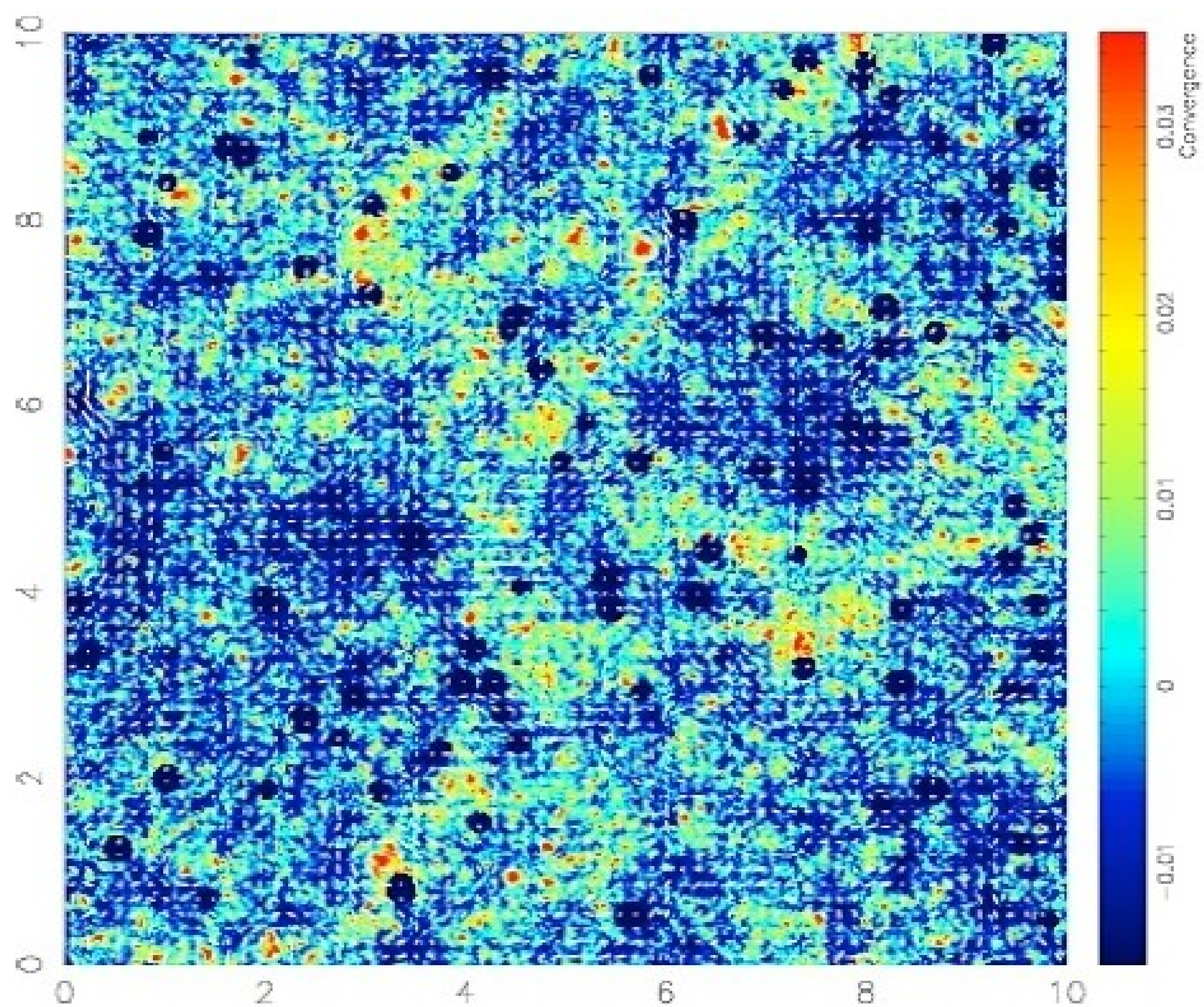
Testing for the Effects of Masking





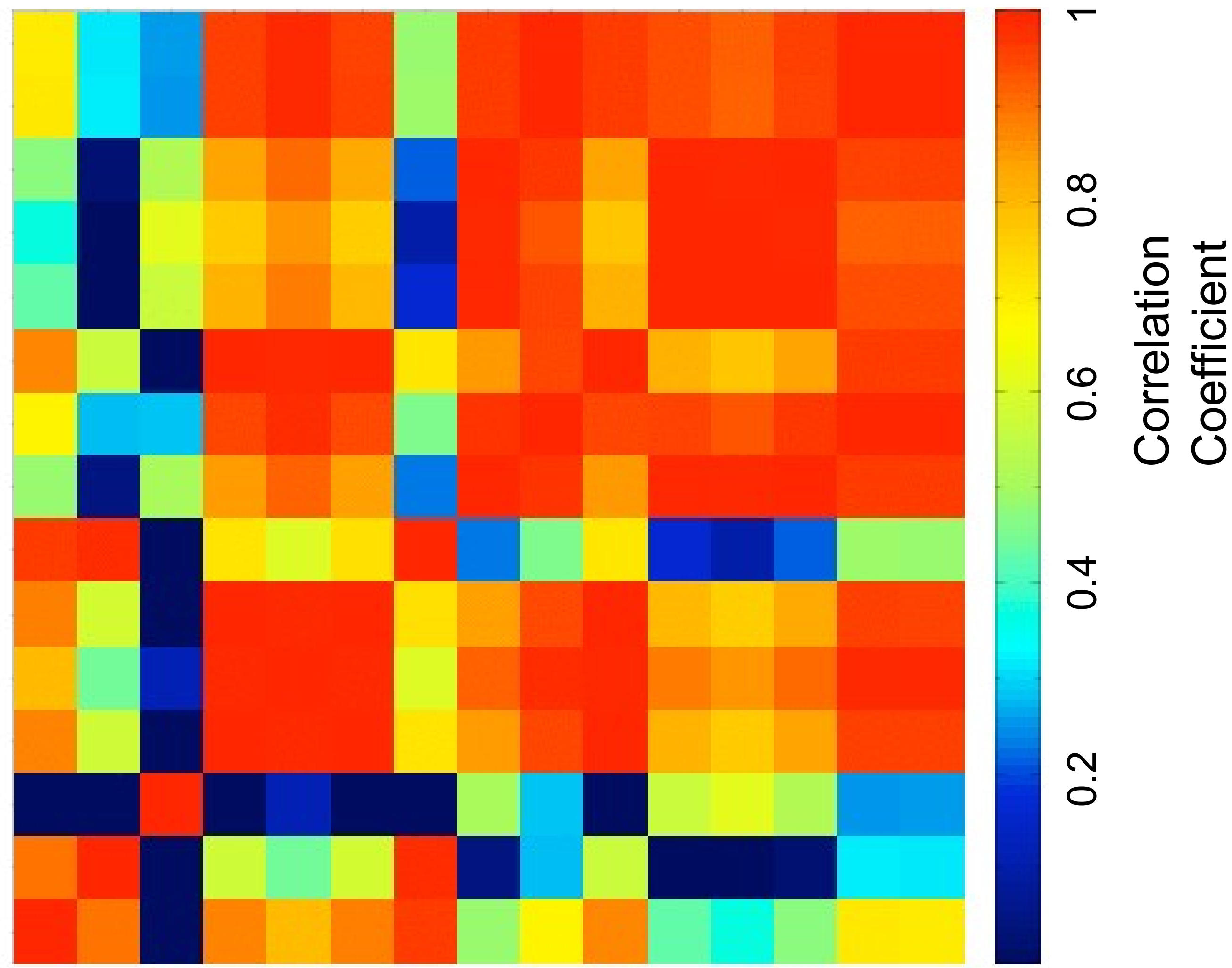
Euclid Red Book

Correlation Coefficient Matrix

$$r = \frac{M}{M \quad M}$$

where

$$M_{££'} = (8.C_{£} \quad 8.C_{££'} \quad)$$



More realisations gives a more stable matrix

£ = 100

£ = 500

R = 2300

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Kiessling et al 2011, MNRAS, 414, 2235

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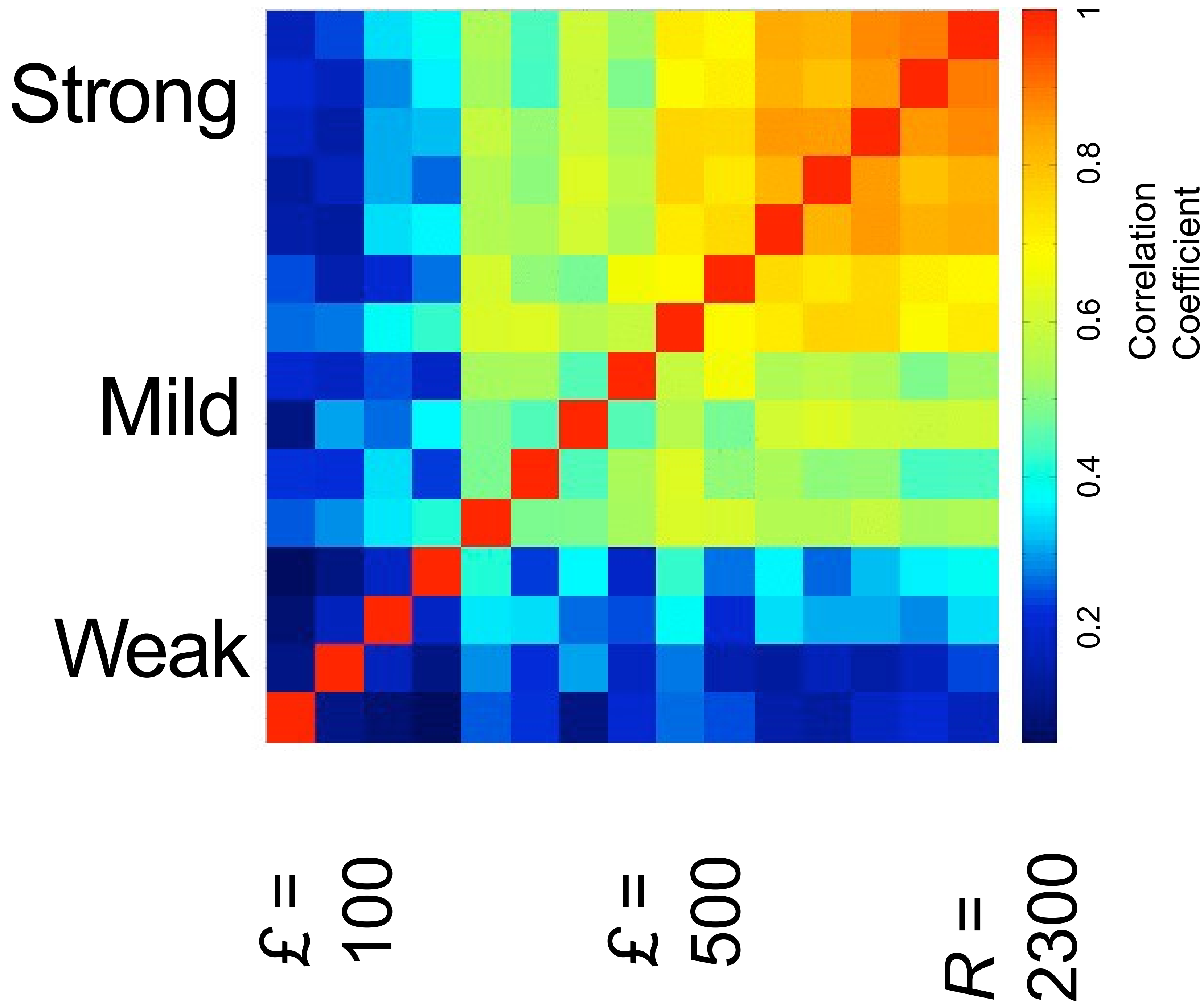

100 realisations

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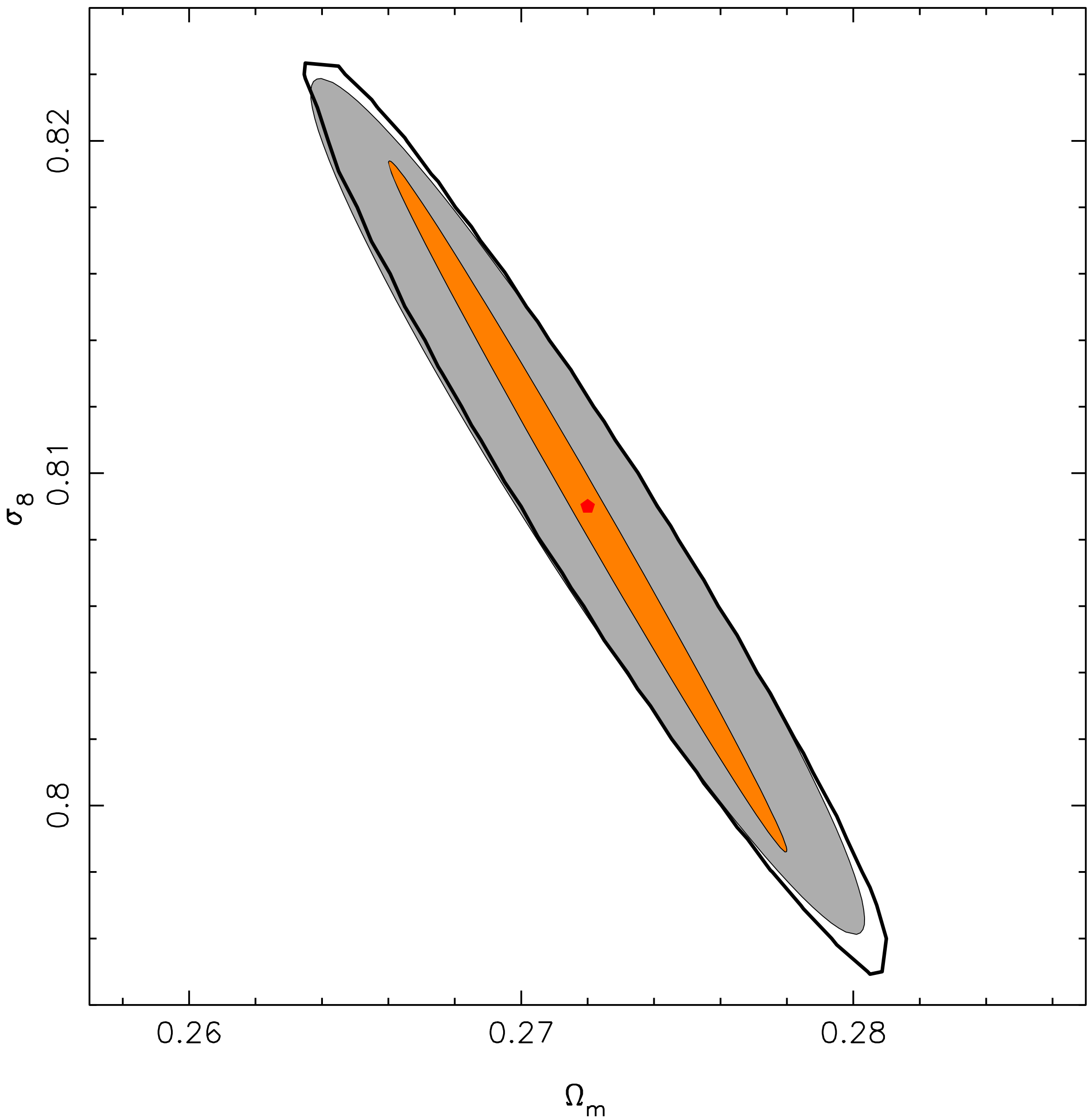
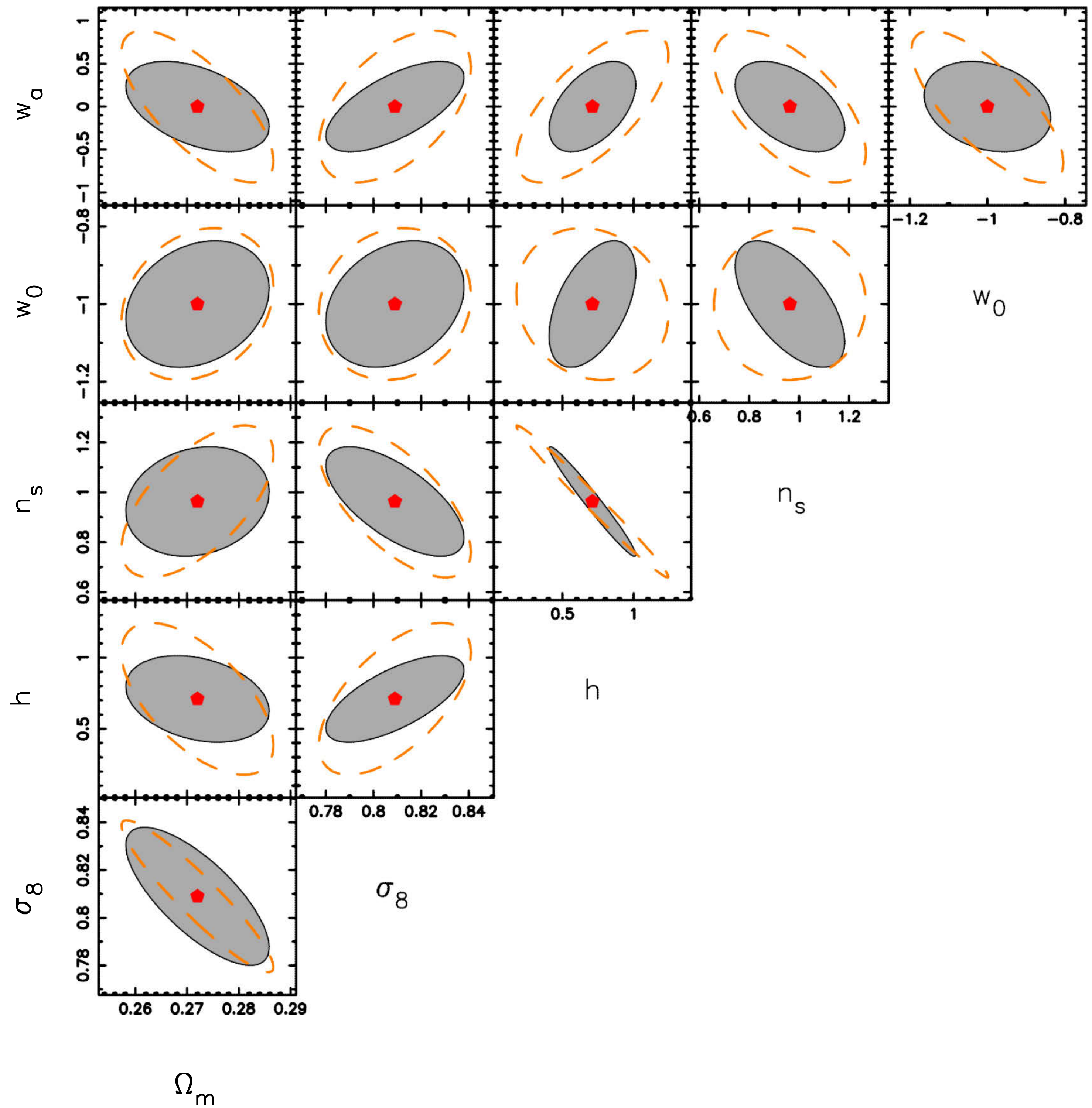
Kiessling et al 2011, MNRAS, 414, 2235

Fisher Matrix Cosmological Parameter Error Estimates





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Kiessling et al 2011, MNRAS, 416, 1045

Simulation Implementation Plan - Models

Questions:

- What alternative models should be investigated?
  1. Quintessence and early dark energy
  2. Inhomogeneous large-voids (LTB)
  3. WDM
  4. Non-Gaussian Initial Conditions
  5. Massive Neutrinos
  6. Self interacting dark matter
  7. Linear spatial dark energy fluctuations
  8. Non-linear spatial dark energy fluctuations

Complexity

- Exists
- Partially developed
- Mostly TB developed

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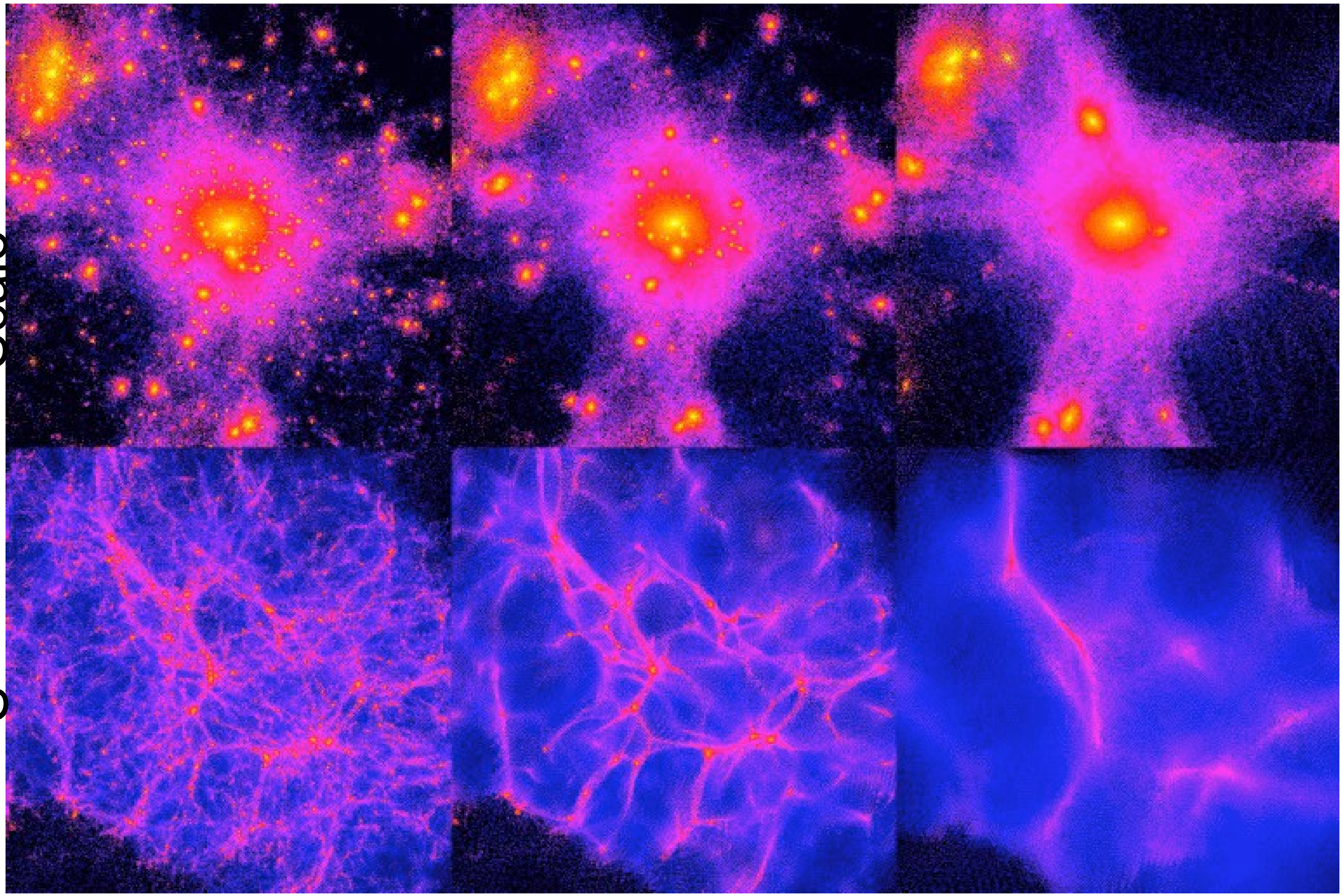
- Can the catalogue generation software be used directly on these simulations or will it need to be modified?

Alternative Dark Matter Models



Credit: Ben Moore

Alternative Gravity Models

Anything that can simultaneously explain angular diameter distances (BAO, CMB) and luminosity distances (SNe Ia) could be called dark energy

BUT - this could be the result of modified gravity!

We need large-scale N-body simulations that will explore the nature of dark energy and alternative gravity theories

Preliminary Tasks and Coordinators Identified by SIM-SWG

1. Large N-body runs and co-ordinated access to supercomputing facilities (Volker Springel)
2. Light-cone data format and ray-tracing tools (TBD)
3. Halo, sub-halo and smooth background decomposition, mass functions, merger trees (TBD)
4. Indexing and database of simulation products, data types (TBD)
5. Covariance estimation of various observables (TBD)
6. Tools for non-standard models (Marco Baldi)
7. Beyond 1% aaccuracy in dark matter statistics (Robert Smith, Pablo Fosalba)
8. The impact of baryons on cosmic statistical indicators (Romain Teyssier, Klaus Dolag)

Summary

- Simulations are essential for the successful undertaking of the Euclid mission
- The simulations requirements for the Euclid mission are **vast**! It is an enormous undertaking that includes development of software and acquisition of hardware facilities.
- The simulations requirements are currently being finalised - please contact myself or Elisabetta Semboloni if you would like to add/modify any requirements (or if you would like to be involved in the development of the simulations).