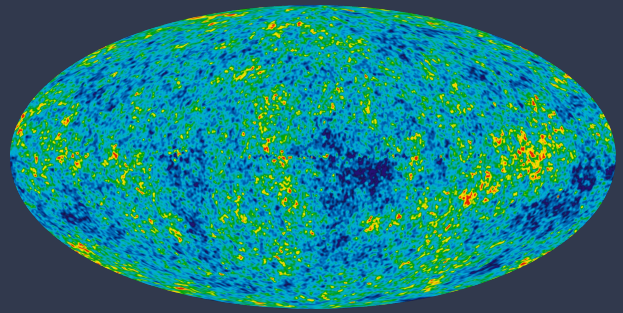
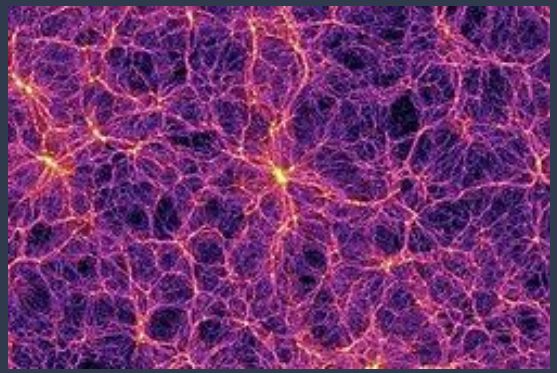
Cosmological perturbation theory

Anjali A. Kugarajh

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

Why?





- To understand current observations of large scale structure and distribution of matter and energy

- Clusters of galaxies and stars
- Cosmic microwave background temperature anisotropies

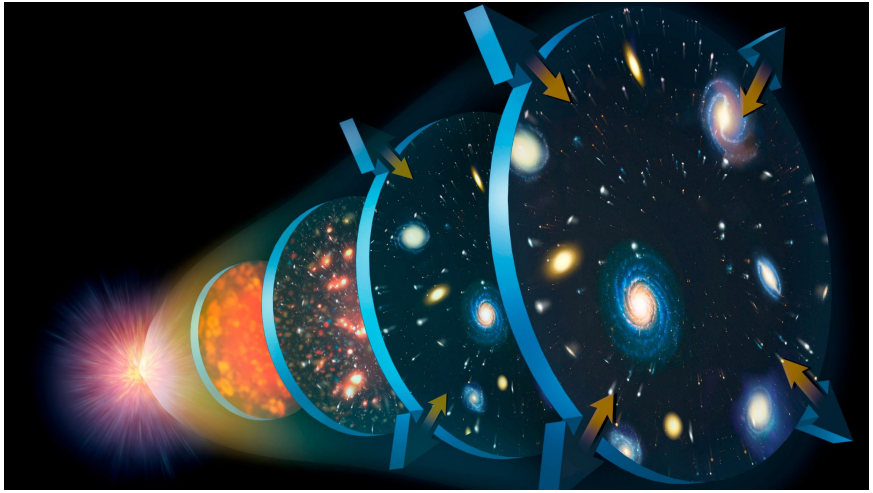
- Understanding of the early universe

Primordial inhomogeneous and anisotropic perturbations

How to explain these observations?

- Primordial perturbations arise from quantum vacuum fluctuations

- Produced in microscopic scales → stretched to large scales



Relativistic cosmological perturbation theory

- Linear perturbative analysis
- Studying small inhomogeneous perturbations on homogeneous and isotropic FRW background
- Decomposition of tensor quantities:

$$g_{\mu\nu} = g^{(0)}_{\mu\nu} + \delta g_{\mu\nu}$$

Gauge dependence

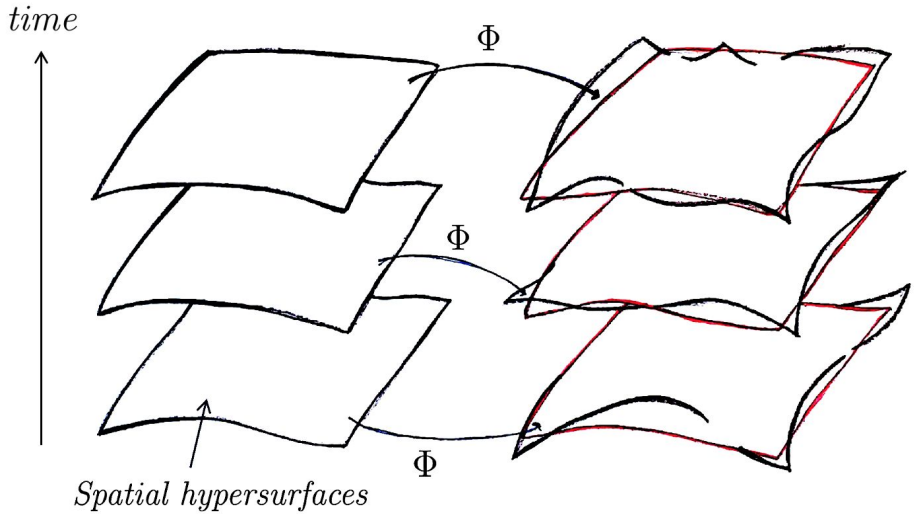
Gauge → mapping between background and perturbed space

Perturbations behave differently in different gauges

Gauge chosen to best suit the model and problem → simplify

Gauge - invariant variables:

- ➔ Combination of variables independent of gauge
- ➔ Advantage of being able to cross reference and work with other gauges

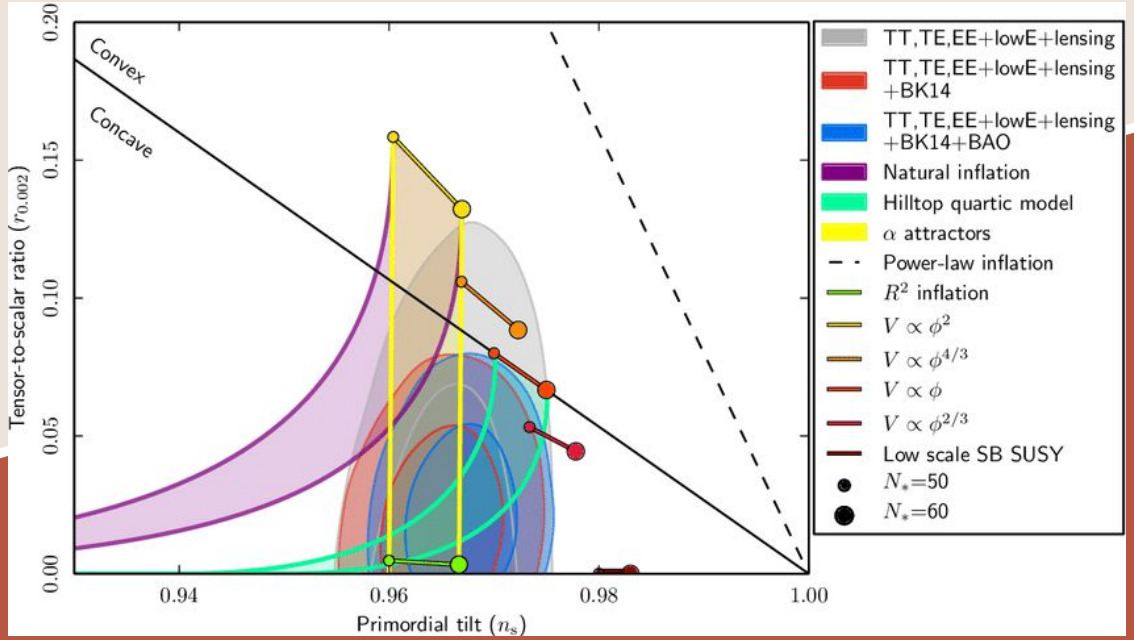


Early universe models

- Accelerated expansion phase, i.e. inflation, stretching primordial fluctuations
- Quantum vacuum fluctuations, expanded rapidly and amplitudes of fluctuation are“frozen-in” in large scales

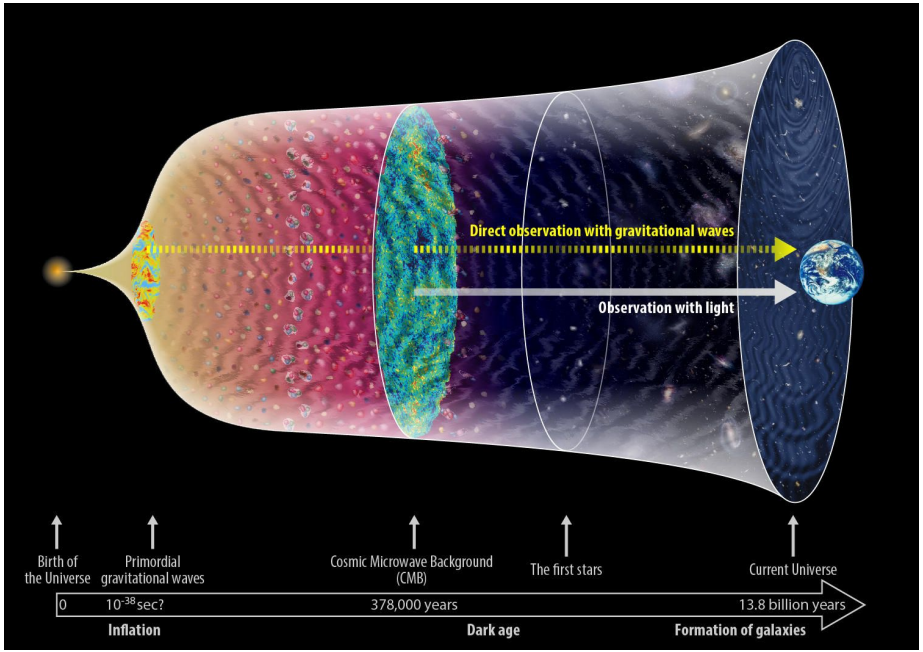
Scalar field

- Simplest model considered is a scalar field driven expansion
- Results of scale-invariant spectrum in agreement to CMB data



Akrami, Y. et al. (2020), 'Planck 2018 results. X. Constraints on inflation', Astron. Astrophys. 641, A10

Scalar-induced gravitational waves



Weak interaction with matter → GW effective tool to study primordial universe

Stochastic gravitational wave background (SGWB)

- GW signals emitted in early universe
- Superposition of different sources
- “Scalar-induced” GW generated from primordial fluctuations

Primordial black holes

Studies of induced GW and perturbation theory used to place constraints on primordial black holes

Conclusion

Cosmological perturbation theory allows us to connect theories of very early universe with current data on large scale structure

With current and future detectors, such as LISA and ET, hopefully induced gravitational waves and SGWB can be detected