Dark Matter Introduction

Joachim Kopp

Max Planck Institut für Kernphysik, Heidelberg

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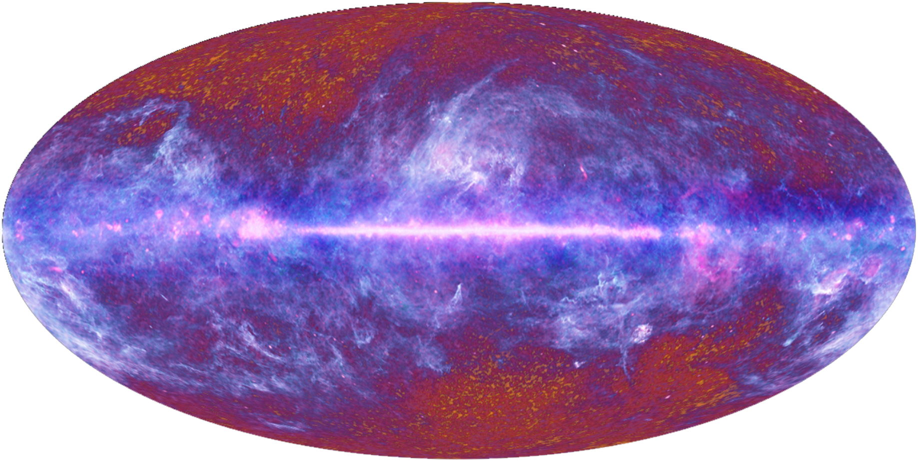
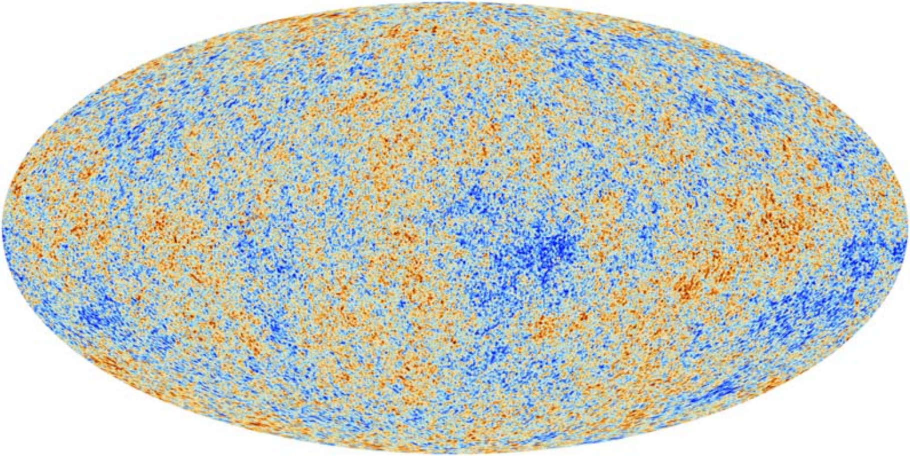
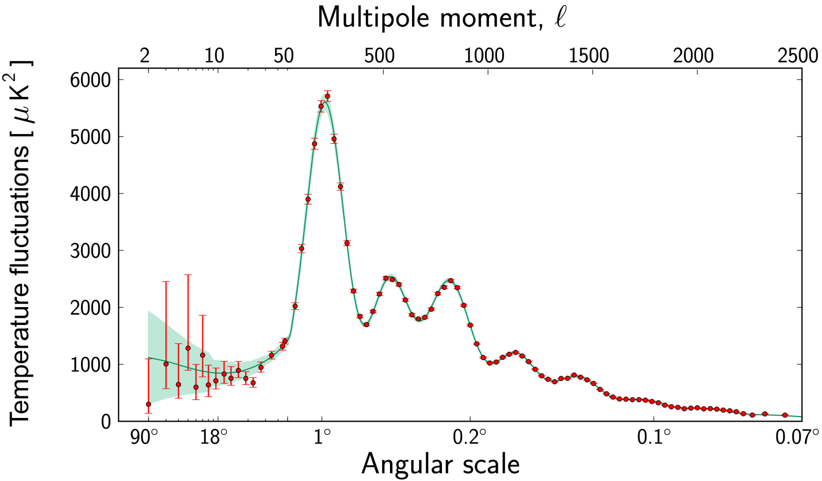
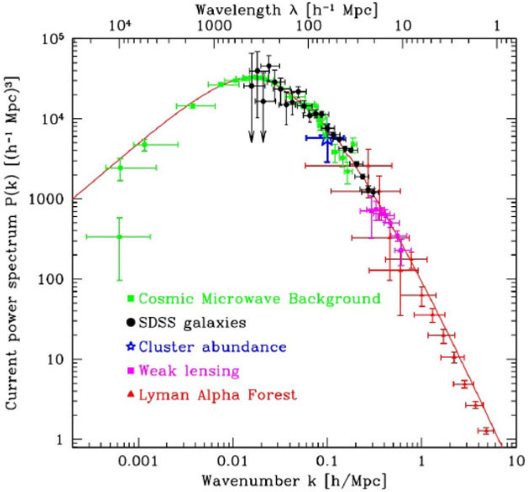
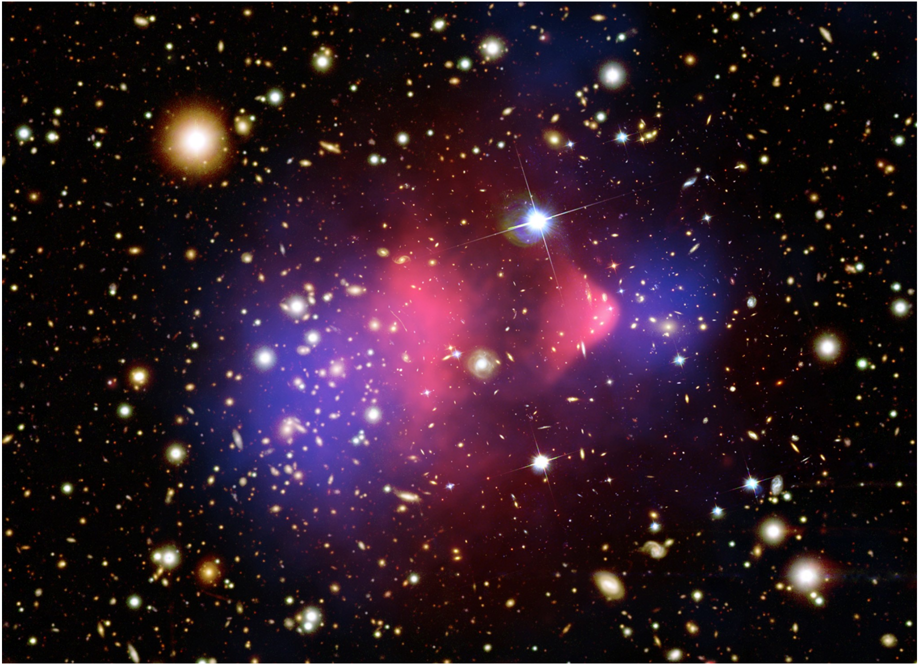




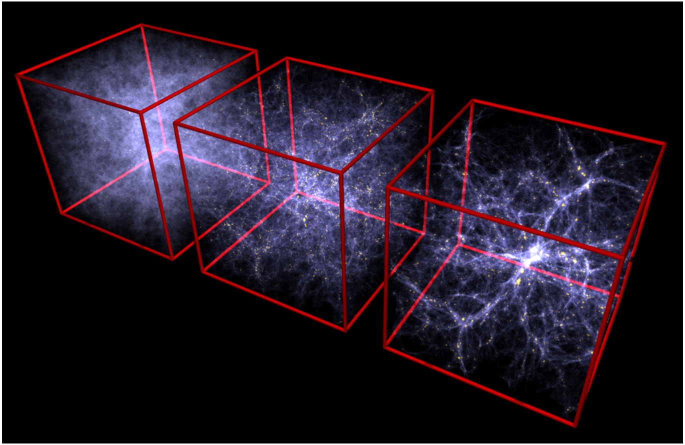

Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK²]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale



Wavelength λ [h⁻¹ Mpc]
Current power spectrum P(k) [(h⁻¹ Mpc)³]
Wavenumber k [h/Mpc]
Cosmic Microwave Background
SDSS galaxies
Cluster abundance
Weak lensing
Lyman Alpha Forest



Simulating structure formation



Movies at

`http://www.mpa-garching.mpg.de/galform/data_vis/index.shtml`

Technical challenges in N-body simulations

Main bottleneck: Large sum in

$$\vec{F}_i = \sum_{j \neq i} \frac{G m_i (\vec{x}_i - \vec{x}_j)}{(|\vec{x}_i - \vec{x}_j|^2 + \epsilon^2)^{3/2}}$$

- Tree methods
  - Divide cubic volume into 8 sub-cubes
  - If sub-cube contains < 2 particles: done, continue with next subcube
  - If sub-cube contains ≥ 2 particles: subdivide again and iterative recursively
  - End result: Each tree node = 1 particle

  When computating $\vec{F}_i$:
  - For small $|\vec{x}_i - \vec{x}_j|$: exact evaluation (use tree leaves)
  - For large $|\vec{x}_i - \vec{x}_j|$: use larger pseudoparticles (higher tree nodes)

Technical challenges in *N*-body simulations

Main bottleneck: Large sum in

$$\vec{F}_i = \sum_{j \neq i} \frac{G m_i (\vec{x}_i - \vec{x}_j)}{(|\vec{x}_i - \vec{x}_j|^2 + \epsilon^2)^{3/2}}$$

- Tree methods
- Mesh methods
  - Compute force field on discrete grid (use Fast Fourier Transform to solve Poisson equation)
  - Use this force field to compute $\vec{F}_i$
  - Adaptive methods: Use smaller grid spacing in “interesting” regions (lots of structure); adapt grid spacings dynamically

Technical challenges in N-body simulations

Main bottleneck: Large sum in

$$\vec{F}_i = \sum_{j \neq i} \frac{G m_i (\vec{x}_i - \vec{x}_j)}{(|\vec{x}_i - \vec{x}_j|^2 + \epsilon^2)^{3/2}}$$

- Tree methods
- Mesh methods
- Hybrid methods
  Use tree method on small scales (more accurate) mesh method on large scale (faster)