14. Cosmological Frontiers

Big cosmological questions when I was in graduate school (1985-1989)

1. Did structure form by gravitational instability?

2. If so, what were the primordial fluctuations like, and where did they come from?

3. What is the dark matter?

4. What is the value of Ω_0?

5. What is the relation between the distribution of galaxies and the distribution of dark matter?

Current answers

1. Yes.

2. Primordial fluctuations have properties in excellent agreement with the predictions of simple inflation models — adiabatic, nearly scale-invariant, and Gaussian.

3. Dark matter is non-baryonic, and it is probably cold and weakly interacting.

4. $\Omega_{m,0} \approx 0.3$, $\Omega_0 = 1 \pm 0.005$. A flat universe dominated by dark energy.

5. "Typical" galaxies roughly trace dark matter on large scales. Properties of galaxies (luminosity, color, age) mainly reflect the mass of the DM halo they live in and whether they are central or satellite galaxies in that halo.

Open cosmological questions today

1. Why is the universe accelerating? A cosmological constant? Some other form of dark energy? Modification of GR?

2. What is the particle nature of dark matter? Is DM completely cold and weakly interacting?

3. What can cosmology tell us about neutrino physics, e.g., masses, additional species?

4. Is inflation the correct theory of the very early universe? What was the physics of inflation? Is our universe one of many?

5. What is the origin of the matter/anti-matter asymmetry?

6. What was the universe like near the Planck epoch?

7. In detail, how do galaxies and other cosmic structures form?

Methods of investigation

Dark matter detection experiments: direct, indirect, colliders.

Improving maps of CMB anisotropy, especially polarization.

Improved expansion history measurements using supernovae and BAO.

Improved measurements of galaxy clustering over a wide range of redshift and scales, from larger imaging and redshift surveys.

Measurements of dark matter clustering using large imaging surveys for weak gravitational lensing.

Measurements of structure using intergalactic hydrogen, seen in Lyα absorption and in 21cm emission and absorption.

Studies of galaxy and cluster dynamics to test for more complex properties of dark matter, e.g., warm or self-interacting or decaying dark matter.

Measurements of the luminosities, colors, stellar masses, sizes, morphologies, gas content, and star formation rates of galaxies over a wide span of redshift and environment, including DM environment measured with weak lensing.

Detailed studies of the Milky Way galaxy to unravel its history. Ditto for the dwarf satellite galaxies that orbit the Milky Way.

Increasingly sophisticated computer simulations of galaxy and structure formation.

Theoretical investigations of dark matter physics, dark energy or modified gravity physics, early universe physics.