The First Galaxies

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Outline

1. *Introduction*
   - 1.1 Observing our past
   - 1.2 Cosmological context: the expanding universe
     - 1.2.1 FRW metric, cosmological parameters
     - 1.2.2 Thermal history of the Universe: inflation, nucleosynthesis, matter-radiation equality, recombination, reionization
     - 1.2.3 Cosmic composition: radiation, baryons, neutrinos, dark matter, dark energy
   - 1.3 Observational overview

2. *From recombination to the first galaxies*
   - 2.1 Initial conditions (power spectrum and its parameters)
   - 2.2 Growth of linear perturbations
     - 2.2.1 The Zel'dovich approximation
   - 2.3 Thermal history during the Dark Ages (adiabatic cooling, Compton heating)

3. *Nonlinear structure*
   - 3.1 Properties of virialized halos ($M_{\rm vir}(z, V_c)$, NFW density profile).
   - 3.2 Abundance and clustering of dark-matter halos
     - 3.2.1 Press-Schechter mass function
     - 3.2.2 Extended Press-Schechter, merger trees
     - 3.2.3 Improvements to the Press-Schechter approach
   - 3.3 Nonlinear clustering: The halo model
   - 3.4 Numerical simulations of structure formation (basic principles)

4. *The Intergalactic Medium*
   - 4.1 The Lyman-α forest: overview
   - 4.2 The ionizing background
   - 4.3 Modeling the forest
     - 4.3.1 Numerical simulations
     - 4.3.2 Semi-analytic models
   - 4.4 Metal-line systems

5. *The First Stars*
   - 5.1 Chemistry and cooling of primordial gas (including H_2, HD).

5.2 Formation of the first metal-free stars
5.2.1 Fragmentation mass (Jeans mass, Bonor-Ebert)
5.2.2 Early accretion phase and mass saturation (simulations and analytic models)
5.2.3 Feedback (UV illumination, metal enrichment, remnants)
5.3 Later generations of stars
5.4 Global parameters of high-redshift galaxies
5.4.1 Minimum mass of galaxies (filtering mass as a function of redshift, mini-halos with no cooling or star formation)
5.4.2 Angular momentum
5.4.3 Formation timescales
5.5 Gamma-ray Bursts: probing the first stars one star at a time

6. *The First Black Holes*
6.1 Quasars: observational overview
6.2 Potential seeds (massive stars, supermassive stars, direct collapse)
6.3 Accretion theory (α-disks, radiatively inefficient accretion)
6.4 Eddington limited growth (L_E, phenomenology of quasars)
6.5 Mergers of black hole binaries (gravitational wave emission, recoil)

7. *The epoch of reionization*
7.1 Growth of a single ionized region
7.2 The global reionization history
7.3 Statistical description of size distribution and topology of ionized regions
7.4 Radiative transfer (numerical methods)
7.5 Recombination of ionized regions
7.6 The sources of reionization
7.6.1 Massive stars
7.6.2 Quasars; limits on hard sources
7.6.3 Exotic reionization scenarios
7.7 Helium reionization

8. *Feedback in the Early Universe*
8.1 Radiative feedback
8.1.1 Heating of the intergalactic medium; minihalos and the clumping factor
8.1.2 Photoheating and the suppression of low-mass galaxies
8.1.3 Recombination radiation
8.2 Large-scale mechanical feedback
8.3 Chemical enrichment

9. *The Lyα line as a probe of the early universe*

9.1 Emission from galaxies
9.2 Scattering in the intergalactic medium (Lyα damping wing, Lyα halos)
9.3 The Gunn-Peterson trough and the Lyα forest

10. *The 21cm line*
10.1 Atomic physics (from first principles)
10.2 Interaction with gas and UV/X-ray radiation backgrounds
10.2 Statistical and imaging tools
10.3 Observational prospects (with images)
10.4 The transition to the post-reionization Universe

11. *Galaxy surveys*
11.1 Stellar populations
11.2 Galaxy evolution
11.3 Luminosity functions
11.4 Lyα and Lyman-break galaxies as probes of reionization
11.5 Molecules, dust, and the interstellar medium

12. *Other observational probes of the first stars and galaxies*
12.1 The cosmic microwave background
12.2 Low-redshift signatures
12.2.1 Clues from the intergalactic medium (thermal history, metal enrichment)
12.2.2 The fossil record of the local group