UCSB PHYSICS 133 Professor Martin
GALAXIES AND COSMOLOGY 2021 Spring Quarter

HOMEWORK #9 (Due 5:00 pm May 28th)

Problem 1: **Evolution of Structure in a Contracting Universe**
Ryden 11.1

Problem 2: **Redshift of Galaxy Formation**
Ryden 11.4

Problem 3: **Baryonic Manisfestation of Acoustic Oscillations**

In this problem, use $z_{LS} \approx 1090$ for the redshift of the surface of last scatterin g.

(a) Calculate the horizon distance at the time of last scattering.

(b) For most of the time prior to last scattering, the sound speed in the photon-baryon fluid was $c_s \approx c/\sqrt{3}$, the same as a that of a pure photon gas. Estimate the sound horizon at the time of last scattering.

(c) Consider an overdense region on the surface of last scattering with the physical size you found in part (b). This region will be a little hotter than the surroundings due to the compression of the photon-baryon fluid. Calculate the angular size of the hot spot imprinted on the cosmic microwave background by photons leaving this region.

(d) The acoustic oscillation described in part (c) also leaves an observable mark on the baryons. Calculate the comoving size of the sound horizon, also known as the acoustic scale.

(e) Calculate the mass scale corresponding to the baryon acoustic oscillations. [Hint: Use the comoving volume of a sphere with radius equal to the acoustic scale and the comoving *total matter* density of the universe.]

Hint: If you need help getting started, please take a look at [R] 11.6.