

Ay 7b – Spring 2012
Section Worksheet 13
Cosmology

1. The evolution of the universe

We've been talking about the universe in many (three) different regimes. Let's put all the eras together and see what the universe has been doing these last 13.7 billion years.

- (a) Write down a COMPLETE version of the Friedmann equation that includes contributions from radiation, matter, and dark energy. Explicitly include the dependence of each density on the scale factor R . What happens to the Friedmann equation when one component dominates?

- (b) The Baby Universe: Find how R scales with t in the radiation-dominated era.

- (c) The Teenage Universe: Find how R scales with t in the matter-dominated era.

- (d) The Adult Universe: Find how R scales with t in the Λ -dominated era.

- (e) The Universe Hits Puberty: Find the value of the scale factor and the redshift z when radiation and matter contribute equally to the evolution of the universe. This corresponds to a time of $t_{r-m} \approx 47000$ yr. Why is this value of t tricky to calculate?
- (f) The Universe Leaves Home: Find the value of the scale factor and the redshift z when matter and dark energy contribute equally to the evolution of the universe. This corresponds to a time of $t_{m-\Lambda} \approx 9.5 \times 10^9$ yr.
- (g) A Photo Album of Our Universe—A Retrospective: Put everything you’ve calculated above together in a sketch of R vs. t . Use a log-log scale and indicate the equality times.