Topics: The full Friedmann equation, evolution of the categories of mass-energy, the consensus model

Reading:

- Re-read section 5 of Ch. 23 (pp. 546-49).
- Read the first several pages of section 1 of Ch. 24 (pp. 551-55), up through the phrase *There is no Big Crunch for the consensus model.*

Summary of work to submit:

- Nothing to hand in for Thursday's class.

Overview:

A *model of the universe* is defined by the values for the three quantities in equation 23.76. That's about it... the current time can also be defined, but basically, knowing those three values now gives the current age. And any particular time can be defined by the observed value of the Hubble constant at that time. Solving the Friedmann equation given those three values (of the Ωs) gives a and $\dot{a}$ and thus the Hubble parameter as a function of time. We can measure $H(t)$ for some range of times and also take a census of photons and baryonic matter and all gravitational matter at the current time. And we can make simple arguments about how the different components evolve with time (or more specifically, with the scale factor) – p. 551.

Commentary on the reading, viewing, and other preparation:

See if you can summarize the differences between the Newtonian and the actual Friedmann equation, and the physical interpretations of the different terms in equation 23.68.

What's with the c^2 in the denominator of the first term on the right hand side? What units does ρ have? And u?

Are you okay with vacuum energy? ...really? Is it plausible that space has energy but we wouldn't notice it? Does it make sense that u doesn't vary in time as the universe expands (the scale factor changes) if the cosmological constant is really vacuum energy?

Does it make sense to you (Fig. 24.2) that if you go back early enough in time, radiation will have more mass-energy than matter? And that in the future, radiation will matter even less to the evolution of the universe than it does now?

As you read about the consensus model, think about *how* we know the things we know (the values of the various Ωs).

Remind yourself, again, that all components of mass-energy contribute positively to curvature, but some act to slow expansion (gravity) while others (cosmological constant) act to speed up the expansion.

And think about how, even if we can't solve the Friedmann equation analytically, we can still make concrete predictions about how the universe will behave in the future.

We have to admit, the values of the Ωs don't actually tell us everything. We also want to know things like what actually is the mass in the universe composed of? (Why the mixture of elements we see? What is and isn't dark matter and how much of it is there?) We can answer some of those questions, though we still don't know what dark energy is or even, for sure, if it has a constant energy density.