41 Astro notes 2018/12/7 - Fri - Cosmology - nucleosynthesis and inflation

41.1 Big Bang Nucleosynthesis

As the hot, early universe cooled, after protons and neutrons were formed, after most neutrons were integrated into He4, there was time for a small amount of nucleosynthesis. The reactions involved are shown here in a figure from Carroll & Ostlie:

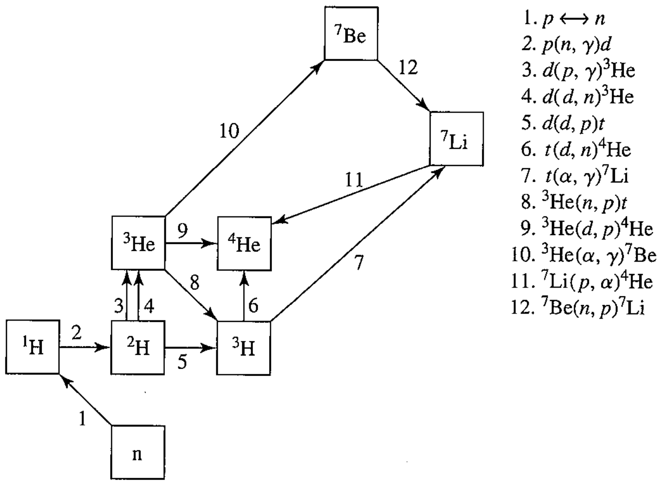
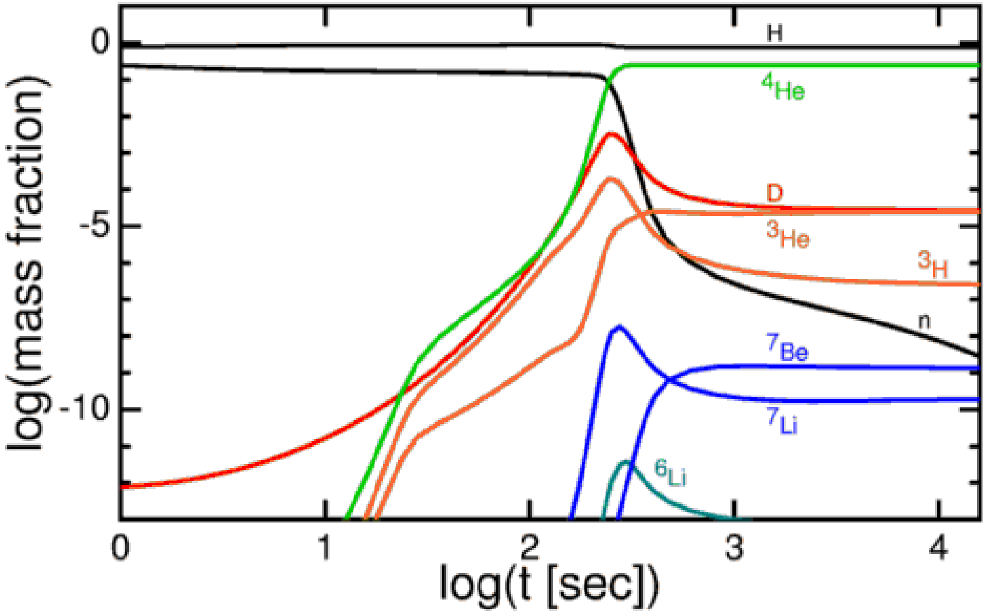
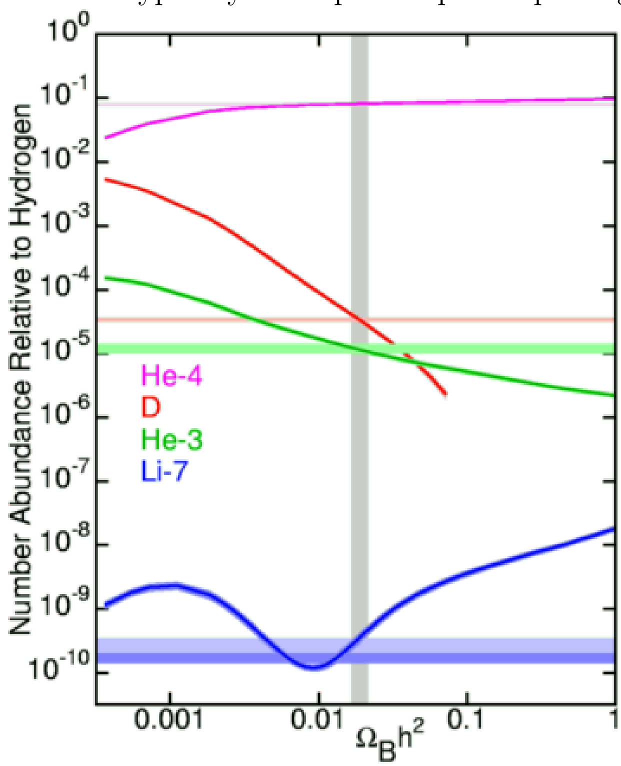


FIGURE 29.13 The reaction network that is responsible for Big Bang nucleosynthesis. The letter "*d*" stands for deuterium, and "*t*" stands for tritium. (Figure adapted from Nollett and Burles, *Phys. Rev. D*, *61*, 123505, 2000.)

Basically a small amount of Deuterium, lithium, and Beryllium are made.
(from `http://www.astro.ucla.edu/~wright/BBNS.html`)
In time:



The measured values can be used to infer the amount of baryons in the universe, parameterized as $\Omega_b h^2$. This is the current mass-energy density of the universe in the form of Baryons, and is approximately 0.021. Getting the pristine gas to measure this in is tricky, and is done typically with quasar spectra passing through the IGM.



Here horizontal bands correspond to measured abundance ranges (with uncertainty) and vertical is the consistent value for $\Omega_b h^2$. Note that the lithium measurement is not quite consistent with the others, but is close.

41.2 Physics in the early universe

Start with physics now:

The standard model of physics governs physics today. Typically phrased as "scattering" of particles:
leptons: electron, muon, tau; and a corresponding neutrino for each.
quarks: up/down, charmed/strange, top/bottom
Force carrying bosons: photon, Z,W, gluons, Higgs

basically three generations of particles, 4 forces, and the Higgs field

The proton is a combination of 2 ups and a down quark, along with the gluon field that holds them together (where most of the mass is). Neutron is udd.

Physics is typically phrased in terms of scattering particles, where force carriers can be emitted and absorbed to change trajectories. These are represented schematically with Feynmann diagrams, which represent a scattering matrix calculation.

Example for electron-electron scattering: (feynman diagram with e scattering from e)

but also particles can change type with sufficient energy: example electron-positron annihilation, and pair creation.

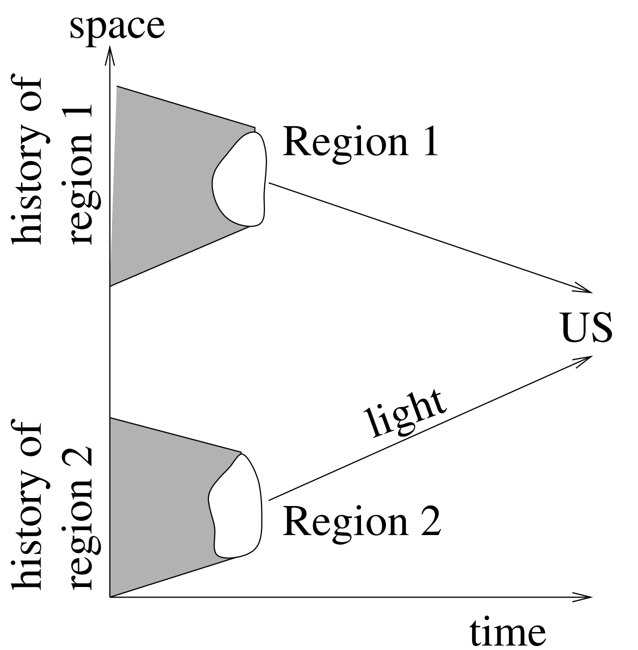
This can happen for ANY particle as long as there is enough energy available for $E = mc^2$.

Thus for high energies, energies above the rest masses of other particles, the forces appear less distinct due to the creation/destruction of intermediary particles.

41.3 The need for inflation – oddities of the Universe

There are several interesting aspects of the large-scale universe that are hard to explain. I will discuss the following two.

1. How can the CMB be so uniform? The horizon at the time the CMB was created, i.e. the the total distance that information could have propagated, is about 2 degrees on our sky. So the CMB temperature is almost uniform across portions of the universe that seem to have no way to be corellated.



2. Why is spacetime flat? Since Omega depends on time, it is somewhat surprising that the total Omega is so close to 1 even at this late time in the universe, when it has had plenty of time to evolve away from 1. Thus it must in fact be very close to 1. What mechanism would set this?

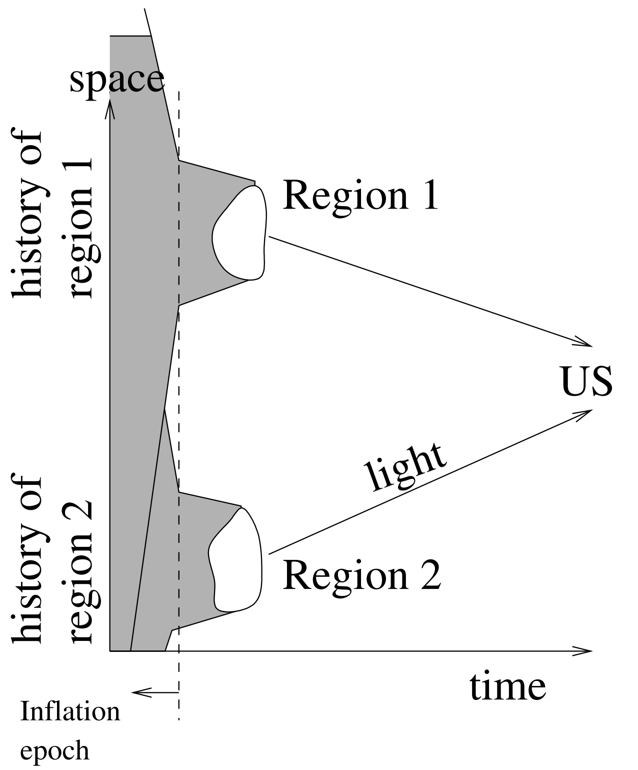
There are two others relating to monopoles and the power spectrum of structure that I won't discuss.

Note that these are observed properties of the universe. But we would like to know why or how they came about.

41.4 Inflation as an explanation

If, in the early universe there were a "false vacuum" that then decayed, there would have been a period of fast expansion (inflation). This false vacuum is analogous to the vacuum energy we now know as the cosmological constant - energy of empty space that is constant density as space expands. Just like the cosmological constant is now moving us toward exponential expansion, this early inflationary phase would have had $R \propto \exp^{(..)t}$. This explains the causal connection between places in the CMB.

This solves the causal structure problem because due to this early inflation, the causal structure of the universe is not what we extrapolated from the current expansion. There was an earlier time when the expansion vastly expanded the light cones, with the expansion of space carrying them beyond the light horizon.



Eventually this false vacuum must decay into our own vacuum (otherwise the exponential expansion would continue forever). Having a higher energy vacuum than we have today is actually quite natural from particle physics, as the natural vacuum you would estimate based on what we know of particles and the uncertainty principle is about 10^{120} times more energy per volume than the density equivalent of the cosmological constant. So what is more puzzling really is why our current vacuum is such low energy, as the natural vacuum energy seems like it should be much higher.

Since we don't know how physics works at the highest energies, it is possible to "make up" a variety of candidate physics for how this epoch of the universe has worked. There are many candidate models already developed.

Also this early epoch of expansion would have stretched the universe into flatness. So that it solves both problems. This is a very nice result of the inflation proposal.