Hi this is Steve Nerlich from Cheap Astronomy, www.cheapastro.com and this is *When the dust settled.*

This the second of two podcasts on the timeline of the Big Bang and subsequent events in the formation of the cosmos.

From one second to three minutes – the lepton epoch

The first podcast, *One Crowded Second*, left of at the end of the first second, at a point where the universe had expanded and cooled sufficiently to become a primordial soup of quarks, leptons and force-carrying bosons. Also the first hadrons, including protons and neutrons, and anti-hadrons formed, most of which then proceeded to annihilate each other leaving behind only a small residue – although it's this small residue that went on to build all the stars and galaxies and stuff we see today.

But let's not get ahead of ourselves. With so much hadron annihilation having taken place, the universe became dominated by leptons – it is the lepton epoch after all. Like the hadrons before them, leptons and anti leptons were initially in a state of thermal equilibrium with everything else in the universe. But at around three seconds, the energy density of the universe had decreased to the extent they began to freeze out– and the leptons and anti-leptons that were present began to annihilate each other, leaving only a small residue behind. With neutrinos having already fled the scene – back in part 1, the 1st second, these interactions are mainly between electrons and positrons – and at the end of it, only a residue of electrons remain.

It's kind of interesting to note that at all steps in the birth and evolution of the universe, it retains a nett electrical charge of zero. For example, although an apparent excess of negatively charged electrons are produced at this time, they balance the nett production of protons, which are positively charged – and which had remained at the end of the hadron epoch.

From three minutes to 380,000 years – the photon epoch

All those hadron anti-hadron annihilations and then the lepton anti-lepton annihilations meant that an awful lot of massive particles had disappeared to be replaced by energy in the form of photons – which were already present in abundance anyway. So from about three minutes on, the universe becomes dominated by photons – which continues to be the case for a very long time.

Nonetheless, it's the remaining residue of hadrons and leptons that do all the interesting stuff in this period. From 3 up to about 20 minutes, the first nuclei begin to form from the same proton-proton chain fusion that takes place in the Sun today. Closely packed protons, which are themselves technically hydrogen nuclei, begin to fuse into helium nuclei with further fusion reactions producing trace amounts of lithium and beryllium nuclei.

After 20 minutes, the universe is no longer hot or dense enough for this fusion to continue – although within this brief 17 minute period the universe's chemistry has changed dramatically so that about 25% of nuclei present were now helium, with the large remainder being hydrogen.

But that's it for about 310,000 years. Within this period the universe is in a similar state to the middle zones of the Sun – a hot plasma of ionized nuclei and free electrons. All the photons in the universe, including even more carrying the energy generated through the brief period of fusion that came earlier, are trapped in thermal equilibrium with the hot plasma of the universe, being constantly absorbed and re-emitted by the closely packed particles of the early universe.

But at 310,000 years all that begins to change. The universe is now cool enough that positively charged electrons and negatively charged ionized nuclei can come together to form the universe's first atoms. As more and more atoms are formed, the hot plasma of the early universe begins to change to a hot gas, of predominantly hydrogen and helium, and for the first time, the universe becomes transparent to light.

It's generally agreed that at about 380,000 years, there was a great burst of light with a temperature of just under 3,000 Kelvin which over the intervening 13.3 billion years or so has red shifted to a temp of only 2.7 Kelvin, and its wavelength stretched into the microwave spectrum and it still carries a snapshot of how everything looked when the universe was 380,000 years. It's like a, you know, cosmic, microwavey thing – but, sorry, I couldn't find any more background on this.

From 380,000 years to 500,000 years – the dark ages

Another pause and another appropriate break to go and make a cup of coffee. The photons of the early universe were moving freely now at the speed of light but there were no point sources of photon generation, like stars – so it's all a bit, well, dark.

From 500,000 to 1 billion years – reionisation and the cosmic renaissance.

Hey, remember that wimpy, weakest of the known four forces – gravity? It's back! The early hydrogen and helium atoms begin to collect together to become the very first stars and galaxies. Based on deep sky observations, it's thought this early stage of the universe is dominated by quasars, which are active galaxies radiating huge amounts of energy, presumably from accretion disks surrounding the supermassive black holes at their centre.

The formation of early quasars reheats and reionises (that is, strips the electrons off) hydrogen and other atoms returning the majority of the universe's matter to a state of plasma. The clustering of matter into stars, galaxies and loose clouds of hydrogen while the universe continues to expand, means that increasing volumes of the universe were now becoming fairly empty of matter and stars were now shining brightly rather than dimly through clouds of hydrogen fog. Hence, the cosmic renaissance idea.

1 billion years on – galaxies and everything

Stars in the renaissance period are called population 3 stars composed of hydrogen, helium and little else. But the next generation of stars (call population 2 stars) contain more complex atoms, like carbon, nitrogen and oxygen developed in fusion reactions of the population 3 stars. This meant population 2 stars can then undertake more complex fusion reactions. Population 3 and 2 stars were formed in a universe where matter was much more densely distributed than today.

So they were probably all big stars that burn through their fuel quickly and go supernova at the end of their lives. All this activity begins populating the universe with much more complex heavy atoms, for example iron and even uranium.

Anyway, that's about it. The Milky Way galaxy is thought to have begun forming at about 5.4 billion years (or about 8.3 billion years ago) and the Sun first lit up about 5 billion years ago – and look, here you are.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where inflation is just a theory. No ads, no profit, just good science. Bye.