Tim Tait – Lecture 1 Questions

Questions marked in green were answered during the Q&A session. I haven't tried to correct grammar/spelling. Where a slide number was given it is shown.

Q1 (slide 8). If there were a dark boson, would we call that dark "matter" as well?

If it were present in the Universe today, yes.

Q2 (slide 18). How do we know DM is uncharged under SU(3)c?

It would form charged hadrons with light quarks, if not.

Q3. Is there any "classical" approach to describe dark matter e.g. non quantum field

To talk about microscopic properties, one needs a QFT description.

Q4 (slide 20). Do DM theories tend to favor DM conservation under either discrete or global symmetries? Thanks!

Right now, we don't know.

Q5 (slide 19). How do we know that the dark matter doesn't decay, as opposed to being destroyed/created at the same rate?

We don't, actually know. One could imagine a theory where the dark matter comes along with a partner state, and in a galaxy it interacts with either other dark matter particles or Standard Model particles such that it flips between the original state and the partner state as it moves around. In that sense it would be created/destroyed at the same rate.

Q6 (slide 27). For Boltzmann equation considering decays, we have an equation which is -Gamma(n - n_eq), which resembles the radioactive decay law, just that there neq = 0. I want to understand that why in radioactive kind of decays, the equation with change in number density has neq = 0?

In radioactive decay, we usually consider the particle to be in vacuum, outside of a thermal bath of its decay products (so their densities are zero). It also considers a Universe that is not expanding at a comparable rate to the decay interaction. That sets these terms to zero in the equation.

Q7 (slide 28). Sometimes the freeze-out condition is stated as Gamma = H, and sometimes it is stated as Gamma = x_F H, where x_F is the freeze-out temperature. Can you please tell which relation is better?

One should really solve the Boltzmann equation to be precise. But H x_F is more accurate, yes.

Q8 (slides 27, 28). In the Boltzmann equation, the Hubble H is decreasing as the temperature drops, however, the decay width \Gamma is a constant which means once it becomes larger than H, it will always be larger than H. So, if a species has a decay term, does it mean it will eventually reach equilibrium no matter what, even if other processes have already gone below Hubble (e.g. frozen out)?

My plots where a little misleading, because the particle will fall out of equilibrium soon after the Temperature falls below the mass. I said this in the lecture, but sorry for the confusing plots!

Q9 (slide 28). Is the decay rate dependent on number density of the particles, which goes like ~T^{-3}? Will this make the decay rate larger than Hubble rate at earlier times and smaller in later times?

Decays are typically smaller than H at early times, but become more relevant at late times.

Q10. When is dark matter produced? What are the current upper bound and lower bound?

If we believe in inflation, dark matter had to be produced after it ended. How late it can be produced is somewhat uncertain, but there would be likely to be problems if it were not around by the time of Big Bang Nucleosynthesis (T ~ 10 MeV).

Q11 (slide 31). Can you review, why do we have to go to 0 annihilation at the mass threshold? (And why is it a step function?)

We don’t have to, but the n_eq falls exponentially for T << m. I just drew it as a cartoon like a step function, but it should be an exponential.

Q12 (slide 37). Does the assumption that DM is in equilibrium with SM particles at early times give us enough info to predict interaction strengths between DM and SM particles?

Yes, given a specific model and assumption about the cosmological history.

Q13 (slide 32). Plasma had dark matter particle along with standard particles and structure formed as we see now then how did dark matter particle end up in halos and not in the center of those structure?

Because the dark matter does not radiate (in typical theories), it does not collapse like ordinary matter.

Q14 (slide 30). What happens when dark matter has a different temperature than the SM bath? Is there a simple way still to proceed this calculation?

Yes, keeping track of both Temperatures.

Q15 (slide 28, 40). In the freeze-in scenario, is the assumption of negligible initial n justifiable if the annihilation rate is higher than H at large T?

No, it would not be justifiable.

Q16. What if DM only interacts with SM particles via gravity? Or this has already ruled out by experimental data

This is still a possibility, but then we would need to understand how it was created in the early Universe.

Q17 (slide 41). Is there a possibility that DM can still freeze-out while being relativistic and still fine with structure? For example, a fairly heavy DM whose mass is much greater than the keV scale. If true, then why most models consider freeze-out in non-relativistic phase?

It requires care, but yes it is possible.

Q18 (slide 40). How does the "freeze-in" mechanism reproduce the relic abundance? Would the number density of dark matter particles decay exponentially after it reaches equilibrium because of Maxwell-Boltzmann distribution?

No, once it freezes in, it stops tracking the equilibrium number density.

Q19 (slide 42). Can you please explain again why when m = H, then field starts oscillating ?

The field obeys an equation that contains Hubble friction, so it looks like a damped harmonic oscillator, with the mass as the frequency. So when H >> m, it is over-damped and cannot oscillate.

Q20 (slide 42). What does it mean for a field to be produced as an initial condition of the universe?

That it starts out with some initial value that is non-zero because of inflation or some other process.

Q21 (slide 42). In non-thermal production, would we see imprints of these oscillations on things like the CMB? With light particles like this, do we go looking for the frequency of oscillations in detection, or for individual particle interactions themselves?

You could, yes!

Q22 (slide 42). Could you explain how dark matter is produced again? Why should we compare mass with the Hubble rate?

The field takes an initial value that is just an initial condition of the Universe. That field eventually translates into a collection of particles.

Q23 (slide 28). Under the Freeze-in context, one could extend the annihilation line backward to intersect the Hubble expansion line, is this intersection possible in real scenario before the temperature drops below the mass?

Yes, so the question is where inflation leaves us, and so whether that extrapolation corresponds to the actual history of the Universe.