

## Questions and answers - Tim Tait Lecture 1

The following questions were submitted through Zoom Q&A. Some / all may have been answered in the Q&A session already. Nevertheless, we request our lecturers to provide written answers here for the benefit of those who could not attend that session. Thank you!

- (1) We only see the gravitational effects from DM, is that right? Since it is not in the framework of the SM, is it truly possible to understand DM without a GUT ?

*It's definitely true that all observations of DM are currently via gravity. A theory of everything could help relate the gravitational interactions to other interactions, but we can just proceed without such a theory, and treat them as independently. In fact, since we don't actually know for sure that gravity unifies with other forces, it is safer not to assume any relationship.*

- (2) You mentioned a Z2 symmetry. Can you explain what it is?

*It's a generalization of parity, where every field transforms either into itself or into -1 times itself. If the Lagrangian is invariant under this symmetry, the symmetry will be exact in nature.*

- (3) Could you please talk a bit more about the origin of the dark matter particle mass? Is it the same as SM particles through coupling with Higgs? What are other possible mechanisms that dark matter can acquire its mass from?

*In general, the dark matter mass need not come from the SM Higgs. In fact, there are some strong constraints on some theories where the DM mass comes from the SM Higgs mechanism, but also some theories which are still allowed. In all of my examples, the DM is allowed to have a mass without invoking the Higgs mechanism.*

- (4) Can you explain the difference between WIMP and WIMPZilla, in term of production mechanism?

*WIMPs are produced by freeze-out as we discussed. I didn't have time to discuss WIMPzillas, but they are an exciting possibility where the particles are very heavy and can be produced by quantum gravitational effects, during inflation.*

(5) Can you give a comment about the latest DESI results about dark energy density slowly decreasing with time and how that affects our understanding of dark matter?

*Most of my discussion was about times before dark energy has much impact on cosmology. Of course, the DESI results are exciting and could point to deviations from Lambda-CDM cosmology, which might also involve dark matter. But that's a very active area of research right now.*

(6) For Boltzmann equations it appears that  $n_{\text{eq}}$  is an external parameter, how is this determined in practice?

*It's just a function of the mass of the particle, its temperature, and number of degrees of freedom,  $g$ . See slide #22.*