Questions and answers - Jure Zupan 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) In Wolfemstein parametrization, why only V13 and V31 are complex? Are there any other consistent choices?

A: Historically other choices have been discussed as well. In fact the original parametrization of Kobayashi-Maskawa had the Vub and Vtd entries that were real. However, in that parametrization it is harder to see how large the CP violating effects are: one needs to calculate observables in order to see the actual effect, and there are cancelation between several seemingly larger contributions. See a more detailed discussion of this in the paper that introduced the standard CKM matrix parametrization: *Ling-Lie Chau, Wai-Yee Keung, "Comments on the Parametrization of the Kobayashi-Maskawa Matrix" Phys.Rev.Lett. 53 (1984) 1802.* Incidentally, note also that the now standard parametrization also has Vcd, Vcb, and Vts that have small imaginary parts (at the current experimental precision these can normally ignored). For the standard parametrization see, e.g., the 2025 PDG review "CKM Quark-Mixing Matrix"

(2) Is the Wolfenstein parameterization of CKM matrix truly unitary or only approximately so? If the latter, are there some processes or measurements where the impact is greater?

A: The Wolfenstein parametrization is unitary order by order. That is, one can expand the CKM matrix in terms of powers of lambda, and then ensure order by order that thus written CKM matrix is unitary. For the lambda^4 corrections, that we ignored in the talk, see for instance Eq. (8) in hep-ph/0605217. That is, both in the standard parametrization of the CKM matrix and in Wolfenstein parametrizations there are only four parameters. These are related order by order in lambda.

(3) Can't there be more dark matter than dark anti-matter? And if so, why would the matter excess over anti-matter be a problem?

A: Yes, this is certainly a possibility. This is the so called asymmetric dark matter. Such a possibility is especially interesting if the creation of dark matter is coupled with the creation of visible matter, that is, if dark matter is involved in the process of baryogenesis. What one gains is that in this case one does not need to violate baryon number. The baryon number only get redistributed between dark sector and our sector (though the other Sakharov conditions: out of equilibrium process, and C/CP violation are still needed). The most straightforward implementation would be out of equilibrium decays of a heavy state into dark matter and visible matter, where these decays are CP violating.