# QSS18 - Piet Schmidt - Questions & Answers

*Piet Schmidt*

Are there specific nuclei that are particularly useful to detect new physics or does mostly mass and charge state matter? If there are such nuclei, what are the features that make them useful in this regard?

**PIET**: It depends on the type of new physics one would like to investigate. For example, to search for possible fifth forces that couple neutrons to electrons using isotope shift spectroscopy, you want as many even isotopes without hyperfine structure (I=0) as possible. Calcium is a good candidate in this regard, since it has 5 stable even isotopes, is relatively light which reduces other effects that could mask the desired signal, and offers narrow optical transitions in a (possibly calculatable) few-electron system.

To what extent do you have to take care of the influence of the logic/readout ion on the "spectroscopy ion"? Does the ability to do this spectroscopy rely on the substantially reduced polarisability for the highly charged ion?

**PIET**: The electrostatic repulsion between the two ions couples their motion, but has no influence on their electronic states, since in equilibrium the ions are always located at the position of vanishing dc electric field. This is also the reason why the polarizability is not a relevant parameter for the interaction between the two ions. However, electric field gradients from the trap and the neighbouring ion couple to electric quadrupole moments of electronic states. Although suppressed in HCI, this is one of the shifts that needs to be taken into account when operating HCIs as clocks, but it can be suppressed using established techniques.

Does one have to choose a particular ion to interrogate another ion of interest? If so, how is that chosen?

**PIET**: Paul traps are operated with oscillating electric fields that exhibit stability regions depending on the charge/mass ratio of the trapped ion and the trap drive frequency. We have to make sure that the ion trap is simultaneously stable for both ions. This is usually achieved by choosing similar charge-to-mass ratios, which makes Be+ the preferred logic ion species for a wide range of HCIs.

What's the hope of bringing highly charged ion spectroscopy to the level of the Al+ clock? It seems that the electromagnetic field sensitivity requires building a Z-times better Al clock?

**PIET**: We believe this possible but may require a bit of technological engineering to provide the right environment for the HCI clock. In more detail: The atomic properties of some of the HCI optical clock candidates are similar to the currently best optical ion clocks based on Yb+ and Al+. The black-body radiation shift (a limiting shift for the Yb+ clock) is negligible for HCI clocks, owing to a combination of their extremely low polarizability and the fact that the ion traps are operated at cryogenic temperatures. Changes in quasi-static electric fields will push the ions away from the zero line of the oscillating electric field that traps the ions. This results in 2nd order Doppler or time dilation shifts. Therefore, we use calibration routines to null this shift on regular time intervals by restoring the HCI to the nodal line. HCI are Z-times more sensitive to changes in dc electric fields and therefore may require more frequent compensation. This is currently under investigation in our laboratory. The other shift one might worry about is the time dilation shift from residual thermal motion due to e.g. inefficient sympathetic cooling. Preliminary measurements indicate that in the presence of small heating rates of the HCI in the trap, sympathetic cooling works well enough to provide small uncertainties also for this shift.

**Yani Zuo**: Thank you for your nice talk! Can I ask you what is the limitation of highly charged ion clock? And why choose Be+?

**PIET**: The limitations are similar to those of singly charged ion clocks. However, we will need better dc electric field stability and low motional heating rates (see above). We chose 9Be+ since the charge-to-mass ratio matches 40Ar13+ and other HCI very well (see also above).

How about a highly charged molecular ion? Could one enhance (for example) the sensitivity of regular molecular ion experiments to EDM even more? Do you think that this would be a promising route to explore?

**PIET**: I am not aware of any study along those lines, but it could be an interesting though. A potential issue that I can see is that in a highly charged molecule, we would essentially remove the electrons that bind the nuclei of the constituent atoms together. Therefore, highly charged molecules might not be stable.

Looking at the big picture of fundamental physics questions. There's clearly a lot of work in cosmology and high energy physics on how to measure fundamental aspects, as well as the really nice techniques you've outlined with precision measurement in atomic physics. To what extent are these complementary in the sense that they're measuring the same things by different means, and to what extent are you really answering different questions?

**PIET**: This is a very good question with no universal answer. The high-energy community is starting to get interested into what the low-energy, high-precision frontier has to offer. The isotope shift analysis I mentioned was borne from a collaboration between research from both communities. The postulated relaxion particle is another example that is expected to solve the hierarchy problem of the standard model of particle physics, while at the same time being a possible dark matter candidate. Recently proposals have been put forward to search for this particle using atomic physics probes. Since I am an expert in neither cosmology nor high energy physics, I see the approaches as largely complementary in the search space for new physics effects, with some overlap at the fringes.

It seems in some senses like the scaling for highly charged ions is very similar to Rydberg atoms where Z replaces the principal quantum number. Do you see opportunities to use Rydberg systems to do any of these things - or does the suppression of polarisability in the case of highly charged ions make this fundamentally different?

**PIET**: I'm not sure I understand the analogy completely, since the scaling for binding energies, fine-structure and QED effects seem to go in the opposite direction for Rydberg atoms compared to HCI. The high sensitivity to the new physics I mentioned arises from the strong relativistic and QED contributions and the large overlap of the electronic wavefunction with the nucleus. To my knowledge, these features are not pronounced in Rydberg atoms, making them less favourable for the new physics effects I mentioned. However, there may be other effects to which Rydberg atoms are more sensitive than HCI.