Contribution ID: **10** Type: **not specified**

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Thursday 4 April 2024 16:50 (2 hours)

We present a theoretical investigation of the expected experimental signals produced by freely falling atoms with time oscillating mass and transition frequency. These oscillations could be produced in a variety of models, in particular, models of scalar dark matter (DM) non universally coupled to the standard matter (SM) such as axion-like particles (ALP) and dilatons. Performing complete and rigorous calculations, we show that, on one hand, two different atomic species would accelerate at a different rate, and on the other hand, they would produce a non-zero differential phase shift in atom interferometers (AI). The former would produce observable signals in equivalence principle tests like the recent MICROSCOPE mission, and we provide a corresponding sensitivity estimate, showing that MICROSCOPE can reach beyond the best existing searches in the ALP case. We also compare the expected sensitivity of two future AI experiments, namely the AION-10 gradiometer and an isotope differential AI considered for MAGIS-100, that we will refer to as SPID. We show that the SPID setup would be more sensitive to these dark matter fields compared to the gradiometer one, assuming equivalent experimental parameters.

Session Classification: Poster Session & Wine & Coffee