Dark Matter Search Using a Subluminal Laser

S M Shahriar[1], R Zhu[2], and Z Zhou[3]

[1]*ECE and Physics, Northwestern University, 2145 Sheridan Road, Evanston IL, USA. Contact Phone: +18474915306*
[2]*ECE, Northwestern University, 2145 Sheridan Road, Evanston IL, USA. Contact Phone: +18474915306*
[3]*Northwestern University, Evanston IL, USA*
Contact Email: shahriar@northwestern.edu

In this talk, we will describe the feasibility of detecting dark matter DM) composed of virialized ultralight fields (VULF's) using a subluminal laser (SLL). Such fields are predicted to lead to oscillating fundamental constants, namely the fine structure constant and the electron mass, resulting in oscillations of the lengths of rigid bodies. In an SLL, demonstrated recently by us, the change in the frequency of the laser due to a change in the length of the cavity is suppressed strongly. To search for DM, we employ an SLL in a ring cavity, with its mirrors mounted on rigid but hollow fused silica spacer tubes, containing a rubidium vapor cell inside, along with two polarizing beam splitters (PBS's). An external laser is brought into the cavity through a hole on the side of the spacer tubes and reflected along the direction of the cavity mode with one of the PBS's. This acts as the Raman pump needed for realizing the SLL, using the self-pumped Raman gain mechanism. The second PBS expels the pump laser from the cavity through another side hole. We make use of Rb-85 atoms, which have a ground state hyperfine splitting of 3.034 GHz. As such, the frequency of the SLL is shifted from that of the pump laser by approximately this frequency, with the actual value determined by the effective resonance frequency of the cavity mode, taking into account the dispersion. The dispersion in an SLL is very steep, with a group index as high as ten million, and the sensitivity of the frequency of the SLL to a change in the cavity length is suppressed by a factor equaling the group index. The output of the SLL is shifted in frequency by an acousto-optic modulator, driven by a voltage-controlled oscillator (VCO), and sent back into the laser cavity. The frequency of the VCO is chosen to ensure that this beam resonates in a higher-order mode (HOM) of the cavity. A feedback signal is applied to the VCO to ensure that this beam remains locked to the peak of the resonance. In the presence of the VULF DM, the length of the laser cavity will undergo oscillations, thereby producing a corresponding oscillation in the frequency of the HOM. In contrast, the frequency of the SLL will undergo a much smaller change in frequency. Thus, in order to keep the frequency shifted beam resonant to the HOM, the feedback applied to the VCO will cause its frequency to oscillate at a frequency matching the Compton frequency of the VULF DM. The variation in the frequency of the pump laser will only affect the intensity, but not the frequency, of the SLL. Furthermore, changes in the fine structure constant and the electron mass will have a negligible effect on the ground state hyperfine splitting and, therefore, the gain profile of the SLL. The beat signal generated by mixing the VCO output with the output of a stable reference oscillator will be sent through a low pass filter followed by a frequency to voltage converter (FVC). The voltage produced by the FVC will be monitored to observe the presence of VULF DM, in the range of 0.1 to 10 kHz. We will describe the advantages of this approach to other techniques being explored for VULF DM search, and address the experimental challenges.

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