White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	

Indicate the primary area this white paper addresses by placing "P" in right column.
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• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	P
• Interactions of plasmas and waves	S
• Plasma self-organization	P
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	
Poster	
Either Oral or Poster	

Title:	Laboratory models of post-Newtonian gravity using high power lasers
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(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format.*)

- ***Describe the research frontier* and importance of the scientific challenge.**

A common misperception of theories that attempt to describe quantum mechanics in curved space-time is that they require accessing energies up to the Planck scale of 10^{19} GeV, which is unattainable from any conceivable particle collider. However, quantum electro-dynamics, as a highly successful quantum field theory, has demonstrated how renormalization involving high energy states can influence low energy physical observables. This is testified, for example, by the observable nature of the Casimir effect, which results from a renormalization of quantum vacuum through boundary conditions set by conducting plates at low energy. Similarly, the experiment of Colella, Overhauser and Werner [1,2] showed a phase shift in the neutron's wave function caused by the lowest order gravity correction in the quantum mechanical Hamiltionian. Later on, the same result was obtained for neutrons in accelerated frames [3], confirming the validity of the weak equivalence principle [4-6] for quantum systems.
To obtain a consistent description of experimental findings, it was shown that the Hamiltonian must consist of two parts, the usual kinetic term and a gravitational term. This forms the basis of a sub-class of equations known as Newton-Schrödinger Hamiltonians [7,8]. While the Newton- Schrödinger formalism has an important role in macroscopic quantum gravity theories as it provides laboratory testable predictions, it should be also pointed out that the Newton- Schrödinger equations are not the semiclassical limit of the Einstein equations [9] and thus do not give a self-consistent description of gravity at scales where curvature, radiation (i.e., gravitational waves) and particle production are important.

Thanks to the development of chirped pulse amplification of optical laser light [10], state-of-art laser systems can now achieve focused intensities $>10^{22}$ W/cm^2, thus being able to accelerate the electron to unprecedented $>10^{27}$ cm/s^2. And, for this reason, high power lasers have been advocated as an ideal tool to study gravity models beyond the Newton-Schrödinger approximation [11-13]. While several experimental proposals have been put forward, at present it remains unclear whether or not such effects are measurable in the laboratory frame [14].

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

As discussed by Crowley et al. [15], a verification of these processes is possible in laboratory experiments (see Fig. 1). These experiments require a high intensity drive laser and a low intensity, higher frequency Thomson scattering probe. By virtue of the equivalence principle, in the laboratory frame, the modified metric tensor of uniformly accelerated electrons would manifest itself as a broadening of the Thomson scattered light. Ideally, these experiments will require a combination of high power laser facilities and 4th generation light sources. Due to the strong low-frequency optical laser field, the motion of the electrons is treated classically, meanwhile, due to its relatively weak perturbative high-frequency field, the effects of the 4th generation free electron laser (FEL) probe on the electrons are treated quantum-mechanically. Assuming that the scattering takes place on a sufficiently short timescale and is confined to a region of the FEL spot in which the acceleration field is relatively homogeneous, Crowley et al. [15] have shown that the resultant scattering spectrum differs from the usual structure factor in Minkowski space-time by the additional imaginary dependence on the wavenumber. The appearance of this imaginary component is associated with the fact that the external gravitational force, i.e., the induced acceleration, imposes a collective motion that is added to the background motion of the particles.

These results are consistent with the concept of mass shift [16,17], that is, an uncertainty in the outgoing photon energy due to the acceleration. This means that the electrons experience an energy change resonant with the bath of optical photons which surrounds them. Because of this change of energy, the work done by the optical laser photons in accelerating the electrons is slightly different from the one done in decelerating them. This difference in energy is thus attributed to a difference in the rest mass of the electron.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

It is expected this will be one of the major breakthroughs of contemporary physics. The connection between gravity and quantum mechanics remains one the unsolved challenges of contemporary physics. Experiments aimed at providing experimental data in this direction are thus strongly welcome.

References (Maximum 1 page)

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Figures (maximum 1 page)

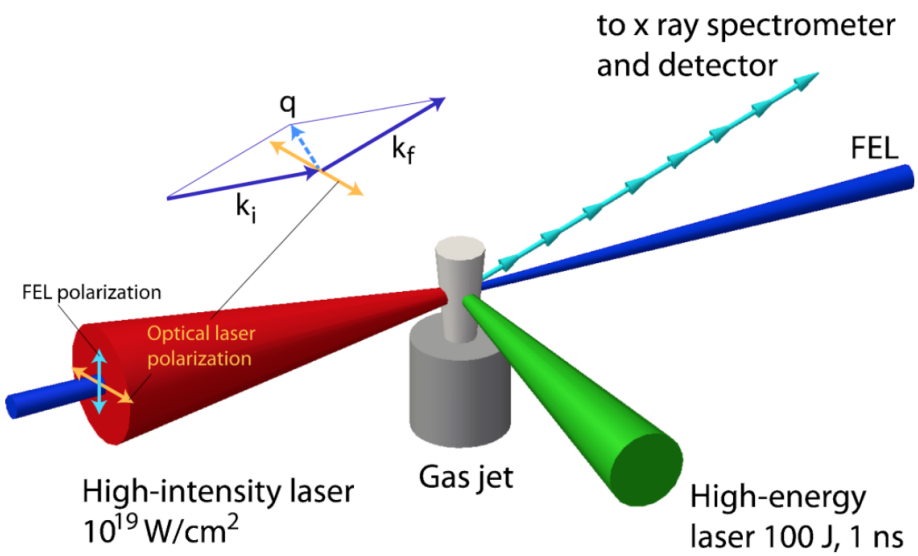

Figure 1. Proposed experimental setup from Ref. [15]. A high-energy laser excites a pulsed gas jet creating a plasma with electron density, ~10^{19} cm^{-3}. A high-intensity chirped pulse amplification optical laser beam then accelerates the electrons while the FEL beam probes them with synchronized pulses in a collinear geometry. In the figure k_i is the incident wavenumber of the x-ray FEL probe and k_f the scattered wavenumber.