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Laser cosmology- a brief overview and a few examples

Pisin Chen

[1] Leung Center for Cosmology and Particle Astrophysics, National Taiwan University

[2] Department of Physics and Graduate Institute of Astrophysics, National Taiwan University

e-mail: pisinchen@phys.ntu.edu.tw

Overview Recent years have seen tremendous progress in our understanding of the cosmos, which in turn points to even deeper questions to be further addressed. Concurrently the laser technology has undergone dramatic revolutions, providing exciting opportunity for science applications. History has shown that the symbiosis between direct observations and laboratory investigation is instrumental in the progress of astrophysics. We believe that this remains true in cosmology [1,2,3]. Current frontier phenomena related to particle astrophysics and cosmology typically involve one or more of the following conditions: 1. extremely high energy events; 2. very high density, high temperature processes; 3. super strong field environments. Laboratory experiments using high intensity lasers can provide the following utilities:

A. Calibrate astrophysical observations,

B. Investigate underlying astrophysical dynamics,

C. Probe fundamental physics in extreme limits.

Figure 1 is a Venn diagram that shows the inter-relationship among three major fields of physics: particle physics, astrophysics, and plasma physics. The overlapping region between astrophysics and particle physics corresponds to the frontier field of particle astrophysics and cosmology, while that between astrophysics and plasma physics corresponds to plasma astrophysics. A smaller circle that encompasses all three fields is the domain for laboratory astrophysics. State of the art intense lasers serve as a very powerful tool for laboratory astrophysical investigations.

Example 1: Plasma wakefield acceleration of ultra-high energy cosmic rays Plasma wakefield acceleration mechanisms driven by lasers [4] or by high-energy particle beams [5] have been confirmed and actively pursued in the past several decades. In 2002, Chen, Tajima and Takahashi [6] applied it as the underlying mechanism for cosmic accelerators. It was suggested that plasma medium waves such as Alfven waves or shocks in an astrophysical relativistic outflow can also induce wakefileds to accelerate particles [6]. The stochastic encounter of acceleration-deceleration phases would result in a power-law energy spectrum that scales as E^{-2}, just like the Fermi mechanism. Confirmation of this media-wave driven plasma wakefield generation and acceleration was demonstrated by Chang et al. [7] and Hoshino et al. [8]. It was validated by laser-based experiment [9].

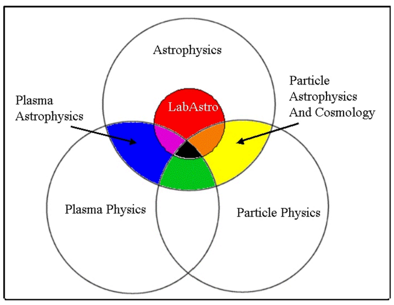

Fig.1: Venn diagram for lab astrophysics and laser cosmology

Example 2: Unruh radiation As demonstrated by Unruh [10], a uniformly accelerated observer would see the surrounding vacuum develops a heat bath with a blackbody temperature of

$$k_B T_U = \frac{\hbar a}{2\pi c},$$

where a is the observer's proper acceleration. A conceptual design of an experiment to detect Unruh radiation [11] is shown in Fig. 2, where two linearly polarized lasers counter-propagate inside a resonant cavity. Test electrons are placed at the nodal points where B=0.

Example 3: Analog black holes Another exciting example of laser cosmology is to accelerate laser-induced flying plasma mirrors as analog black holes in the laboratory to investigate the celebrated Hawking radiation and the associated black hole information loss paradox [12] (Fig.3). The international AnaBHEL (Analog Black Hole Evaporation via Lasers) Collaboration is currently pursuing such an experiment [13].

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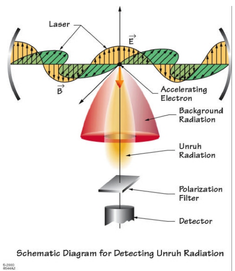

Fig.2: Concept of detecting Unruh radiation

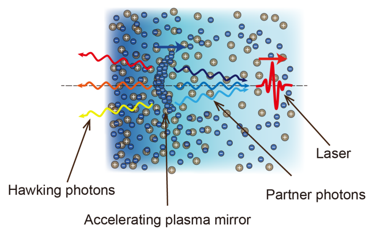

Fig.3: Laser-induced accelerating mirror for Hawking radiation