1st Asia-Pacific Conference on Plasma Physics, 18-22, 09.2017, Chengdu, China

Ball Lightning: History, Theory and Perspective

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Ball lightning (BL), one of the most mysterious natural phenomena, is defined as a fireball observed in thunderstorms. The earliest BL record appeared in the books of Aristotle (384BC-322BC) and Kuo Shen (1031-1095). In the past 300 years, BL had attracted great interests from scientists, including Musschenbrock, Arago, Faraday, Lodge, Tesla, Bohr, Kapitza, Weisskopf, and Ginzburg etc. In this talk, we would first introduce the definition, characteristics, and research history of BL.

There are tens of models, but none of them are convincing enough to explain leading characteristics of BL. There is still no consensus on such fundamental questions: What is the nature of BL? How does it form? We will present a comprehensive BL theory [1]: At the tip of a lightning reaching the ground, a relativistic electron bunch can be produced, which in turn excites intense microwave radiation. The latter ionizes the local air and the radiation pressure evacuates the resulting plasma, forming a spherical plasma bubble that stably traps the radiation. This formation mechanism is verified by particle-in-cell simulations. The model can explain most properties of BL, such as the occurrence site, relation to the lightning channels, appearance in aircraft, its shape, size, sound, spark, spectrum, motion, as well as the resulting injuries and damages. It should be stressed that an explanation of fireball appearance in aircraft or far away from lightning channels is required by the BL community for a successful theory. Our theory is unique to explain such peculiarities of BL.

Our BL theory infers that someone might have detected microwave or radio waves of the same origin as BL. Indeed, we find these radio signals, i.e. so-called trans-ionospheric pulse pairs (TIPPs), which are the most powerful natural radio source on Earth. They were first discovered by a USA satellite in 1993. We point out that the popular TIPP model fails to explain some critical features of TIPPs. Using the same mechanism of exciting BL, we quantitatively explain almost all the features of TIPPs [2]. The work verifies that electrons from lighting can reach the ground and emit strong electromagnetic radiation, which is a fundamental assumption in the BL theory. The existence of TIPPs and their successful explanation give a strong physical evidence to support the new BL theory.

High-energy phenomena (γ-ray, relativistic electrons, positrons, neutrons) was just discovered from lightning or spark discharges in the past 15 years. These surprising findings are still enigmatic and will strongly reshape the understanding of discharge physics. Radio or microwave emission from energetic electrons can be used to retrieve the 3D structure of electron bunches produced within air discharges.

We will also discuss possible experimental approaches to trigger or stimulate the BL generation. Our theory implies that the peak power of BL is about 10 times greater than any manmade microwave devices. The work may drive developing relativistic microwave sources and study relativistic microwave matter interaction.

Our works [1,2] have gained strong interests and supports from the community of lightning and ball lightning [3,4,5]. These will be of great significance to lightning protection, storm monitor, aviation safety, high-voltage discharge, high-power microwave, intense electron sources, as well as z-pinch physics.

References

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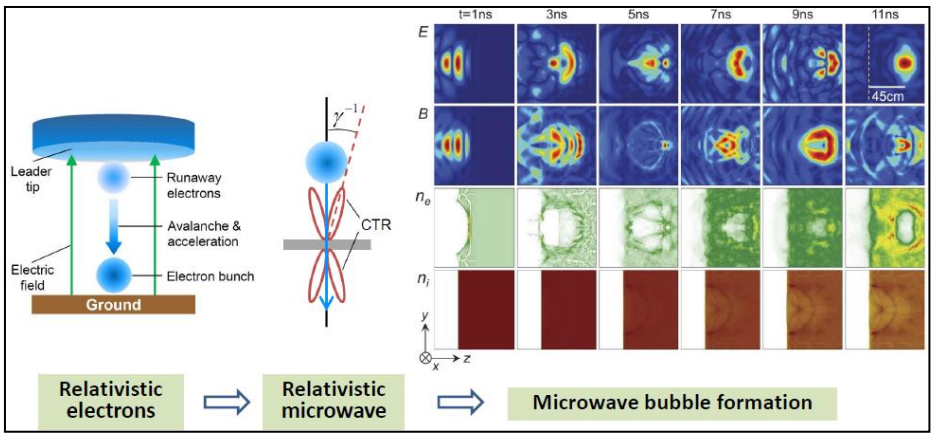

BL formation: Lightning first produces an intense electron beam, and then strong microwave is emitted when the electrons strike the ground. Microwave bubble is formed in air plasmas by relativistic radiation effects.