Critical Parameters for Big-Bang Thermal Explosion

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1 Introduction

Theoretical proposals of possible physics before a Big Bang [1] (or after a Big Crunch [2] considering the cyclic universe proposal) have been raised by many researchers (cf. [1–10] for the recent progresses). The most interesting ones are relevant to a high significance detection of concentric circles in the Cosmic Microwave Background (CMB) maps with anomalously low variance [4–6]. It is argued that such concentric circles could be signatures of a pre-big-bang phase of our universe (originally introduced within the context of conformal cyclic cosmology [4]). In fact our present (limited) knowledge of the laws of nature is not too well adapted to the description of the Universe near a Big Bang (or near a Big Crunch considering the cyclic universe model).

Up to now it is known that the cosmic background radiation is the thermal radiation with a temperature of 2.75 K still present throughout the universe, a relic of its hot, big bang, initial phase [11]. In fact, Dicke and his colleagues explained this specific temperature excess radio noise as the thermal radiation remaining from the hot big bang origin of the universe some $1–2 \times 10^{10}$ years ago. In this hot big bang model, first outlined in a prescient series of papers by Gamow [12] and his colleagues (please see [13, 14]), the universe begins in a state of high temperature and density, and subsequently expands and cools. However, if the
radiation is left over from a hot, dense phase of the early history of the universe, the spectrum should be black body. The black-body or Planck spectrum is produced during the early phase of thermal equilibrium, and that spectrum is maintained in the subsequent expansion of the universe \([15, 16]\). Another fundamental problem of the standard cosmology is that the observed abundance of baryonic matter is \(\sim 10^9\) times greater than the relic abundance expected from a state of thermal equilibrium, while no antimatter is observed (see \([17]\)), thus requiring a primordial asymmetry between matter and antimatter.

Researchers already understand that the standard cosmological model of an adiabatically expanding, homogeneous and isotropic universe requires extreme fine tuning of the initial conditions of the big bang which might have a very-hot spot or thermal instability at certain space as well as time. Note that it has become increasingly clear that particle physicists can no longer afford to ignore the cosmological ’laboratory’, which offers a powerful probe of new physical phenomena far beyond the reach of terrestrial laboratories. In 1948 Gamow has concluded that the temperature during the big bang must have the order \(\sim 10^9\) K (corresponds to the dissociation energy of deuterium nuclei) or higher \([12]\).

In this presentation we like to examine the very-hot spot formation resembling the big-bang thermal instability based on the more advanced approximation of an ideal gas (see \([18]\)) which is usually a good one. In general a proper study of radiation heating involves, e.g., solving Maxwell’s equations of electromagnetism and the forced heat equation where all thermal, electrical, and magnetic properties of the matter are nonlinearly dependent on the temperature \(T\). In the full mathematical problem, Maxwell’s equations and the forced heat equation are coupled and grossly nonlinear and this depth of complexity is revealed in applications through the appearance of unusual and often unexpected physical behavior such as ’hot spots’ and ’waiting time’ phenomena.

Hot spots occur in matter irradiated by radiations due to the temperature-dependent matter properties. The rate of absorption of radiation energy referred to as the thermal absorptivity usually increases with temperature, hence thermal runaway can result. The location of a hot spot in matter arises from differential heating and can be due to a small temperature anomaly, an impurity of higher thermal absorptivity, or simply to a geometrical feature such as a corner or edge. In addition certain matter is transparent to radiation and yet after heating by conventional means they respond to radiation energy. Similarly, waiting-time behavior is exhibited by matter that respond to radiation heating only after a finite amount of time has elapsed.

Thermal instability such as the catastrophic phenomenon of thermal runaway in which a slight change of external heating (e.g., radiation) power causes the temperature to increase rapidly to the melting point of the matter have been studied for simple geometry cases \([19]\). Up to now, the basic understanding of the (radiation) heating process still remains somewhat empirical and speculative due to its highly nonlinear character. The mathematical description of this process is accordingly fraught with nonlinearities (not to mention the external heating): The heat equation is highly temperature dependent at the temperatures required for sintering. Moreover, the thermal boundary conditions must take into account both convective and radiation heat loss. The result is a highly nonlinear initial-boundary value problem. Even for simple geometry problems, because of the highly nonlinearity characteristic, numerical approaches were often adopted to solve the corresponding equations and boundary conditions \([20]\). Relevant approaches have also a wide field of applications in combustion theory or for safety of storage of materials capable of exothermic chemical reaction \([20]\).

In this paper, we shall consider the above mentioned problems within a simple geometry (say, an annulus). However, real interfaces are rough \([21]\). We presume the roughness to be wavy-like in transverse direction along the outer and inner surfaces of the annulus which...