

# I

## A new phase of matter?

### 1 Micro-bang and big-bang

#### 1.1 Energy and time scales

When atomic nuclei, generally called heavy-ions, collide at very high energies, such that the kinetic energy exceeds significantly the rest energy, dense hadronic\* matter is produced. We refer to these reactions as (ultra)relativistic heavy-ion, or nuclear, collisions. The energy density of hadronic matter with which we are concerned has a benchmark value of

$$\epsilon = 1 \text{ GeV fm}^{-3} = 1.8 \times 10^{15} \text{ g cm}^{-3}. \quad (1.1)$$

The corresponding relativistic matter pressure is

$$P \simeq \frac{1}{3}\epsilon = 0.52 \times 10^{30} \text{ bar}. \quad (1.2)$$

Dense matter with these properties must have existed in the early Universe about 10  $\mu\text{s}$  after the big-bang. It might have been recreated extremely rarely in interactions of very-high-energy cosmic-ray particles. Some astrophysical objects may reach these extreme conditions. It had been speculated that a catastrophic change in the Universe could ensue when these conditions are recreated in laboratory experiments, but these fears have been refuted [85].

Experimental study of the physics of the early Universe requires in principle a large, practically infinite, volume of matter. For this reason, it is necessary to study high-energy collisions of the heaviest nuclei, rather than the more elementary and simpler-to-handle interactions of protons or leptons. However, we cannot study in the laboratory physical systems

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\* In Greek, *barys* means strong and heavy; *leptos* is weak, light; *mesos* is intermediate, and *hadros* is strong. Hadronic (strong) interactions involve baryons and mesons (heavy and semi-heavy particles) but not leptons, the light and relatively weakly interacting electrons, muons, the heavy tau, and nearly massless neutrinos.