IRSTI 27.35.55

A.T. Temiraliev , Z. Mazhit
Al-Farabi Kazakh National University, Almaty, Kazakhstan
z.mazhit@satbayev.university

AN INVESTIGATION OF NUCLEAR MATTER IN EXTREME CONDITIONS

Abstract: In the paper a dynamics of the quark-gluon plasma has been defined by the evolution parameter, which at high energies depends on collision energy of atomic nuclei for appropriate multiplicities of secondary hadrons. A purpose of present work is to investigate processes occurred in the QGP at external conditions change (i.e. the evolution parameter, that is energy, exposed in the system) on the basis of nonlinear dynamics one-dimensional equation solution in phase momentum space. The nonlinear evolution equation for partons momentum distribution has been solved by the method of Poincaré mappings. The state of hadronic matter under critical conditions (that is the QGP) is defined by macroparameters such as density >10 ρ_0, ρ_0~1,6 10^{14} g/cm^3, temperature T~200 MeV and chemical potential. As a first approximation, the dynamics of the system has been determined by means of the evolution parameter. For specified region of the evolution parameter values 0.75÷0.89 intermediate phase mixture, i.e. a compound, which consists of quarks, gluons and hadrons, probably exist.

Key words: quark-gluon plasma, nonlinear dynamics, phase transition

A.T. Temiraliev, Z. Mazhit
Al-Farabi Kazakh National University, Almaty, Kazakhstan

ЭКСТРЕМАЛ ЖАҒДАЙЫНДАҒЫ ЯДРОЛЫҚ ЗАТТЫ ЗЕРТТЕУ

Аңдатпа: Мақалада кварк-глюондық плазманың динамикасы эволюция параметрі арқылы анықталады. Бұл жұмыстың мақсаты – фазалық импульс кеңістігінде сызықты емес динамиканың бір өлшемді теңдеуінің шешімі негізінде сыртқы жағдайлардың өзгеруі кезінде (яғни эволюция параметрі, яғни жүйеде әсер ететін энергия) QGP-де болатын процестерді зерттеу.

Жоғары энергиялар үшін эволюция параметрі сәйкес екінші реттік адрондардың көптік мәні үшін атомдық ядролар соқтығысу энергиясына тәуелді болады. Қозғалыс мөлшері бойынша партондар үлестіруі үшін Пуанкаре қима әдісі арқылы сызықты емес эволюция теңдеуінің шешімі табылды. Адрондық заттардың критикалық жағдайдағы күйі (яғни QGP) тығыздық >10 ρ0, ρ0~1,6 1014 г/см3, температура T~200 МэВ және химиялық потенциал сияқты макропараметрлермен анықталады. Бірінші жуықтау ретінде жүйенің динамикасы эволюция параметрі арқылы анықталды.

Эволюция параметрінің 0,75 ÷ 0,89 мәндері үшін аралық қоспа, яғни кварктар, глюондар мен адрондардан тұратын құрылымдардың, пайда болуы әбден мүмкін.

Кілт сөздер: кварк-глюондық плазма, сызықты емес динамика, фазалық ауысу

A.T. Temiraliev, Z. Mazhit
Al-Farabi Kazakh National University, Almaty, Kazakhstan

ИССЛЕДОВАНИЕ ЯДЕРНОЙ МАТЕРИИ В ЭКСТРЕМАЛЬНЫХ УСЛОВИЯХ

Аннотация: В работе динамика кварк-глюонной плазмы определяется параметром эволюции, который при высоких энергиях зависит от энергии столкновения атомных ядер для соответствующих множественностей вторичных адронов. Целью настоящей работы является исследование процессов, происходящих в КГП при изменении внешних условий (т.е. параметра эволюции, то есть энергии, выставленной в системе) на основе решения одномерного уравнения нелинейной динамики в фазово-импульсном пространстве.

Нелинейное эволюционное уравнение для распределения партонов по импульсам решено методом отображений Пуанкаре. Состояние адронной материи в критических условиях (то есть КГП) определяется такими макропараметрами, как плотность >10 ρ0, ρ0~1,6·1014 г/см3, температура T~200 МэВ и химический потенциал. В первом приближении динамика системы определялась с помощью параметра эволюции.

Для области значений параметра эволюции 0,75 ÷ 0,89 возможно существование промежуточной смеси фаз, т.е. соединений, состоящих из кварков, глюонов и адронов.

Ключевые слова: кварк-глюонная плазма, нелинейная динамика, фазовый переход

Introduction

There is formed superdense matter with a density tens and hundreds of times higher than cold nuclear matter density, in heavy relativistic nuclei colliders, for example in experiments at LHC (Large Hadron Collider), RHIC (Relativistic Heavy Ion Collider) in Brookhaven National Laboratory, etc. This matter is regarded as the quark-gluon plasma (QGP) [1]. It is supposed, that QGP is a substance state at superhigh energies/temperatures and densities. QGP is generated in the heavy ions collisions at their energy ~3.5 TeV [2].

A first order phase transition involves a discontinuous jump in some statistical variable [3]. It is known, that the discontinuous properties include a variety of physical values. At the first-order phase transition a new phase appears gradually in the form of nuclei, for example, clusters. An abrupt change in the properties of a substance occurs at critical point, the critical point can be critical temperature. It should be mentioned, that primarily the critical point existence is a characteristic of the second-order phase transition [3].

Numerical estimates reveal transition to the quark-gluon plasma state taking place as the first-order phase transition at a temperature corresponding to the kinetic energy of hadrons ~200 МэВ [1] and densities $\rho \sim 5-10\rho_0$, here ρ_0 is the nuclear matter density [2].

Macroparameters of hadronic matter are as follows: the density, temperature (energy) and chemical potential [2]. QGP is non-abelian system of point particles. Their interaction is the subject of quantum chromodynamics (QCD) [4].

One assumes the phase transition, associated with the formation of QGP, takes place with density, energy and other quantities fluctuations. A nonperturbative process, accompanied by large amplitude fluctuations, has been possible until the critical temperature is reached. It promotes phase mixing [5, 6].

Forward and reverse phase transitions in the system have been related to the confinement (confinement of quarks and gluons inside a hadron) and the asymptotic freedom. An average distance of the color interaction is about 1fm. The color deconfinement is possible at distances less than 1fm.

At phase transition of the system spontaneous symmetry breaking is induced, i.e. chiral condensate symmetry breaks down [7]. As the order parameter authors suppose a value, reverse to R_0, R_0 is the color screening length: $R_0 \simeq 1\,fm$.

In [8], the formation of parton (quark) structures in QGP has been studied by solving the one-dimensional equation of nonlinear dynamics for the Bjorken variable by A. Poincaré section method. In phase space the solutions are stable attractor structures. One has treated the phase transition of QGP to hadrons as fractal structures formation. Similarly, one suggests this way for considering the phase transition of hadrons to the QGP, that is as fractals decay. The approach mentioned should need evidences, which could indeed point out on fractals emerging.

In [9], on the basis of nonlinear equation solution with taking into account the distribution of partons over momenta one has presented that chaotic dynamics takes place in the system for the values of the evolution parameter, $\lambda \geq 0.89$. The chaotic state matches the quark-gluon plasma formation.

A purpose of present work is to investigate processes occurred in the QGP at external conditions change (i.e. the evolution parameter, that is energy, exposed in the system) on the basis of nonlinear dynamics one-dimensional equation solution in phase momentum space by the Poincaré section method.

QGP nonlinear dynamics

A nucleon consists of various types point QCD partons as well as quarks and gluons. The partons can carry the initial nucleon’s different fractions x of the momentum and energy. QGP nonlinear dynamics equation in vacuum can be represented as [7]:

$$\left|x_{j+1}\right\rangle = \lambda F_2(x_j)\left|x_j\right\rangle \quad (1)$$

Here x_j is the Bjorken variable (i.e. parton momentum fraction), j corresponds to an iteration number, λ is the evolution parameter (control parameter), $F_2(x_j)$ are parton momentum distributions, which were derived from deep inelastic reactions [3, 10].

The evolution parameter λ depends on temperature, at temperature growth λ increases. Its dependence on energy can be expressed as [11]: $\lambda \cong \lambda_c - \frac{a \cdot m_\pi}{\sqrt{s}}$, where λ_C is a critical value of the parameter, $\sqrt{s}$ is incident particles center of mass energy, measured in GeV, m_π is π-meson mass in GeV too and a is a proportion coefficient.

The normalization condition for the structure function can be defined as $\int_0^1 F_2(x_j)dx = 1$.

The first figure represents the solution of the equation of QGP nonlinear dynamics in the first approximation. It is possible, that the bifurcation (splitting) point corresponds to a phase transition in the system.

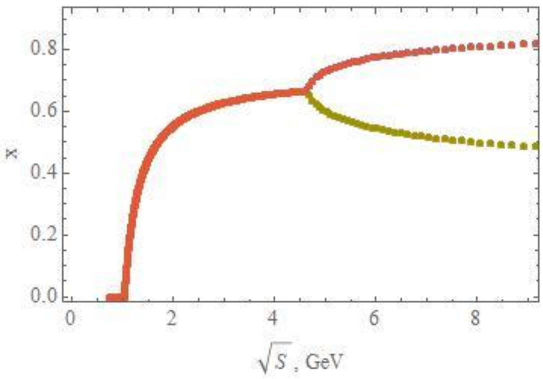

Fig. 1. – The dependence of parton momentum fraction on the collision energy

The solution of (1) can be presented in another form (Fig.2). Time iterations include dimensionless interval 0-100. There isn't resolution on time in Fig.2. Points, corresponding to different time moments, overlap, so there are a lot of points on the right side of the Fig. 2. 3D dependence is represented in 2D form.

In Fig. 2 with the evolution parameter growth, multiple bifurcations take place. One can correspond multiple bifurcation points to physical property of the system known as the multiplicity. It seems this point of view should be discussed in further investigations.

From the second figure it is seen, that initial bifurcation corresponds to the control parameter ~0.75. So if follow the results of [8], the evolution parameter values region 0.75÷0.89 correspond to intermediate phase mixture, that is a compound, which consists of QGP and hadrons.

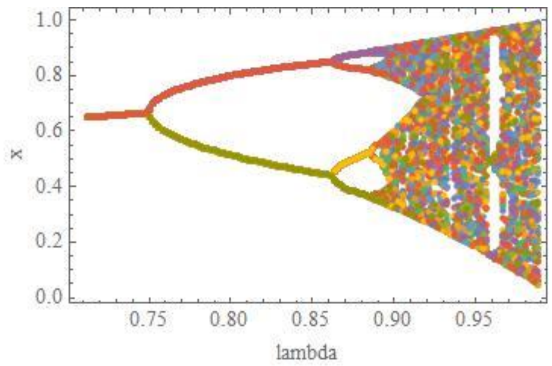

Fig. 2. – The dependence of parton momentum fraction on the evolution parameter

QGP properties appear as jet properties. Jet phenomena are a proof of complex internal structure of hadrons [1]. The jet phenomena in the QGP dynamics can be taken into account by the term related to viscosity, which should be introduced into equation (1):

$$\left|x_{j+1}\right\rangle = \left(\lambda F_2(x_j) + \eta \cdot \Delta\right)\left|x_j\right\rangle, \qquad (2)$$

where η is QGP viscosity, Δ is the Laplace operator. The equation (2) might be more applicable to describe QGP from the point of nonlinear dynamics' view. At the same time it should be mentioned, that the approach presented is purely, better to say more qualitative, than numerical, treatment.

Conclusion

The state of hadronic matter under critical conditions (that is the QGP) is defined by macroparameters such as density >10 ρ_0, ρ_0~1,6 10^{14} g/cm^3, temperature T~200 MeV and chemical potential. As a first approximation, the dynamics of the system has been determined by means of the evolution parameter.

The dependence of parton momentum fraction on the evolution parameter has been obtained. By it the evolution parameter values region 0.75÷0.89 is received, for the region specified intermediate phase mixture, i.e. a compound, which consists of the quark-gluon plasma and hadrons, should exist.

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Accepted to print at 23.09.2021