Vol. 39 (2008) *ACTA PHYSICA POLONICA B* No 2

OBSERVATION OF HYPERHEAVY TOROIDAL CONFIGURATIONS IN BUU SIMULATIONS OF HEAVY ION COLLISIONS*

A. Sochocka†, R. Płaneta

M. Smoluchowski Institute of Physics, Jagellonian University
Reymonta 4, Kraków, Poland

N.G. Nicolis

Department of Physics, University of Ioannina, Ioannina 45110, Greece

(Received December 10, 2007)

We study the formation of toroidal nuclear configurations in central and semi-central ^{124}Sn + ^{124}Sn and Au+Au collisions. BUU simulations indicate that the threshold energy for toroidal configuration formation decreases with increasing mass of the interacting system.

PACS numbers: 25.70.Lm, 25.70.Pq

The existence of nuclei with nonspherical shapes was first suggested by Wheeler [1]. This idea was investigated by many authors who studied the stability of exotic nuclear shapes, see *e.g.* [2–4].

Theoretical investigations related with the synthesis of superheavy long-living nuclei beyond the island of stability show that they can be reached only if non-compact shapes are taken into account. Calculations done for bubble structures with the liquid drop model with shell corrections [5,6] and the HFB theory with the Gogny D1S force [7–9] show that bubble nuclei can be stable for $Z > 240$ and $N > 500$.

Recently the axially symmetric toroidal structure of super-heavy nuclei with $Z > 130$ has been analyzed in frame of the HFB theory with Gogny D1S force. It was found that for nuclei with $Z > 140$ the global energy minimum corresponds to the toroidal shapes [10]. In contrast to bubble nuclei the synthesis of toroidal nuclei is experimentally feasible in collisions between stable isotopes. The crucial issue is the selection of the colliding nuclei and collision energy.

---

* Presented at the XXX Mazurian Lakes Conference on Physics, Piaski, Poland, September 2–9, 2007.

† ania_sochocka@poczta.fm

To address this issue it is necessary to perform calculations with dynamical models. Already performed simulations using the BNV and BUU transport equations show that disc, bubble, and toroidal shapes may be created in central and semi-central collisions. Such simulations were done mostly for systems with $A_{\rm sys} < 200$ and they cover a large range of collisions energies (60–100 MeV/nucleon) [11–17]. For heavier systems such simulations are limited to ^{155}Gd$+^{238}$U system at 27 and 35 MeV/nucleon [18] and ^{208}Pb$+^{197}$Au at 20 to 55 MeV/nucleon [19].

In this work we present the simulations results for Au+Au and ^{124}Sn$+^{124}$Sn systems performed for central and semicentral collisions in a wide range of incident energies.

In our simulations the BUU code developed by Bao An Li is used [17]. The BUU equation is solved using the test — particles method. The number of test particles is equal 200, a cell size is 1 fm, a time step is 0.2 fm/c. The simulations were performed for time up to $t = 250$ fm/c. Calculations were done for two values of imcompressibility parameter $K = 200$ MeV and 380 MeV. Two values of curvature parameter of symmetry energy $K_{\rm sym} = -69$ MeV and 61 MeV were also in our calculations.

Fig. 1 shows the time evolution for Au+Au central collisions at 8, 15, 23 and 40 MeV/nucleon. Here nuclear matter density distributions in the x and y plane for $z = 0$ (z axis is beam direction) are shown. One can observe that after the initial contact of the target and projectile, the nuclear matter is compressed to high density. This is followed by expansion. At the lowest energy the system evolves to the shape of spherical bubble at the time 200 fm/c. At 15 MeV/nucleon energy the system reaches the shape of a bubble contracted in the beam direction. Going up with the incident energy one observes that the system evolves to an oblate bubble nuclear matter, which subsequently changes into ring-shaped structure. At the highest energy the radial expansion of the system is stronger. The oblate bubble shape is contracted in the z direction at the time of 100 fm/c and finally one observes several separated fragments arranged in a toroidal structure.

Toroidal shapes are predicted also for semicentral collisions. The calculations indicate that for Au+Au reaction at 23 MeV/nucleon the toroidal objects can be seen also for noncental collisions up to impact parameter about 7 fm.

Our calculations were also performed for much lighter system ^{124}Sn$+^{124}$Sn. These results are presented in Fig. 2 for central collisions at 15, 25, 35 and 50 MeV/nucleon. Here nuclear matter density distributions in the x and y plane for $z = 0$ (z axis is beam direction) presented. For this lighter system at the lowest energy the system reaches the spherical shape with small depletion of matter in the centre. At 25 MeV/nucleon the system evolves to the shape of a disc perpendicular to the beam direction. One can no-

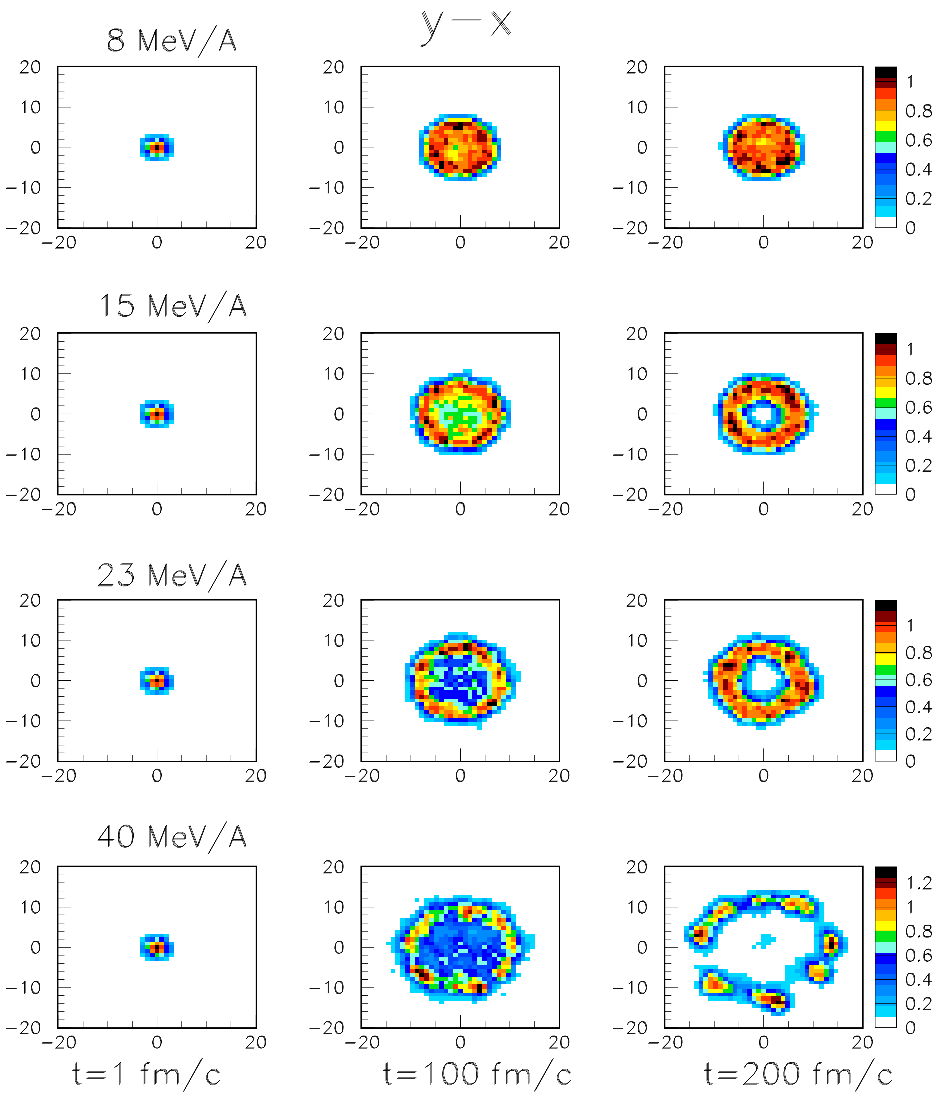

Fig. 1. (Color online) BUU calculations for central collisions of Au+Au at 8, 15, 23, and 40 MeV/nucleon for $K = 200$ MeV and $K_{\rm sym} = -69$ MeV. A time evolution in the x and y plane (cuts of the density distribution for $z = 0$, z axis is beam direction) is presented.

tice also some depletion in the central region of this object. At energies 35 and 50 MeV/nucleon the time evolution of the system is similar to that observed for the Au+Au reaction at 23 and 40 MeV/nucleon. The formation of toroidal structures is observed. One can notice here that the treshold energy for toroidal objects increases with decreasing mass of the colliding system.

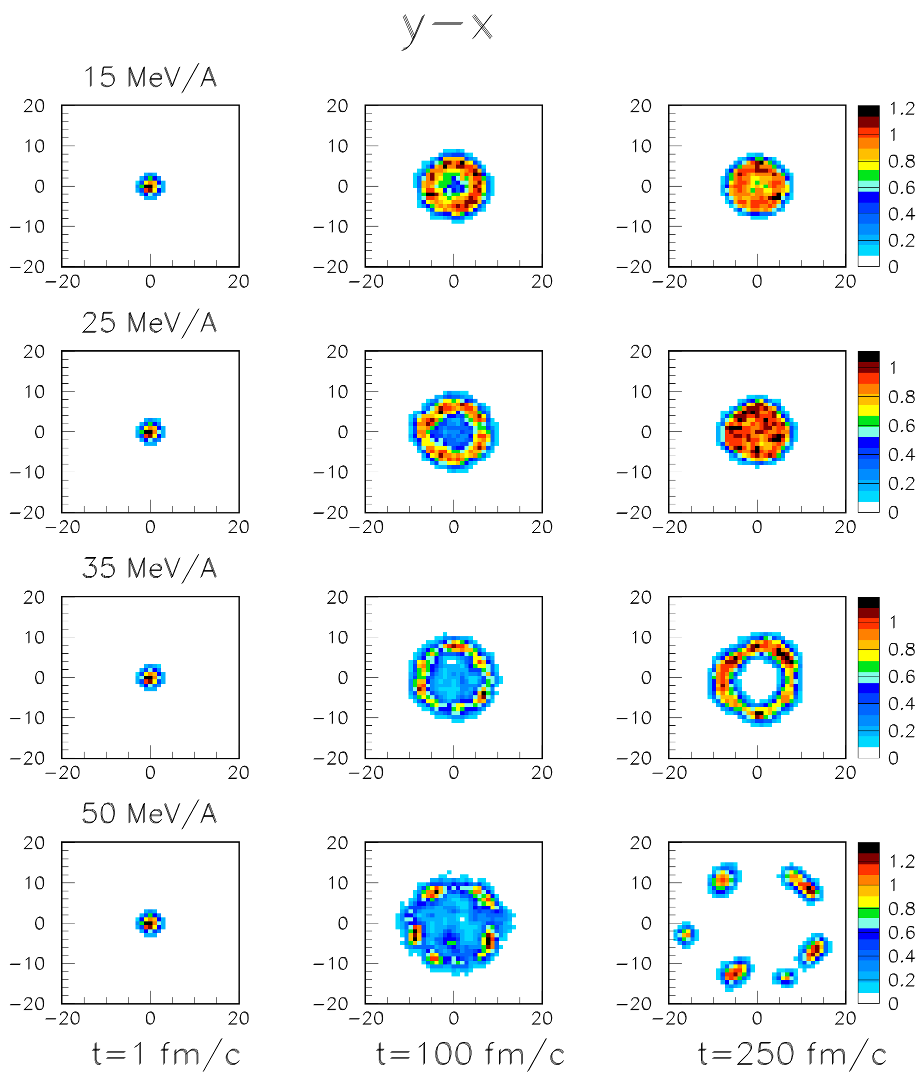

Fig. 2. (Color online) BUU calculations for central collisions of ^{124}Sn + ^{124}Sn at 15, 25, 35, and 50 MeV/nucleon for $K = 200$ MeV $K_{\rm sym} = -69$ MeV. A time evolution in the x and y plane (cuts of the density distribution for $z = 0$, z axis is beam direction) is presented.

We presented results of dynamical model simulations for ^{124}Sn + ^{124}Sn and Au+Au systems. One observes the evolution of the system shape with incident energy. For both systems at the correspoding lowest energies the spherical, bubble shapes are replaced by disc and toroidal objects going up with incident energy. The BUU calculations indicate that the threshold energy for toroidal nuclear shapes formation is located around 23 MeV/nucleon for the heavier system and this value increases to 35 MeV/nucleon for the lighter system. The calculations indicate that toroidal structures can be also formed for semicentral collisions. For the Au+Au interaction at 23 MeV/nucleon the deformed toroidal structures can be seen up to impact parameter about 7 fm.

In order to study the aplicability of the CHIMERA multidetecter [20] for detection of decay products of toroidal objects the ETNA code [21] calculations are in progress. This code is simulating the decay of nuclear systems assuming different break-up geometries. Sensitivity of different decay observables is being tested.

REFERENCES

[1] J.A. Wheeler, *Nucleonic Notebook* (1950), unpublished.

[2] P.J. Siemens, H. Bethe, *Phys. Rev. Lett.* **18**, 704 (1967).

[3] C.Y. Wong, *Phys. Rev. Lett.* **55**, 1973 (1985).

[4] L.G. Moretto *et al., Phys. Rev. Lett.* **78**, 824 (1997).

[5] K. Dietrich, K. Pomorski, *Nucl. Phys.* **A627**, 175 (1997).

[6] K. Dietrich, K. Pomorski, *Phys. Rev. Lett.* **80**, 37 (1998).

[7] J. Decharge *et al., Phys. Lett.* **B451**, 275 (1999).

[8] J.F. Berger *et al., Nucl. Phys.* **A685**, 1 (2001).

[9] J. Decharge *et al., Nucl. Phys.* **A716**, 55 (2003).

[10] M. Warda, *Int. J. Mod. Phys.* **E16**, 452 (2007).

[11] L.G. Moretto *et al., Phys. Rev. Lett.* **69**, 1884 (1992).

[12] H.M. Xu *et al., Phys. Rev.* **C48**, 933 (1993).

[13] H.M. Xu *et al., Phys. Rev.* **C49**, R1778 (1994).

[14] D.O. Handzy *et al., Phys. Rev.* **C51**, 2237 (1995).

[15] S.R. Souza, C. Ngo, *Phys. Rev.* **C48**, R2555 (1993).

[16] W. Bauer *et al., Phys. Rev. Lett.* **69**, 1888 (1992).

[17] Lie-Wen Chen *et al., Phys. Rev.* **C68**, 014605 (2003).

[18] B. Borderie *et al., Phys. Lett.* **B302**, 15 (1993).

[19] B. Jouault *et al., Nucl. Phys.* **A591**, 497 (1995).

[20] A. Aiello *et al., Nucl. Phys.* **A583**, 461 (1995).

[21] A. Sochocka *et al.*, in Proceedings of the IWM 2005, Eds.: R. Bougault, A. Pagano, S. Pirrone, M.F. Rivet and F. Rizzo, Conf. Proc. Vol. 91, Societa Italiana di Fisica, 2006.