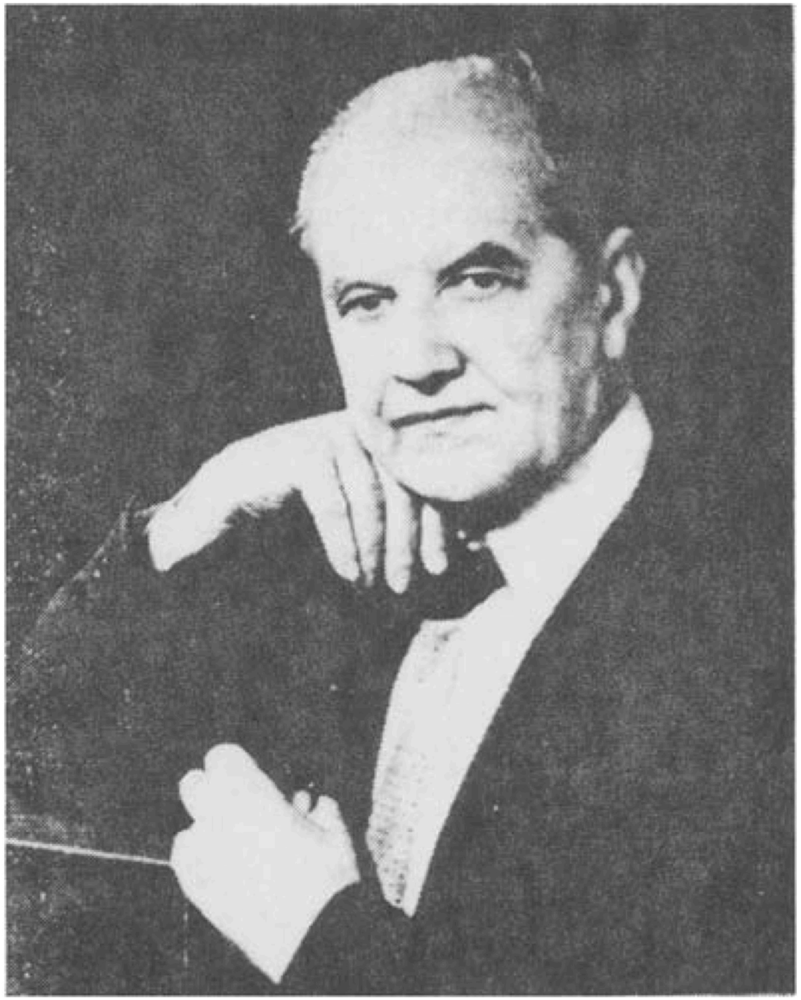
Dubna, 18.4.2018

Laudatio D.N. Zubarev

The NSO method

Gerd Röpke
Universitaet Rostock



BIOGRAPHY OF D. N. ZUBAREV (1917 - 1992)

born Nov. 27, 1917, Moscow , Russia.
died July 29, 1992, Moscow , Russia.

Nonequilibrium statistical operator (NSO)

- D. N. Zubarev, *Nonequilibrium Statistical Thermodynamics* [in Russian], Nauka, Moscow (1971); English transl., Consultants Bureau, New York (1974)*; "The statistical operator for nonequilibrium systems,"* Sov. Phys. Dokl., 6, 776–778 (1962).

- D. Zubarev, V. Morozov, and G. Ropke, *Statistical Mechanics of Nonequilibrium Processes, Vol. 1, Basic Concepts, Kinetic Theory,* Akademie-Verlag, Berlin (1996).
- D. Zubarev, V. Morozov, and G. Ropke, *Statistical Mechanics of Nonequilibrium Processes, Vol. 2, Relaxation and Hydrodynamic Processes*, Akademie-Verlag, Berlin (1997).

- N. N. Bogoliubov, *Problems of Dynamical Theory in Statistical Physics* [in Russian], Gostekhteorizdat, Moscow (1946).
- L. Boltzmann, *Vorlesungen ueber Gastheorie*, Vol. 2, J. A. Barth, Leipzig (1912).
- De Groot / Mazur, Gibbs, Shannon, etc.

Father of methods

principle of weakening of initial correlations (Bogoliubov)

$$\rho_\epsilon(t) = \epsilon \int_{-\infty}^{t} e^{\epsilon(t_1 - t)} U(t, t_1) \rho_{\mathrm{rel}}(t_1) U^\dagger(t, t_1)\, dt_1$$

time evolution operator $U(t, t_0)$

relevant statistical operator $\rho_{\mathrm{rel}}(t)$ maximum of information entropy

selection of the set of relevant observables $\{B_n\}$

self-consistency relations $\mathrm{Tr}\{\rho_{\mathrm{rel}}(t) B_n\} \equiv \langle B_n \rangle^t_{\mathrm{rel}} = \langle B_n \rangle^t$

extended von Neumann equation

$$\frac{\partial}{\partial t} \varrho_\varepsilon(t) + \frac{i}{\hbar} [H, \varrho_\varepsilon(t)] = -\varepsilon \left(\varrho_\varepsilon(t) - \varrho_{\mathrm{rel}}(t) \right)$$

$\varrho(t) = \lim_{\varepsilon \to 0} \varrho_\varepsilon(t)$ after thermodynamic limit

The freeze-out approach

selection of the set of relevant observables $\{B_n\}$: H,N_n,N_p

maximum of information entropy at $\mathrm{Tr}\{\rho_{\mathrm{rel}}(t)B_n\} \equiv \langle B_n\rangle^t_{\mathrm{rel}} = \langle B_n\rangle^t$

generalized Gibbs ensembles

Lagrange parameters T, μ_n, μ_p elimination: EoS

$$\rho_\epsilon(t) = \epsilon \int_{-\infty}^{t} e^{\epsilon(t_1-t)} U(t,t_1)\rho_{\mathrm{rel}}(t_1)U^\dagger(t,t_1)\, dt_1$$

Markov approximation

expanding fireball: dependence on time t

composition (formation of bound states) relaxation time becomes large

L. P. Csernai and J. I. Kapusta, Phys. Rep. **131**, 223 (1986)

Kinetic equations

selection of the set of relevant observables $\{B_n\}$:

single-particle distribution function $f_1(\mathbf{r}, \mathbf{p}, t)$

$$\mathrm{Tr}\{\rho_{\mathrm{rel}}(t) B_n\} \equiv \langle B_n \rangle_{\mathrm{rel}}^t = \langle B_n \rangle^t$$

Boltzmann equation $$\frac{\partial}{\partial t} f_1 + \mathbf{v} \frac{\partial}{\partial \mathbf{r}} f_1 + \mathbf{F}^{\mathrm{external}} \frac{\partial}{\partial \mathbf{p}} f_1 = \left(\frac{\partial}{\partial t} f_1 \right)_{\mathrm{St}}$$

collision integral

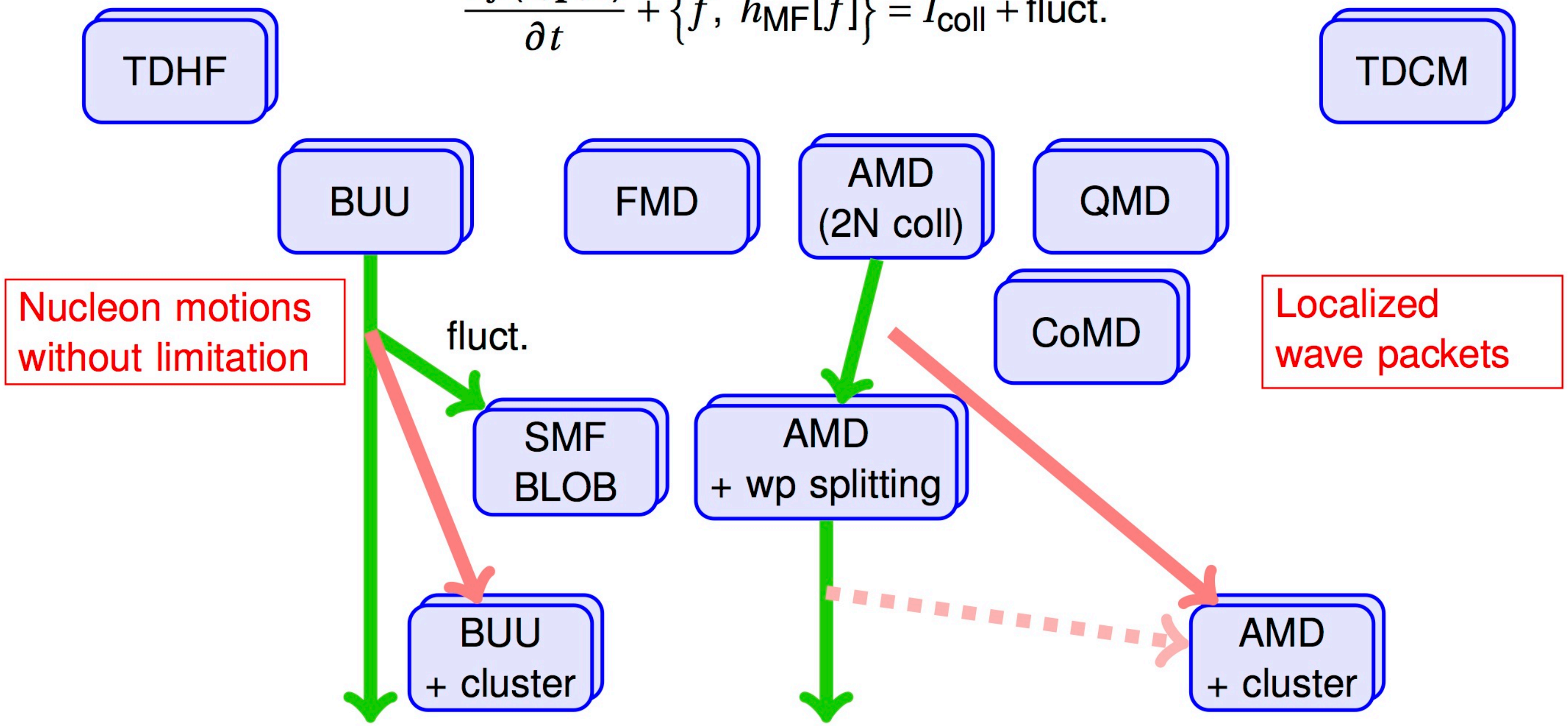
$$\left(\frac{\partial}{\partial t} f_1 \right)_{\mathrm{St}} = \int d^3 \mathbf{v}_2 \int d\Omega \frac{d\sigma}{d\Omega} |\mathbf{v}_1 - \mathbf{v}_2| \{ f_1(\mathbf{r}, \mathbf{p}_1', t) f_1(\mathbf{r}, \mathbf{p}_2', t) - f_1(\mathbf{r}, \mathbf{p}_1, t) f_1(\mathbf{r}, \mathbf{p}_2, t) \}$$

formation of clusters ? coalescence model

Various transport theories

Based on the one-body distribution function $f(\mathbf{r},\mathbf{p},t)$ ⇔ One-body density matrix $\rho(\mathbf{r},\mathbf{r}')$

$$\frac{\partial f(\mathbf{r},\mathbf{p},t)}{\partial t} + \left\{f,\ h_{\mathrm{MF}}[f]\right\} = I_{\mathrm{coll}} + \text{fluct.}$$



- Fluctuation/branching is a way to handle many-body correlations.
- Not many models treat cluster correlations explicitly.

Cluster formation

selection of the set of relevant observables $\{B_n\}$:

single-particle distribution function

distribution function of bound states quasi-particles

$$f_{A\nu}^{\mathrm{Wigner}}(\mathbf{p},\mathbf{r},t)$$

from the A-particle Green function

local thermodynamic equilibrium

$$T(\mathbf{r},t), \mu_n(\mathbf{r},t), \mu_p(\mathbf{r},t)$$

D. N. Zubarev, V. G. Morozov, I. P. Omelyan, and M. V. Tokarchuk, Theoret. Math. Phys. **96**, 997 (1993)

G. Ropke and H. Schulz, Nucl. Phys. A **477**, 472 (1988)

Formation of light clusters in heavy ion reactions, transport codes

PHYSICAL REVIEW C, VOLUME 63, 034605

Medium corrections in the formation of light charged particles in heavy ion reactions

C. Kuhrts,[1] M. Beyer,[1,*] P. Danielewicz,[2] and G. Röpke[1]
[1]*FB Physik, Universität Rostock, Universitätsplatz 3, D-18051 Rostock, Germany*
[2]*NSCL, Michigan State University, East Lansing, Michigan 48824*
(Received 13 September 2000; published 12 February 2001)

Wigner distribution

cluster mean-field potential

$$\partial_t f_X + \{\mathcal{U}_X, f_X\} = \mathcal{K}_X^{\text{gain}}\{f_N, f_d, f_t, \ldots\}(1 \pm f_X) - \mathcal{K}_X^{\text{loss}}\{f_N, f_d, f_t, \ldots\} f_X, \quad X = N, d, t, \ldots .$$

loss rate

in-medium
breakup transition operator

$$\mathcal{K}_d^{\text{loss}}(P,t) = \int d^3k \int d^3k_1\, d^3k_2\, d^3k_3 |\langle k_1 k_2 k_3 | U_0 | kP\rangle|^2_{dN \to pnN} \times f_N(k_1,t) f_N(k_2,t) f_N(k_3,t) f_N(k,t) + \cdots . \quad (3)$$

breakup cross section

$$\sigma_{\text{bu}}^0(E) = \frac{1}{|v_d - v_N|} \frac{1}{3!} \int d^3k_1\, d^3k_2\, d^3k_3 |\langle kP | U_0 | k_1 k_2 k_3\rangle|^2 \times 2\pi\delta(E' - E)(2\pi)^3 \delta^{(3)}(k_1 + k_2 + k_3), \quad (4)$$

P. Danielewicz and Q. Pan, Phys. Rev. C 46, 2002 (1992)

Mott effect, in-medium cross section

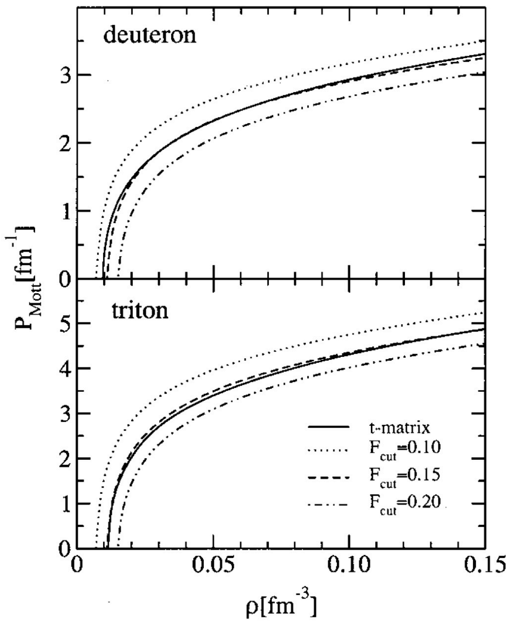


FIG. 1. Deuteron and triton Mott momenta P_{Mott} shown as a function of density ρ at fixed temperature of $T=10$ MeV. The solid line represents results of the t matrix approach. The dashed, dotted, and dashed-dotted lines represent the deuteron Mott momenta from the parametrization given in Eq. (24) for three different cutoff values F_{cut}.

$$\int d^3q\; f\left(\mathbf{q}+\frac{\mathbf{P}_{\mathrm{c.m.}}}{2}\right)\;|\phi(\mathbf{q})|^2 \leqslant F_{\mathrm{cut}}$$

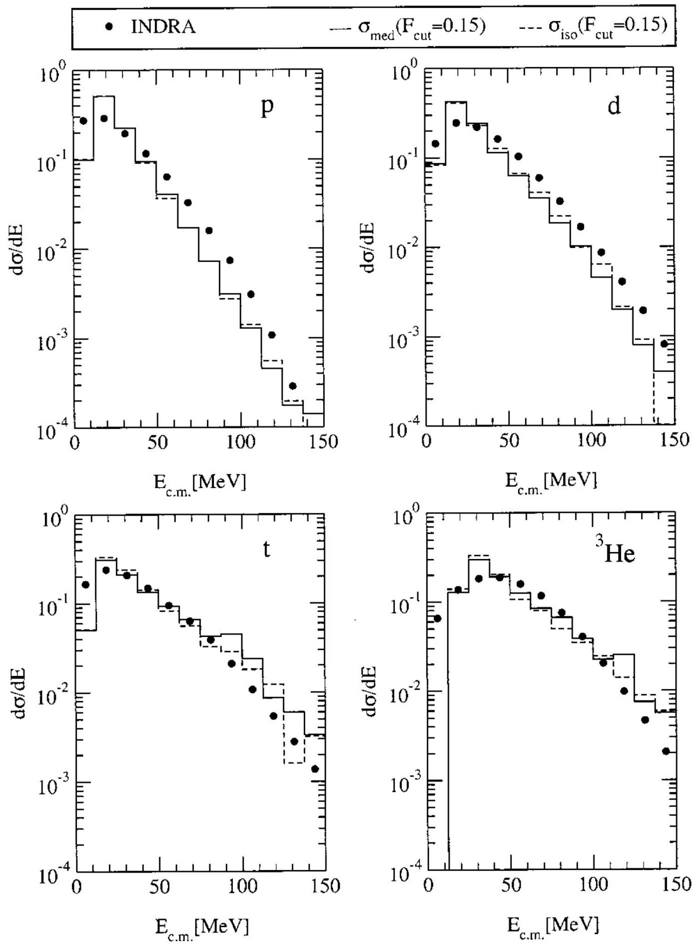
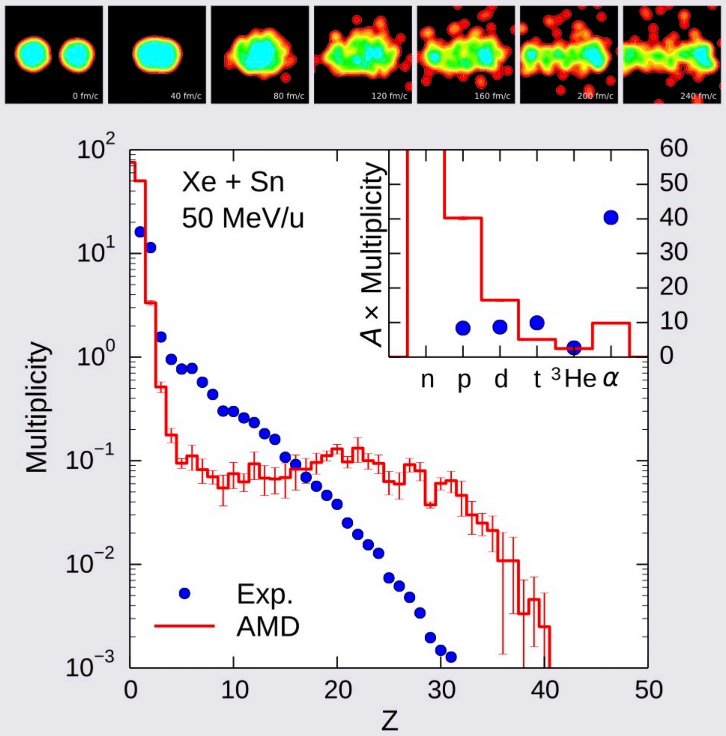


FIG. 5. Renormalized light charged light particle spectra in the center of mass system for the reaction ^{129}Xe+^{119}Sn at 50 MeV/nucleon. The filled circles represent the data of the INDRA Collaboration [21]. The solid line shows the calculations with the in-medium Nd reaction rates, while the dashed line shows a calculation using the isolated Nd breakup cross section; both with $F_{\mathrm{cut}}=0.15$.

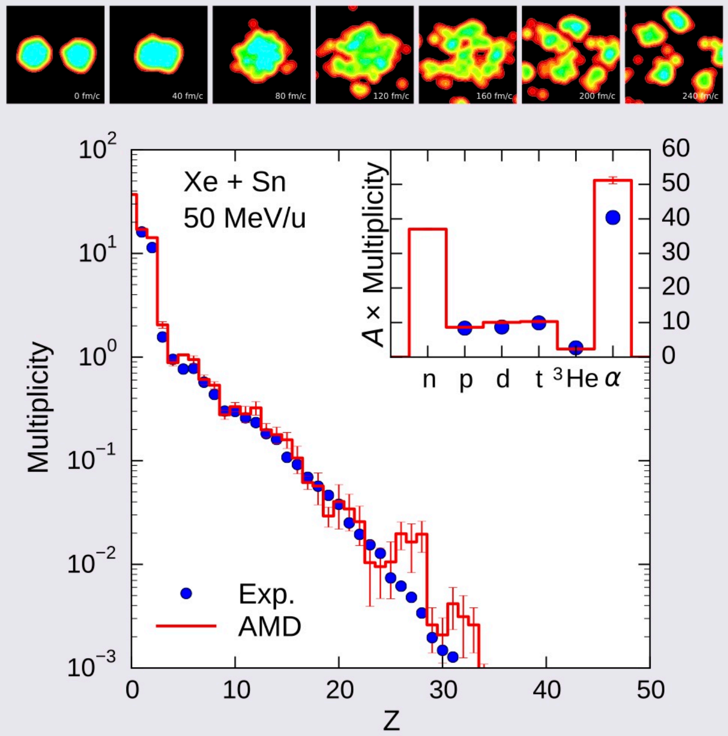
C. Kuhrts, PRC **63**,034605 (2001)

Effect of cluster correlations: central Xe + Sn at 50 MeV/u

Without clusters



With clusters

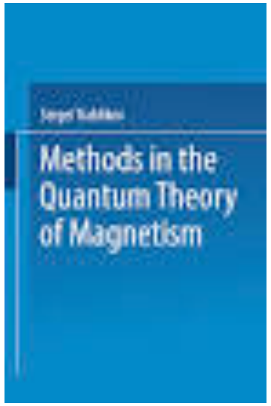


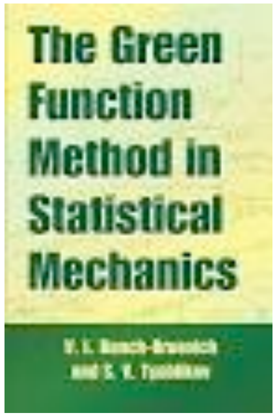
My stay at MIAN 1968 - 69

Spin waves
in magnetism

- S. V. Tyablikov
- born: September 7, 1921, Klin
- died: March 17, 1968, Moscow

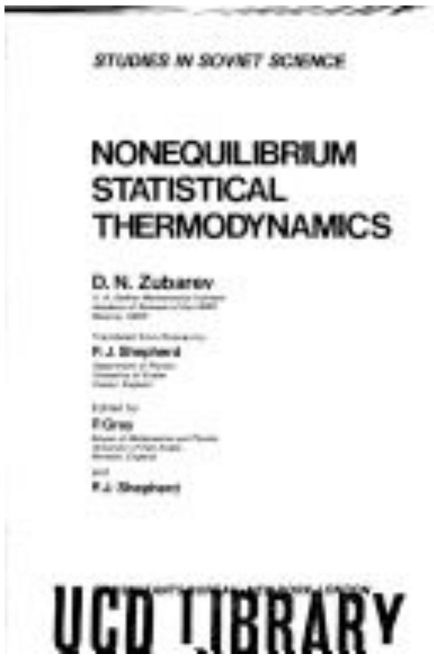
Y.G. Rudoy, Theor. Math. Phys. **168**, 1318 (2011)
The Bogoliubov-Tyablikov Green's function method in the quantum theory of magnetism





Zubarev’s Book on NSO

D. N. Zubarev, *Nonequilibrium Statistical Thermodynamics* [in Russian], Nauka, Moscow (1971)


STUDIES IN SOVIET SCIENCE

NONEQUILIBRIUM STATISTICAL THERMODYNAMICS

D. N. Zubarev

P. J. Shepherd

P. J. Shepherd

UCD LIBRARY

- Dmitrii Nikolaevich Zubarev. Nonequilibrium Statistical Thermodynamics. Studies in Soviet Science. Consultants Bureau, New York, 1974.
- Translated from Russian by P. J. Shepherd. Edited by P. J. Shepherd and P. Gray. 243

German translation:
Statistische Thermodynamik fuer das Nichtgleichgewicht

P. J. Shepherd

johnshepherd1943@hotmail.co.uk

08.02.2013

Our books, and Russia in 1969

Герд, привет!

I remember you well from the days when we both worked with Dmitrii Nikolaevich Zubarev at the Steklov Institute in 1969. (I subsequently translated his Nonequilibrium Statistical Mechanics for Plenum.)

I attach a photo taken when we visited Vladimir in June 1969. I hope you like it. I like it very much, not least because we all look so young!

Best wishes,

John


Гостиница

Some personal retrospections

- 25 years after 2nd world war
- participated in the Battle of Moscow and met the end of the war in Berlin (de-miner).
- With G. Hertz who was made head of Institute G, in Agudzery, about 10 km southeast of Sukhumi and a suburb of Gulrip'shi. Separation of isotopes by diffusion in a flow of inert gases.
- Participation in Soviet Nuclear Project
- Wife: Galina Rudolfovna, Leningrad blockade
- Overnight at a railway station: main idea NSO
- accommodation: book1, book 2 for a car.
- Accurate and “European” style
- Contacts to many people, Nikolay Nikolayevich
- visits to Germany/Rostock

Publication output

citations

Total Publications
53
1989 2008

***h*-index**
17

Average citations per item
42.09

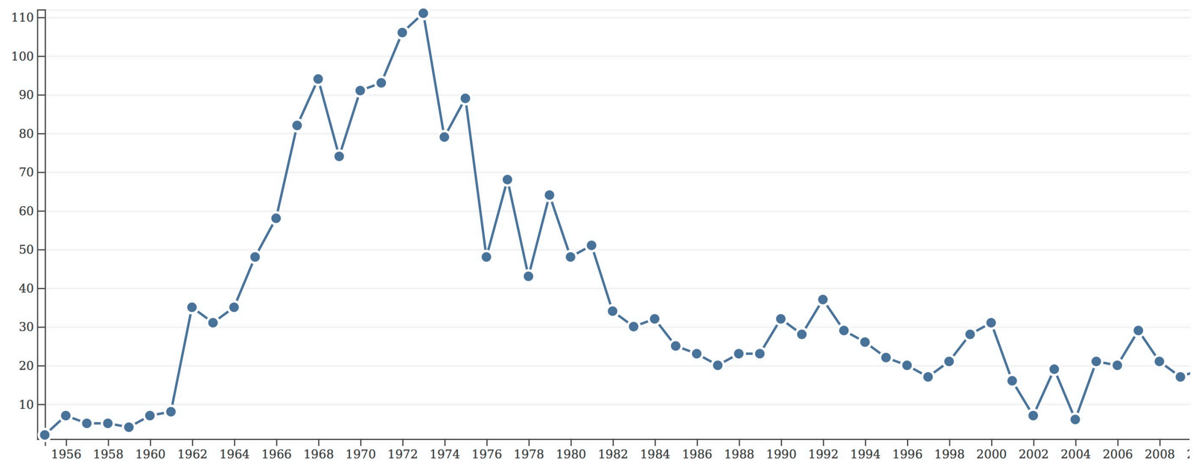
Sum of Times Cited
2,231

Without self citations
2,181

Citing articles
1,989

Without self citations
1,964

Sum of Times Cited per Year



The mostly cited papers

2-TIME GREEN FUNCTIONS IN STATISTICAL PHYSICS

By: ZUBAREV, DN
USPEKHI FIZICHESKIKH NAUK Volume: 71 Issue: 1 Pages: 71-116 Published: 1960 1326

THE WAVE FUNCTION OF THE LOWEST STATE OF A SYSTEM OF INTERACTING BOSE PARTICLES

By: BOGOLIUBOV, NN; ZUBAREV, DN 141
SOVIET PHYSICS JETP-USSR Volume: 1 Issue: 1 Pages: 83-90 Published: 1955

STATISTICAL OPERATOR FOR NO-EQUILIBRIUM SYSTEMS

By: ZUBAREV, DN
DOKLADY AKADEMII NAUK SSSR Volume: 140 Issue: 1 Pages: 92-& Published: 1961 106

METHOD OF NON-EQUILIBRIUM STATISTICAL OPERATOR AND ITS APPLICATIONS .1.

By: ZUBAREV, DN
FORTSCHRITTE DER PHYSIK-PROGRESS OF PHYSICS Volume: 18 Issue: 3 Pages: 125-& 65
Published: 1970

THE PHASE TRANSITION THEORY

By: BOGOLUBOV, NN; ZUBAREV, DN; TSERKOVNIKOV, YA
DOKLADY AKADEMII NAUK SSSR Volume: 117 Issue: 5 Pages: 788-791 Published: 1957 63

STATISTICAL-MECHANICS OF NON-LINEAR HYDRODYNAMIC FLUCTUATIONS

By: ZUBAREV, DN; MOROZOV, VG
PHYSICA A Volume: 120 Issue: 3 Pages: 411-467 Published: 1983

GIBBSS LOCAL EQUILIBRIUM ENSEMBLE AND ITS RELATION TO THEORY OF FLUCTUATIONS AND TRANSFER PHENOMENA

By: ZUBAREV, DN
DOKLADY AKADEMII NAUK SSSR Volume: 162 Issue: 3 Pages: 532-& Published: 1965

AN ASYMPTOTICALLY EXACT SOLUTION FOR THE MODEL HAMILTONIAN OF THE THEORY OF SUPERCONDUCTIVITY

By: BOGOLYUBOV, NN; ZUBAREV, DN; TSERKOVNIKOV, YA
SOVIET PHYSICS JETP-USSR Volume: 12 Issue: 1 Pages: 88-93 Published: 1961

DERIVATION OF NONEQUILIBRIUM STATISTICAL OPERATOR FROM EXTREMUM OF INFORMATION ENTROPY

By: ZUBAREV, DN; KALASHNIKOV, VP
PHYSICA Volume: 46 Issue: 4 Pages: 550-+ Published: 1970

TRANSFER PROCESSES IN SYSTEMS OF PARTICLES WITH INTERNAL DEGREES OF FREEDOM

By: ZUBAREV, DN
DOKLADY AKADEMII NAUK SSSR Volume: 162 Issue: 4 Pages: 794-& Published: 1965

NSO: progress and challenges

- General method, unifying different approaches
- Very powerful, various problems
- Discussion of entropy, irreversibility
- Open questions: selection of relevant observables, limit $\epsilon \to +0$
  really increase of entropy?
- Turbulence
- Let us work along the lines given by D.N. Zubarev

Equilibrium correlations and transport codes

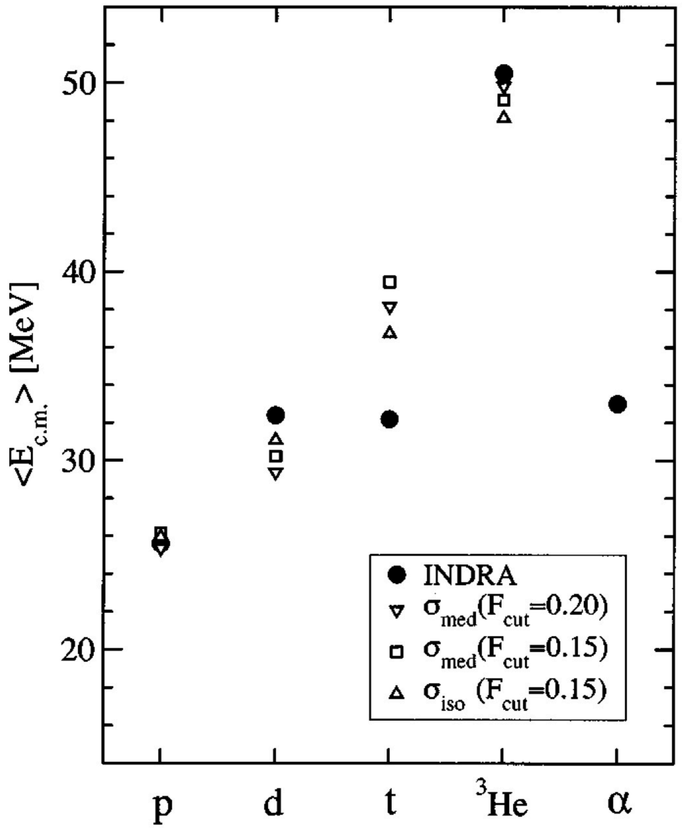


FIG. 6. Mean transverse energy of light charged fragments in the angular range of $-0.5 \leq \cos\theta_{c.m.} \leq 0.5$.

C. Kuhrts, PRC **63**,034605 (2001)

Important: Mott effect

Minor effects:
in medium cross sections

Missing: inclusion of alphas

Correlated continuum,
correlated medium

Freeze-out and local
thermodynamic equilibrium

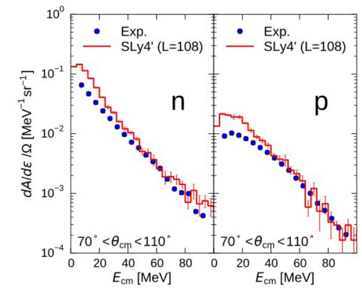
single-particle quantum kinetic
equations and correlations

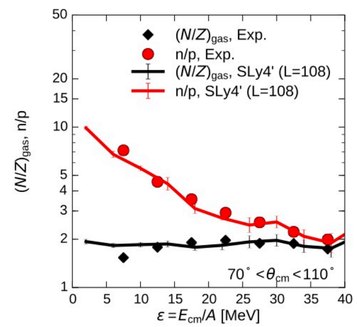
Equilibrium solution?

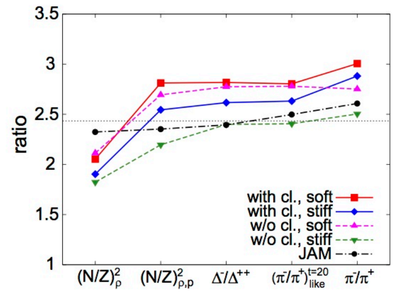
AMD (Akira Ono)

Summary

- AMD has been extended to include cluster correlations.
  - The correlation to bind several light clusters is also important.
  - Transition from a wave packet to a plane wave is taken into account to improve nucleon spectra.
- Clusters have strong impacts.
  - Good reproduction of cluster and fragment productions, in various reaction systems simultaneously.
  - The neutron/proton ratio is sensitive to the production of α particles (as well as to the density dependence of the symmetry energy).
  - If clusters start to appear at early times, they change the way how the symmetry energy is reflected in final observables such as the π^-/π^+ ratio.

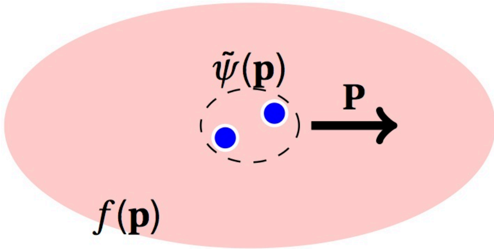






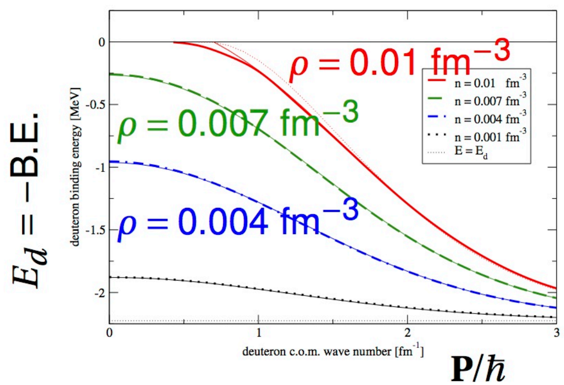
One-body dynamics $\Leftarrow$ $\Rightarrow$ Clusters
Bulk properties (EOS)

A cluster in medium & Clusterized nuclear matter



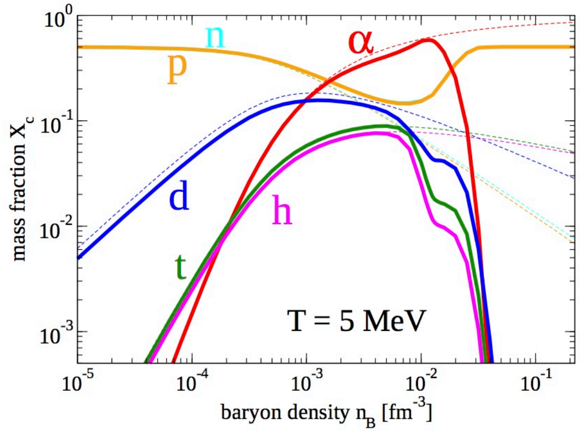
Equation for a deuteron in uncorrelated medium

$$\left[e(\tfrac{1}{2}\mathbf{P}+\mathbf{p})+e(\tfrac{1}{2}\mathbf{P}-\mathbf{p})\right]\tilde{\psi}(\mathbf{p})$$
$$+\left[1-f(\tfrac{1}{2}\mathbf{P}+\mathbf{p})-f(\tfrac{1}{2}\mathbf{P}-\mathbf{p})\right]\int\frac{d\mathbf{p}'}{(2\pi)^3}\langle\mathbf{p}|v|\mathbf{p}'\rangle\tilde{\psi}(\mathbf{p}')$$
$$=E\tilde{\psi}(\mathbf{p})$$



Momentum ($\mathbf{P}$) dependence of B.E.

Röpke, NPA867 (2011) 66.



QS for symmetric nuclear matter

Röpke, PRC 92 (2015) 054001.

from A. Ono

Light cluster production at NICA*

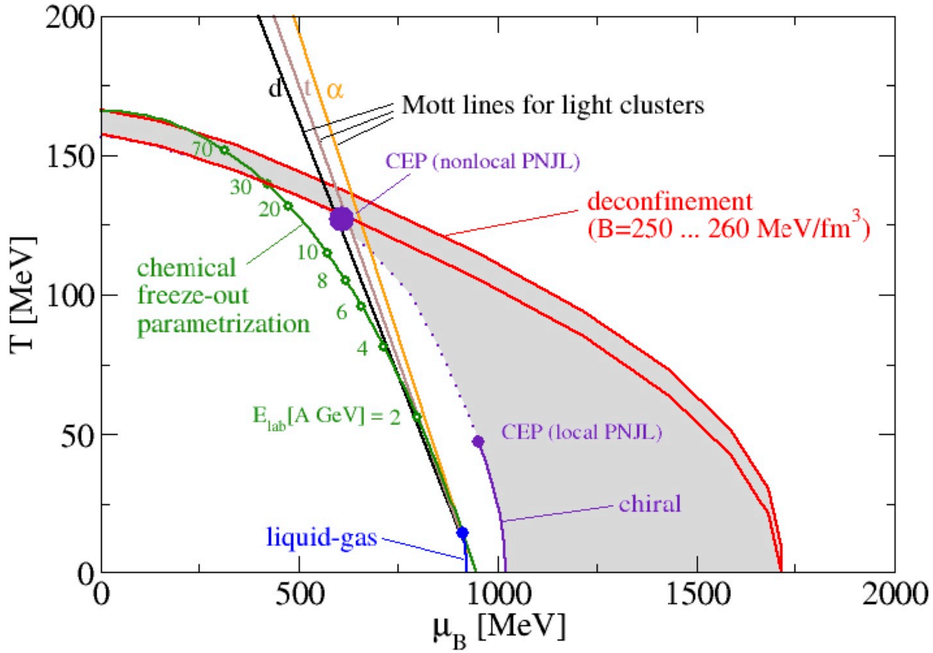


Fig. 1. Phase diagram of dense nuclear matter in the plane of temperature T and baryochemical potential μ_B. The diagram includes Mott lines for the dissociation of light nuclear clusters, extrapolated also to the deconfinement region. For details, see text.

N.-U. Bastian, P. Batyuk, D. Blaschke, P. Danielewicz, Yu.B. Ivanov, Iu. Karpenko, G. Ropke, O. Rogachevsky, and H.H. Wolter, Eur. Phys. J. A (2016) 52: 244

Light cluster production at

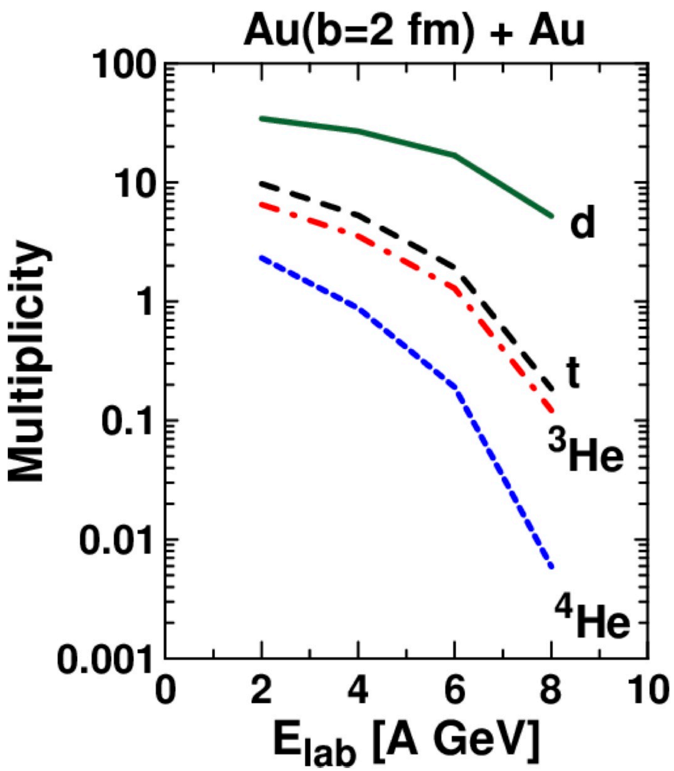


Fig. 5. Multiplicities of light clusters in central Au + Au collisions in the NICA energy range (calculated for an energy scan with $E_{\rm lab} = 2, 4, 6, 8\,A\,{\rm GeV}$). Results from a 3-fluid hydrodynamics description with cluster coalescence [22].

N.-U. Bastian, P. Batyuk, D. Blaschke, P. Danielewicz, Yu.B. Ivanov, Iu. Karpenko, G. Ropke, O. Rogachevsky, and H.H. Wolter, Eur. Phys. J. A (2016) 52: 244

Participation in Soviet Nuclear Project

On 27 April 1945, Thiessen arrived at von Ardenne's institute
in an armored vehicle with a major of the Soviet Army,
who was also a leading Soviet chemist.
All four of the pact members were taken to the Soviet Union.
Hertz was made head of Institute G, in Agudseri (Agudzery),
about 10 km southeast of Sukhumi and a suburb of Gul’rips (Gulrip'shi).
Topics assigned to Gustav Hertz's Institute G included:
(1) Separation of isotopes by diffusion in a flow of inert gases,
for which Gustav Hertz was the leader,
(2) Development of a condensation pump, for which Justus Mühlenpfordt was the leader,
(3) Design and build a mass spectrometer for determining
the isotopic composition of uranium, for which Werner Schütze was the leader,
(4) Development of frameless (ceramic) diffusion partitions for filters,
for which Reinhold Reichmann was the leader, and
(5) Development of a theory of stability and control of a diffusion cascade,
for which Heinz Barwich was the leader.

In his first meeting with Lavrentij Beria, von Ardenne was asked to participate
in building the bomb, but von Ardenne quickly realized that participation
would prohibit his repatriation to Germany, so he suggested isotope enrichment
as an objective, which was agreed to.