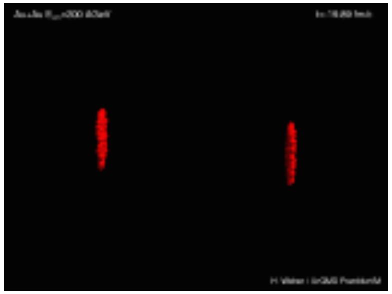
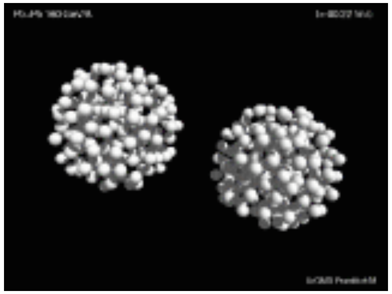


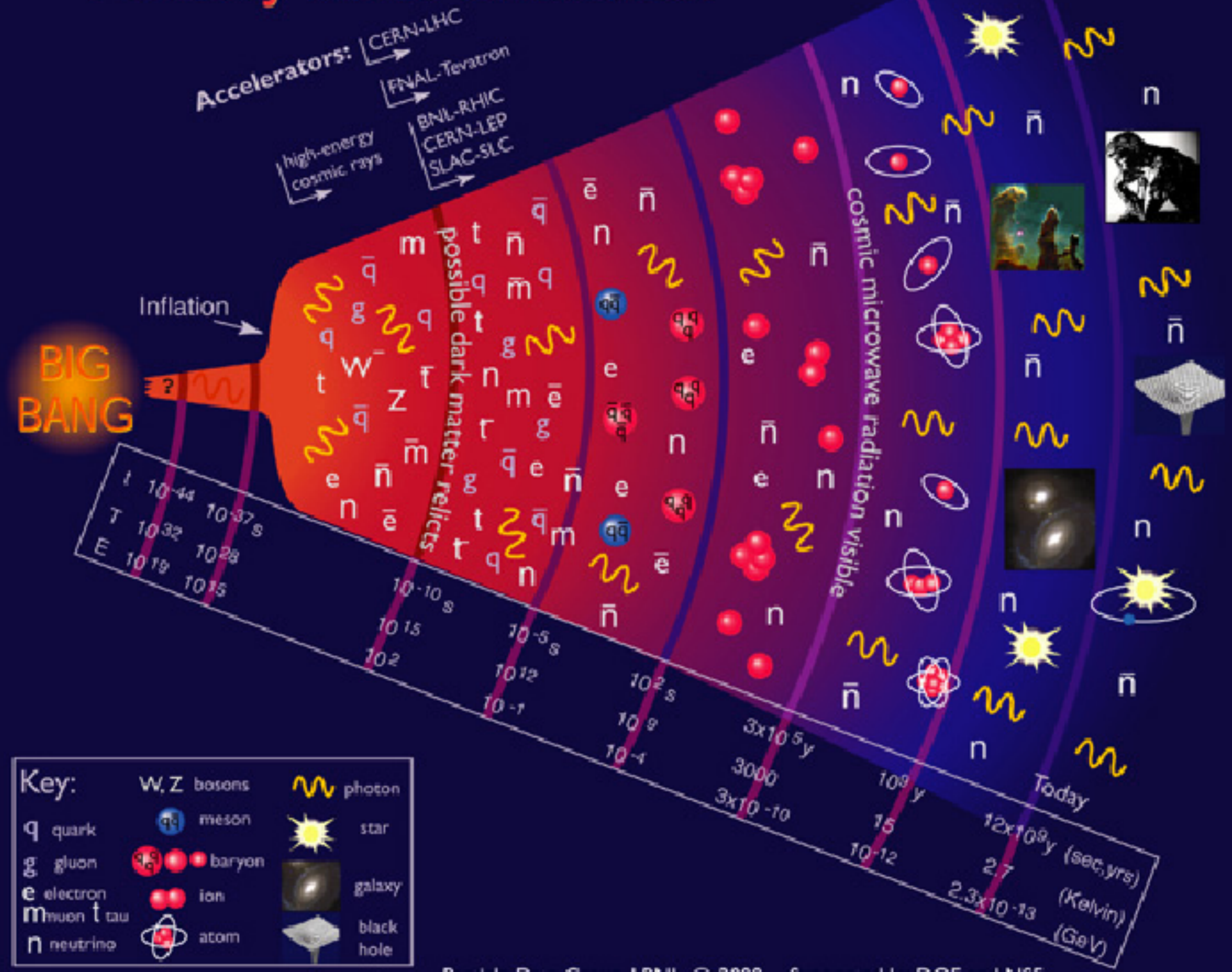


Introduction to Relativistic Heavy Ion Collisions

Azwinndini Muronga

Nelson Mandela University
Port Elizabeth, South Africa

History of the Universe



Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Origins of Ultrarelativstic Heavy Ion Colisions:

Workshop on BeV Collisions of Heavy Ions: How and Why

Nov 29 - Dec 1 1974

Bear Mountain New York

Introduction and Summary:

The history of physics teaches us that profound revolutions arise from a gradual perception that certain observations can be accommodated only by radical departures from current thinking. The workshop addressed itself to the intriguing question of the possible existence of a nuclear world quite different from the one we have learned to accept as familiar and stable.

Leon Lederman and Joseph Weneser

It would be interesting to explore new phenomena by distributing high energy or high nuclear density over a relatively large volume.

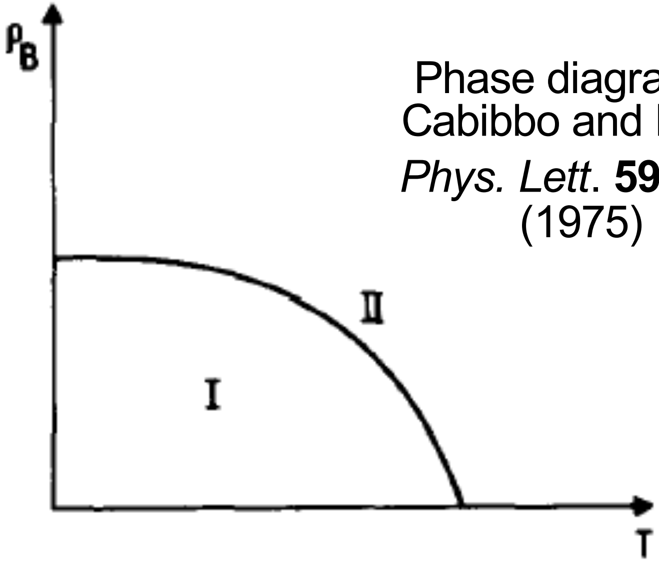
T. D. Lee

Early Work on the Phase Diagram of QCD

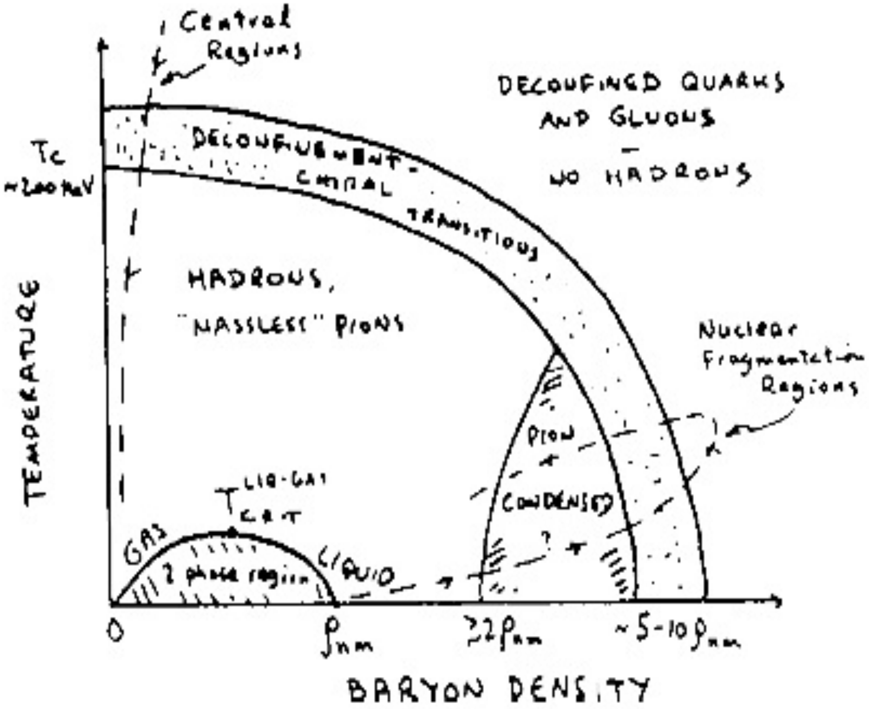
N. Itoh, *Prog. Theor. Phys*. **44**, 291 (1970)

P. Carruthers, *Coll. Phenom*. **1**, 147 (1973)

Arguments using asymptotic freedom by J. Collins and M. Perry, *Phys. Rev. Lett*. , **34**, 1353 (1975)



Phase diagram of Cabibbo and Parisi *Phys. Lett*. **59B**, 67 (1975)



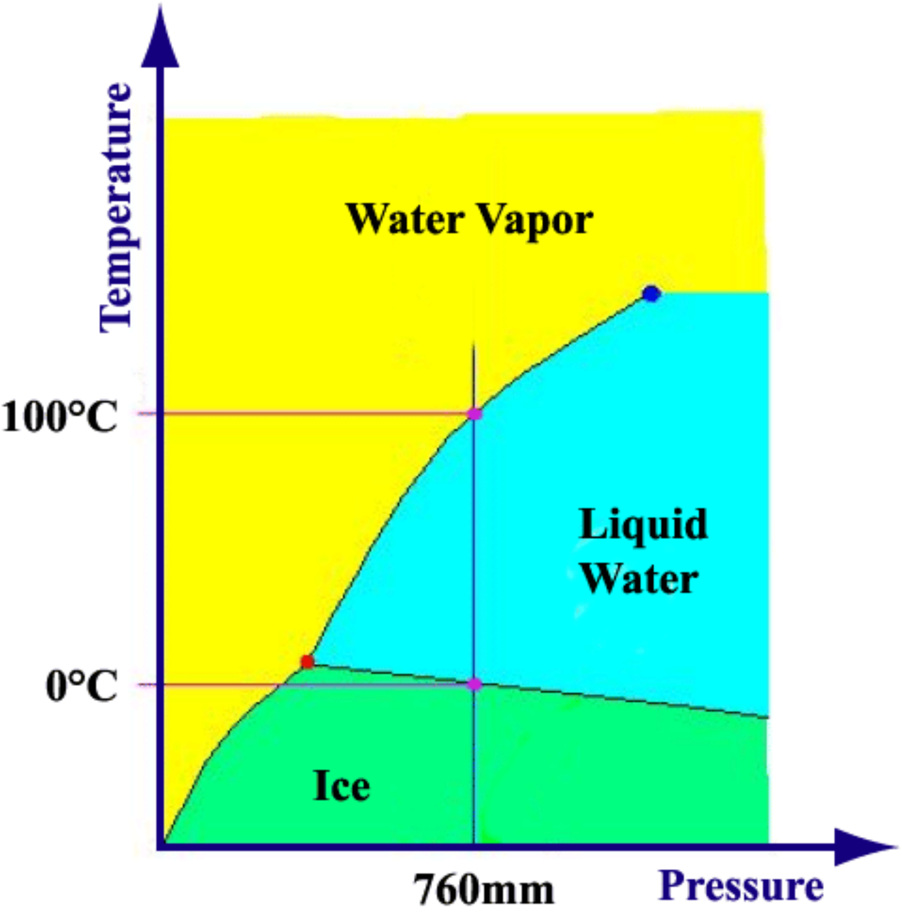
Higher order computations by Baym and Chin 1976; McLerran and Freedman 1977;

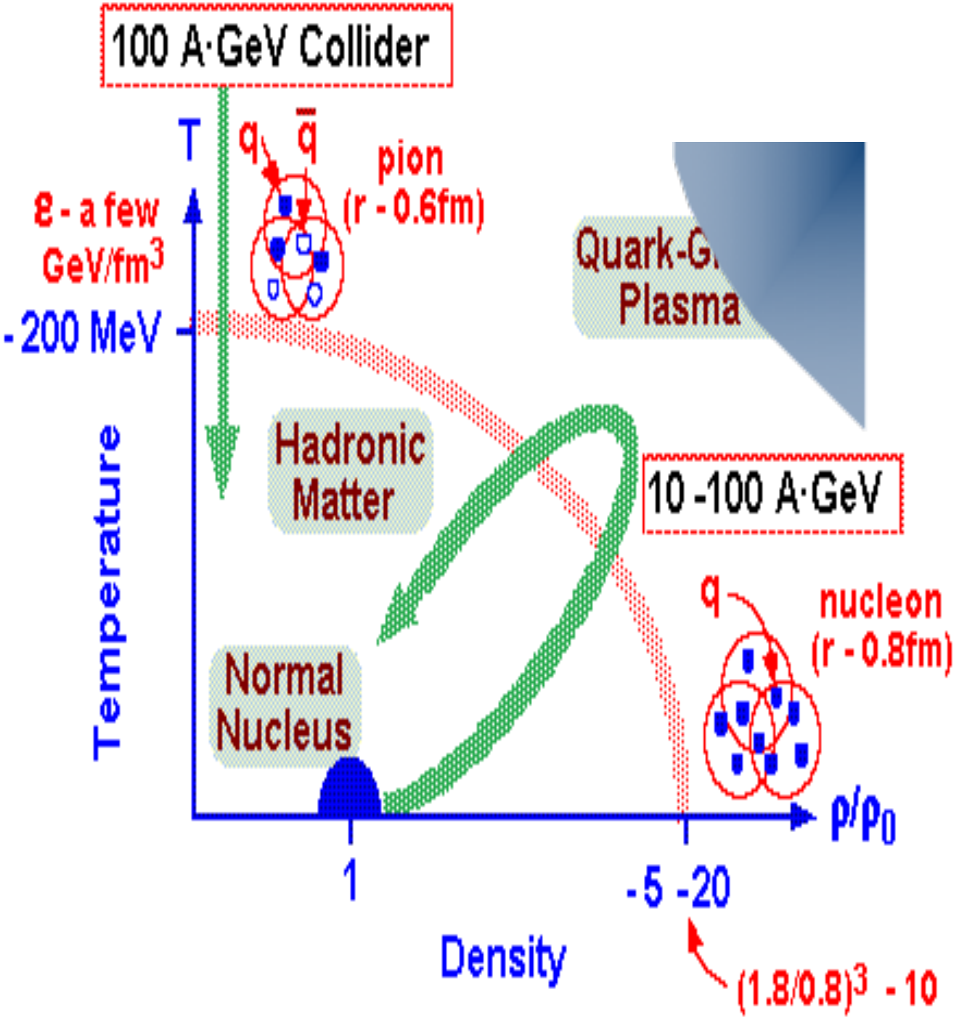
Finite T and name Quark Gluon Plasma by Shuryak 1978;

Kapusta 1979

Phase diagram of Baym from 1983 NSAC Long Range Plan

The phase transition of nuclear matter



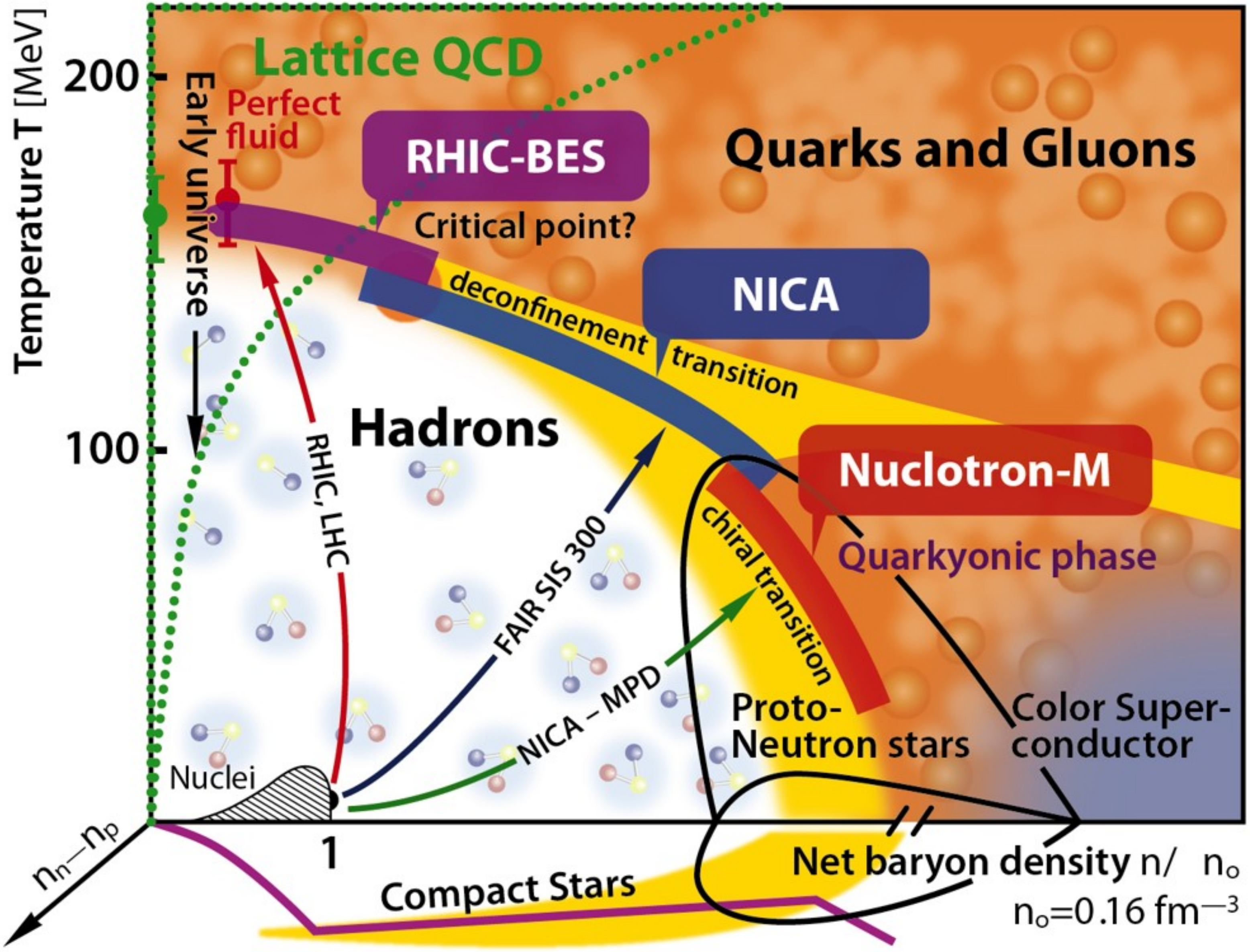


Water

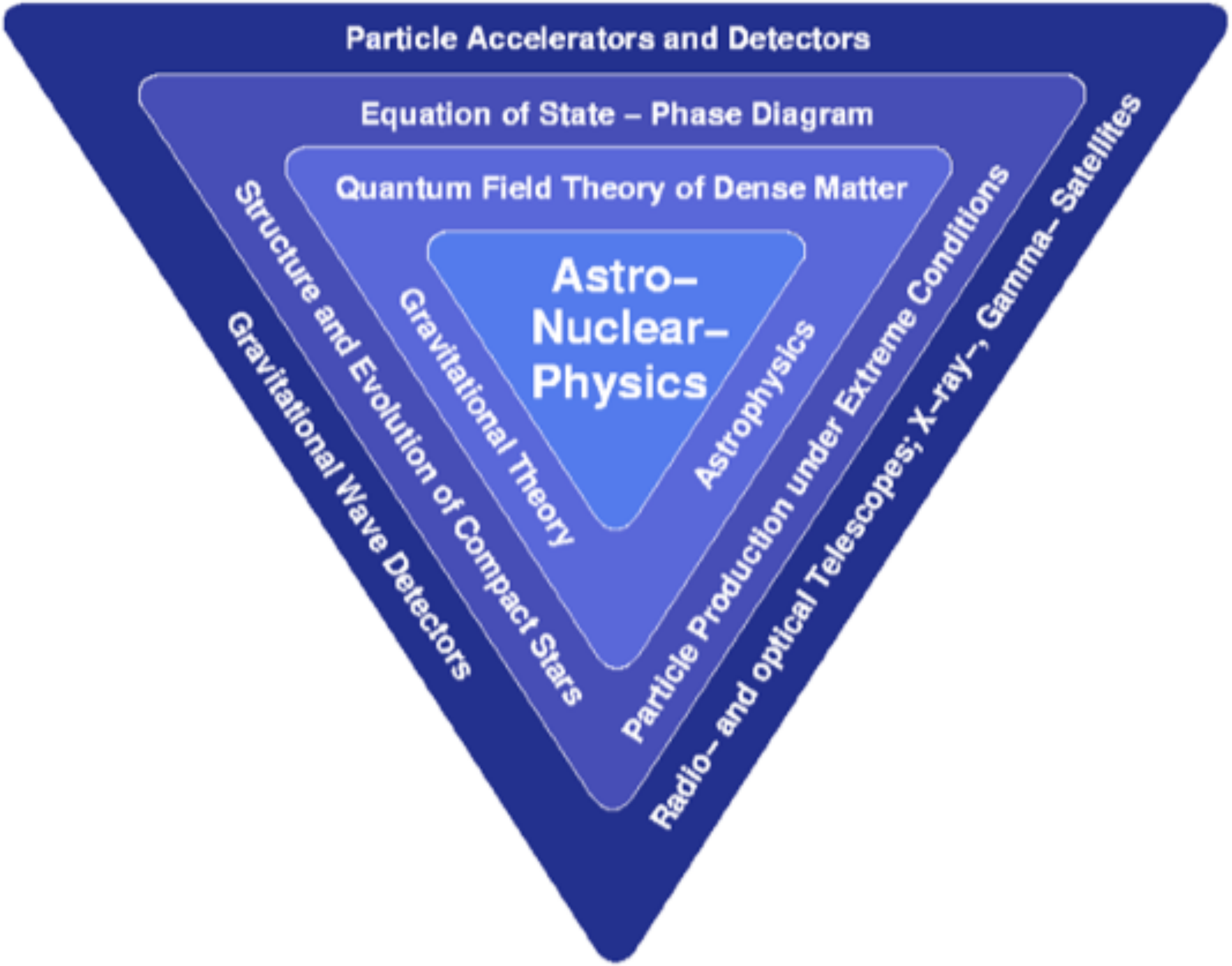
Phase Diagrams

Nuclear Matter

Nuclear Matter Phase Diagram

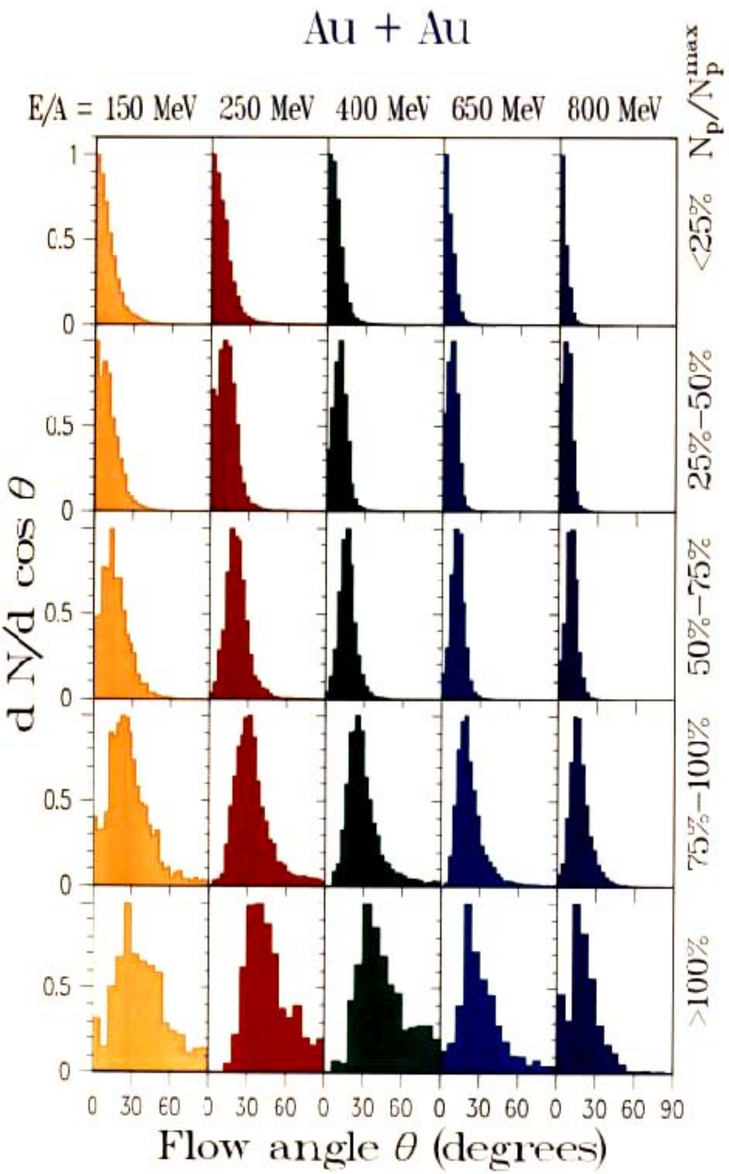


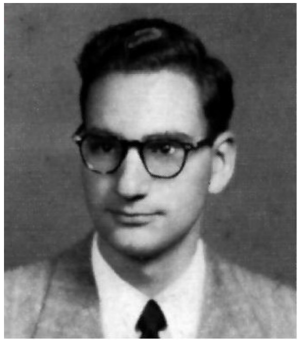
Intersection of other branches of physics

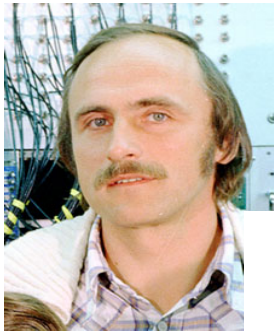


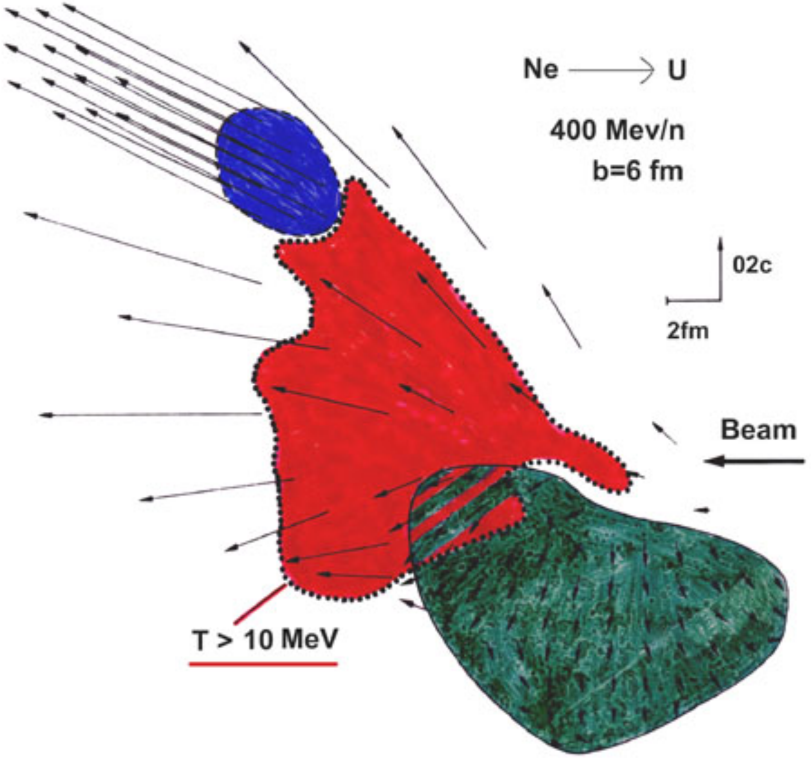
Discovery of Flow at the Bevalac

Plastic Ball and Streamer Chamber







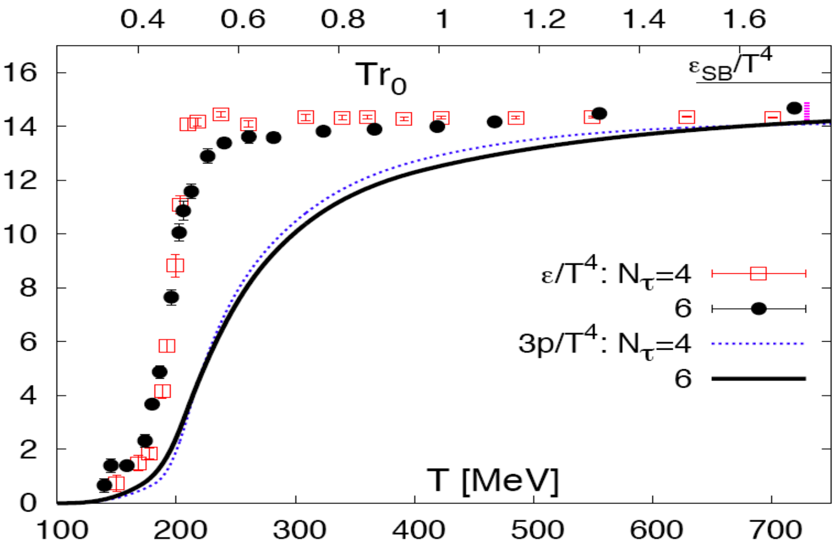


Lattice Gauge Theory and Deconfinement:

L is similar to a spin variable
=> Confinement-
Deconfinement transition

Polyakov 1978 Susskind 1979

$$e^{-\beta F_q} =< L >$$

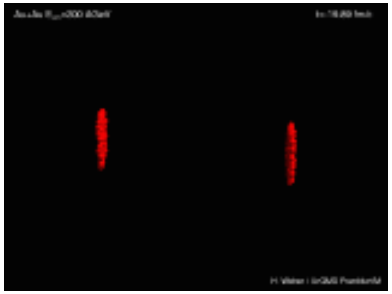


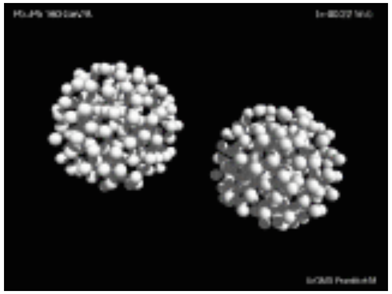
Wuppertal, Bielefeld,BNL, MILC, Mumbai …

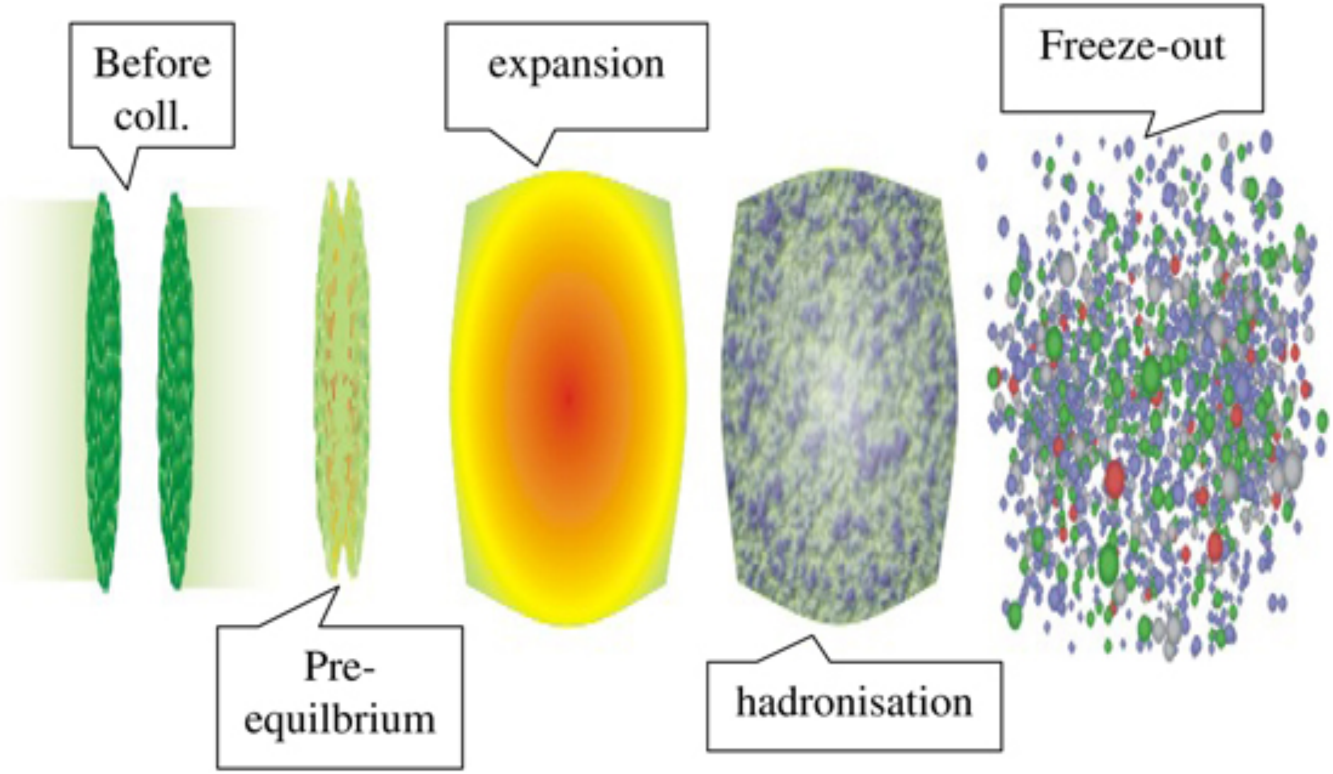
First lattice computations at finite T; Kuti, Polonyi and Szlachanyi; McLerran and Svetitsky

Beginning of Bielefeld lattice gauge theory effort: Engels, Gavai, Karsch, Montvay and Satz

Relativistic Dynamics in Heavy Ion Collisions







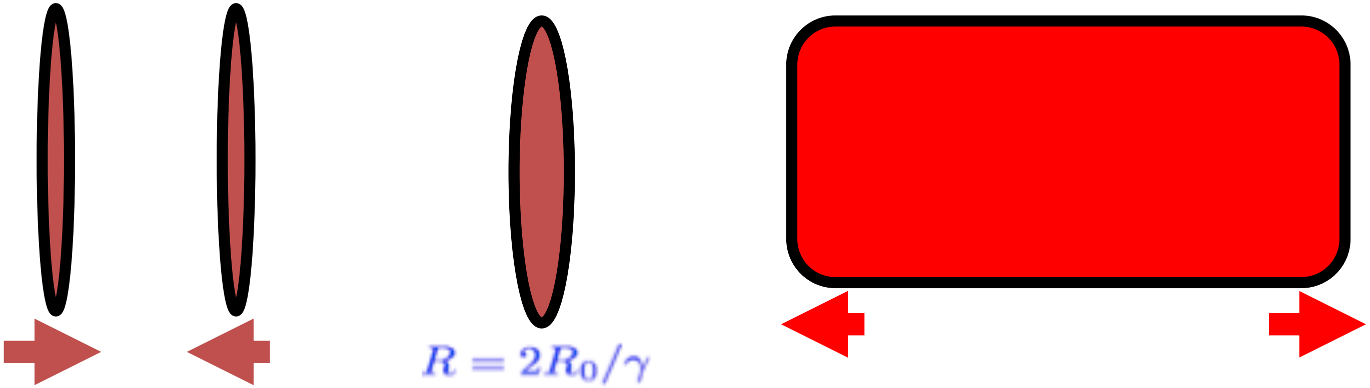
Space-Time Picture:

Early work on
energy densities:

Shuryak 1974

Ansiehtty et. al.
1980

$$\epsilon = \frac{1}{2}\gamma^2\rho_0$$



$$\tau = \sqrt{t^2 - z^2}$$

$$R = 2R_0/\gamma$$

$$E = \gamma M_N V_0 \rho_0$$

Landau Hydrodynamics

$$\eta = \frac{1}{2} ln \left(\frac{t+z}{t-z} \right)$$

Colliding
Nuclei

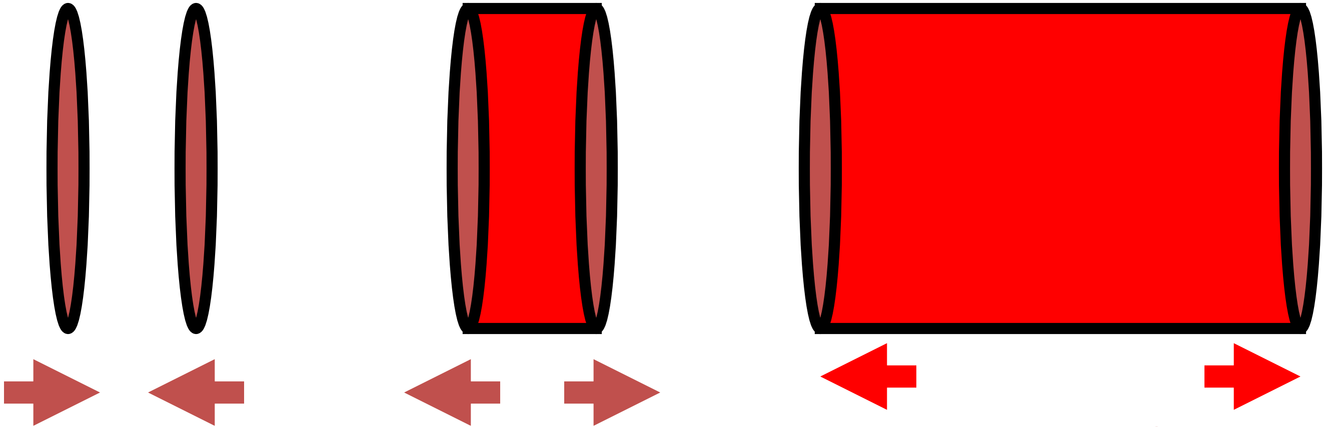
Collision

Expanding Fireball

Landau

Feynman

Bjorken



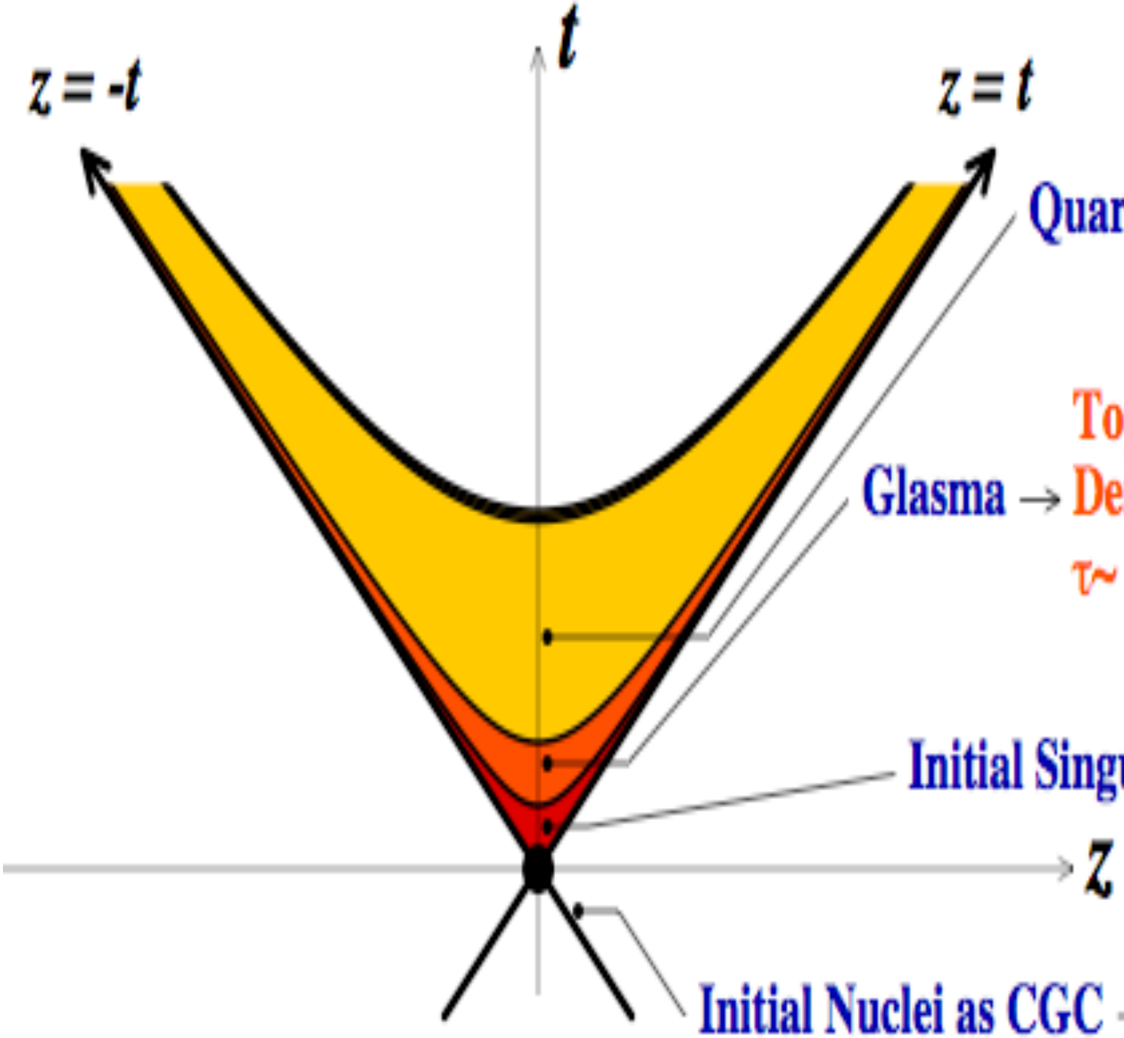
Longitudinal flow

Bjorken Hydrodynamics

$$\epsilon_0 = \frac{1}{\pi R^2 \tau_0} \frac{dE_T}{dy}$$

$$y = \eta$$

Space-time Descriptions:

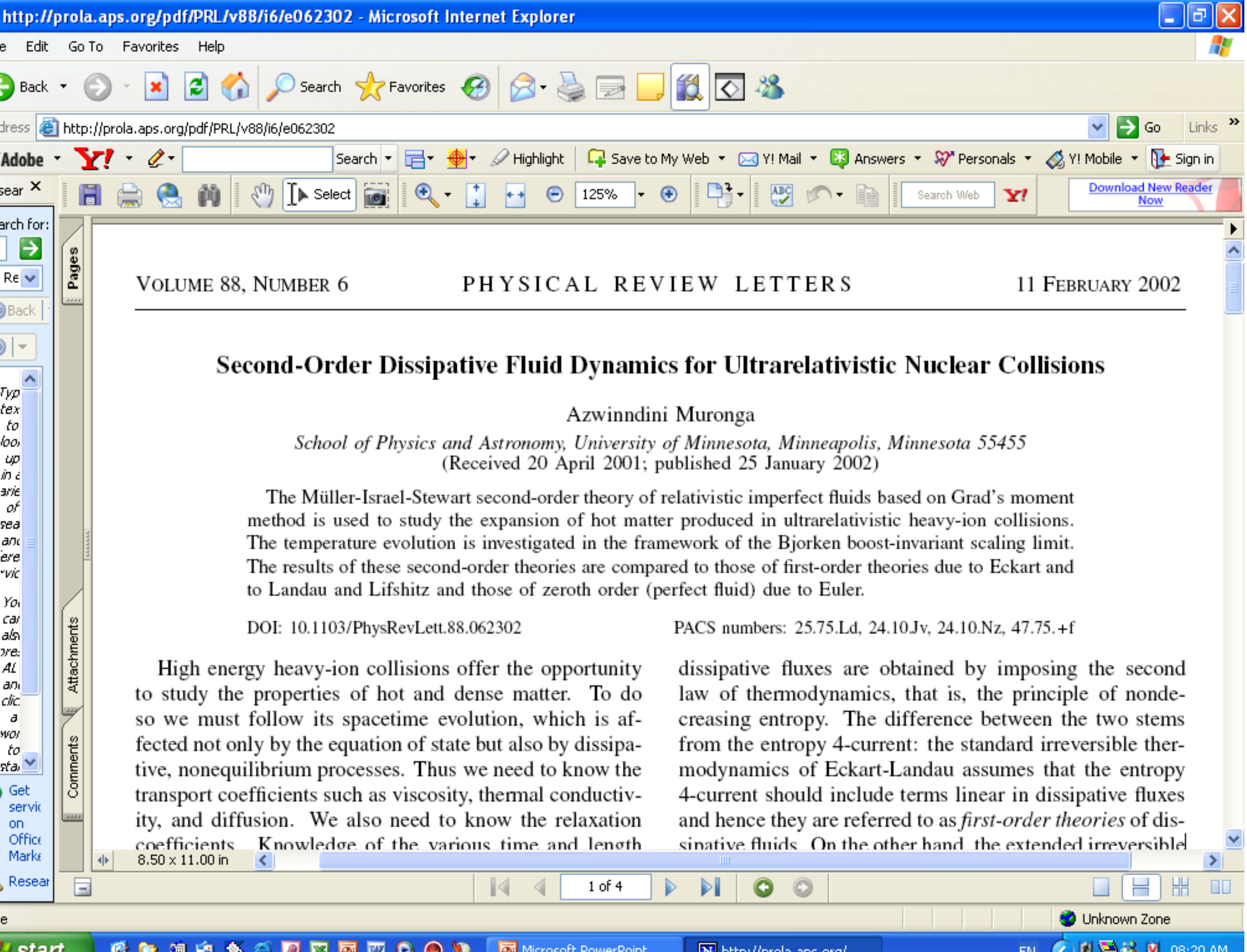


Quark Gluon Plasma → Perfect Fluid
Hadronization
τ~ 1 - 10 fm/c

Glasma → Topological Excitations
Density Fluctuations, Thermalization
τ~ 0.1 - 1 fm/c

Initial Singularity → Event Horizon
Quantum Fluctuations
τ~ 0 - 0.1 fm/c

Initial Nuclei as CGC → Coherent, High-density Gluons



VOLUME 88, NUMBER 6 PHYSICAL REVIEW LETTERS 11 FEBRUARY 2002

Second-Order Dissipative Fluid Dynamics for Ultrarelativistic Nuclear Collisions

Azwinndini Muronga

School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455

(Received 20 April 2001; published 25 January 2002)

The Müller-Israel-Stewart second-order theory of relativistic imperfect fluids based on Grad's moment method is used to study the expansion of hot matter produced in ultrarelativistic heavy-ion collisions. The temperature evolution is investigated in the framework of the Bjorken boost-invariant scaling limit. The results of these second-order theories are compared to those of first-order theories due to Eckart and to Landau and Lifshitz and those of zeroth order (perfect fluid) due to Euler.

DOI: 10.1103/PhysRevLett.88.062302 PACS numbers: 25.75.Ld, 24.10.Jv, 24.10.Nz, 47.75.+f

High energy heavy-ion collisions offer the opportunity to study the properties of hot and dense matter. To do so we must follow its spacetime evolution, which is affected not only by the equation of state but also by dissipative, nonequilibrium processes. Thus we need to know the transport coefficients such as viscosity, thermal conductivity, and diffusion. We also need to know the relaxation coefficients. Knowledge of the various time and length

dissipative fluxes are obtained by imposing the second law of thermodynamics, that is, the principle of nondecreasing entropy. The difference between the two stems from the entropy 4-current: the standard irreversible thermodynamics of Eckart-Landau assumes that the entropy 4-current should include terms linear in dissipative fluxes and hence they are referred to as *first-order theories* of dissipative fluids. On the other hand, the extended irreversible