The nuclear liquid gas phase transition

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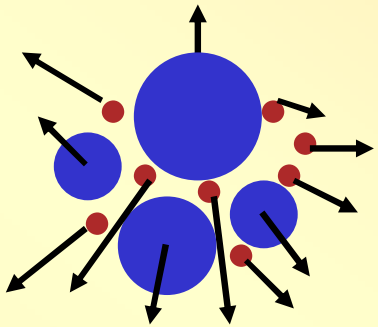
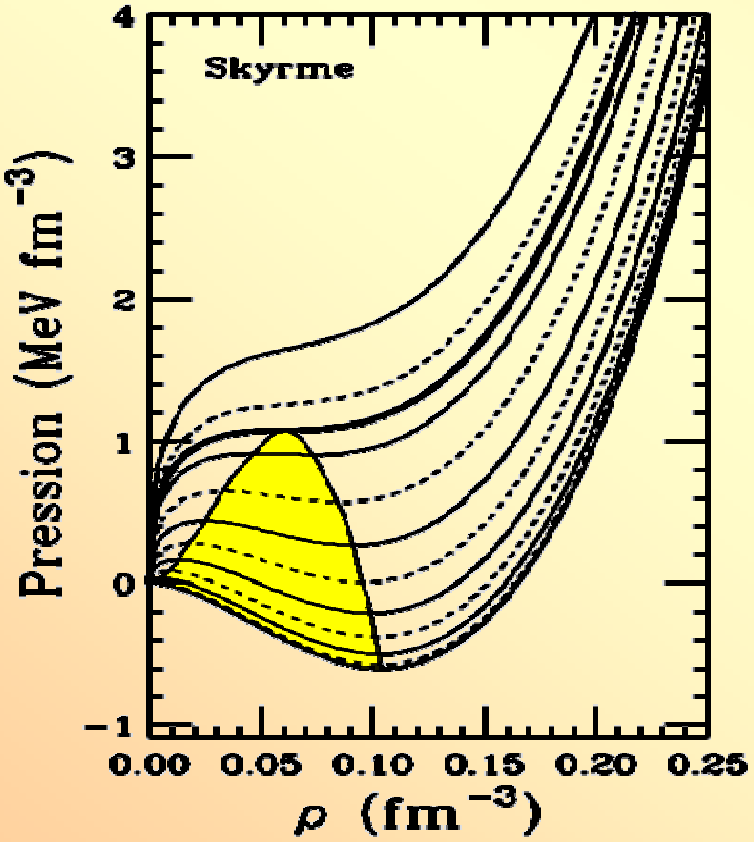
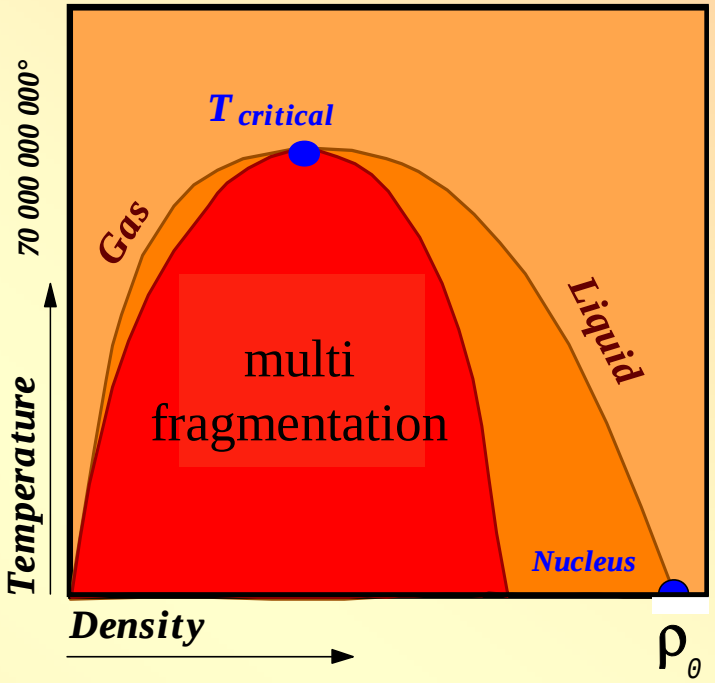
- **The status of the art**
- **The isospin degree of freedom**
  - **the properties of the EOS**
  - **the observables of the transition**
- **Conclusions**



Boiling nuclei

P.J.Siemens Nature 1983



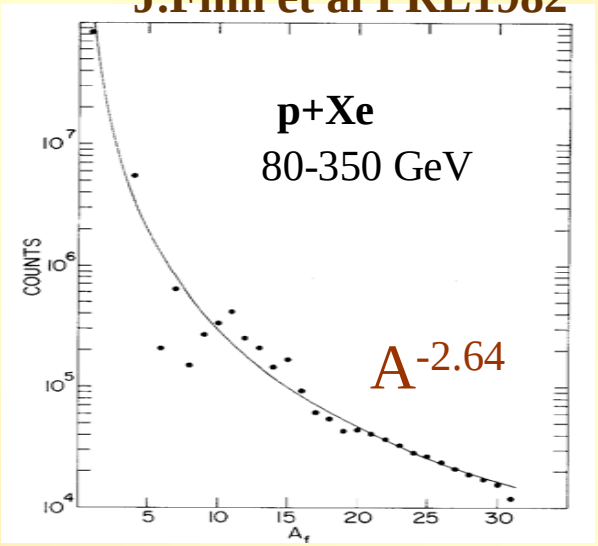


Motivations:

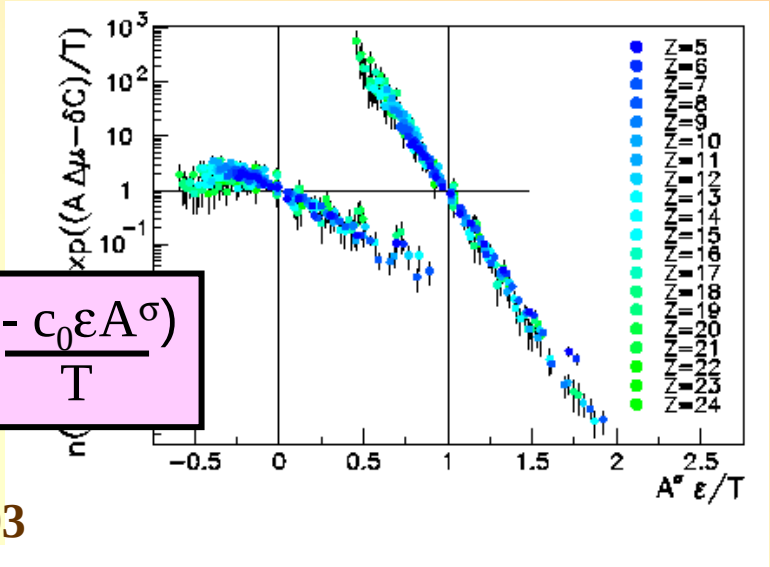
- *nuclear thermometry*
- *dense matter and stars*
- *interdisciplinary connections*

Self similarity and scalings

J.Finn et al PRL1982



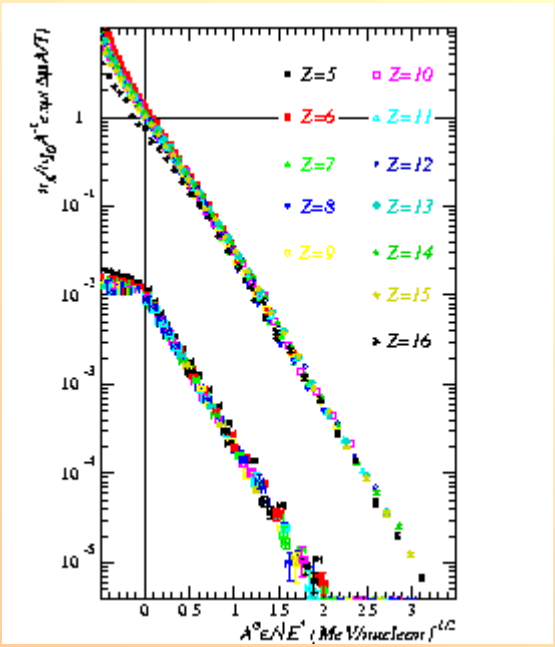
Multics PRC2003



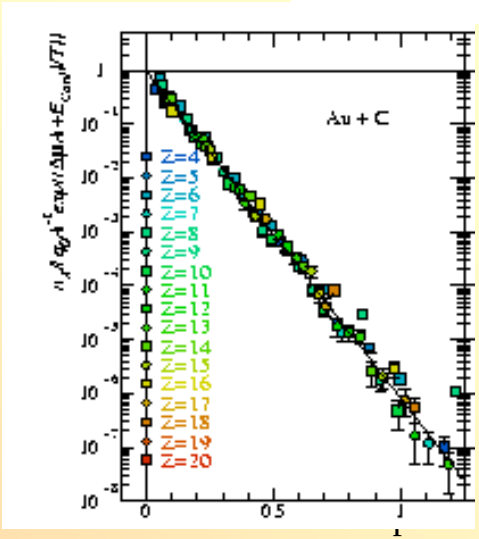
Fisher 1967

$$n_A = q_0 A^{-\tau} \exp\left(-\frac{c_0 \varepsilon A^{\sigma}}{T}\right)$$

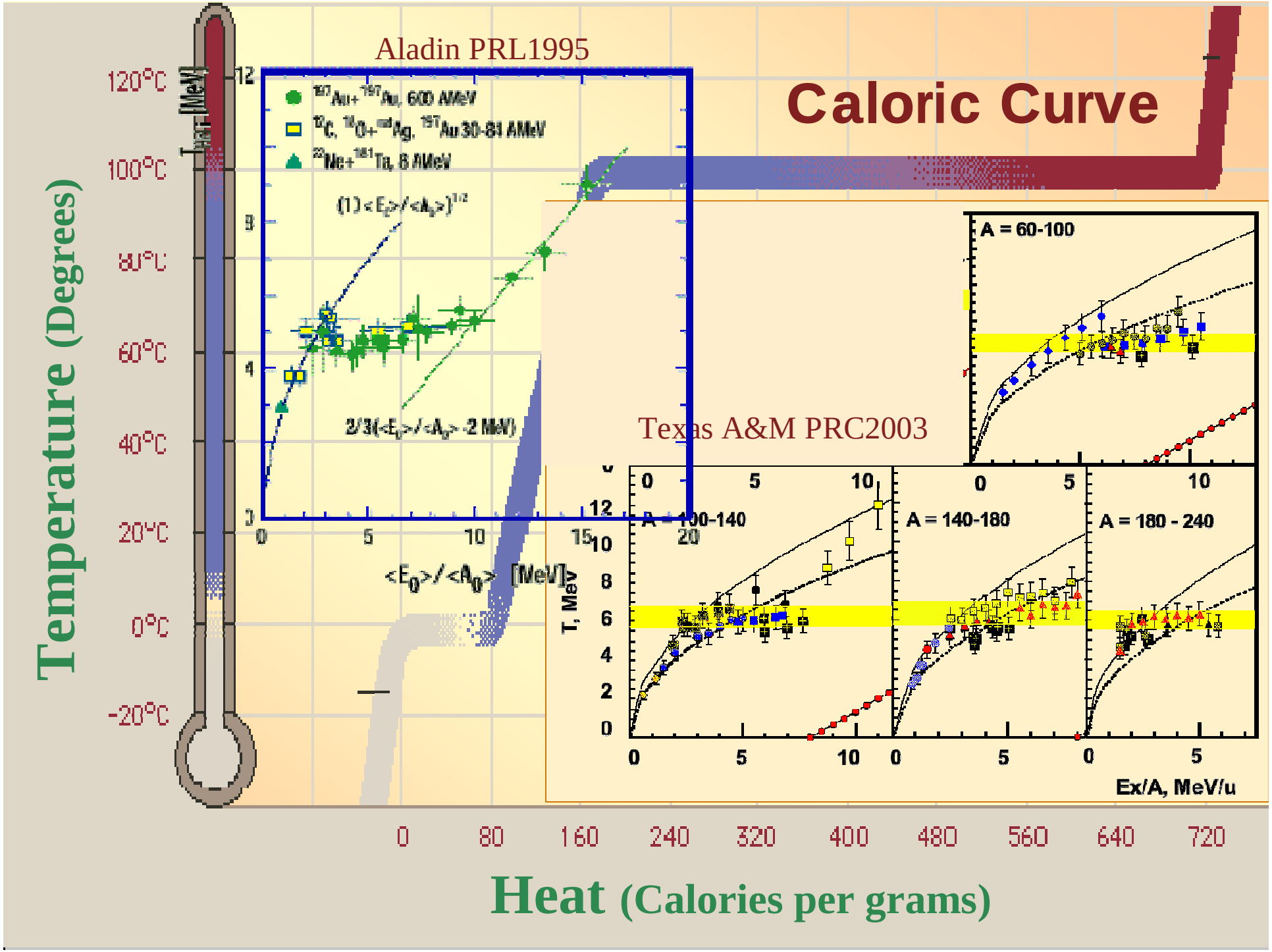
IsIs PRL2002



EoS PRC2003

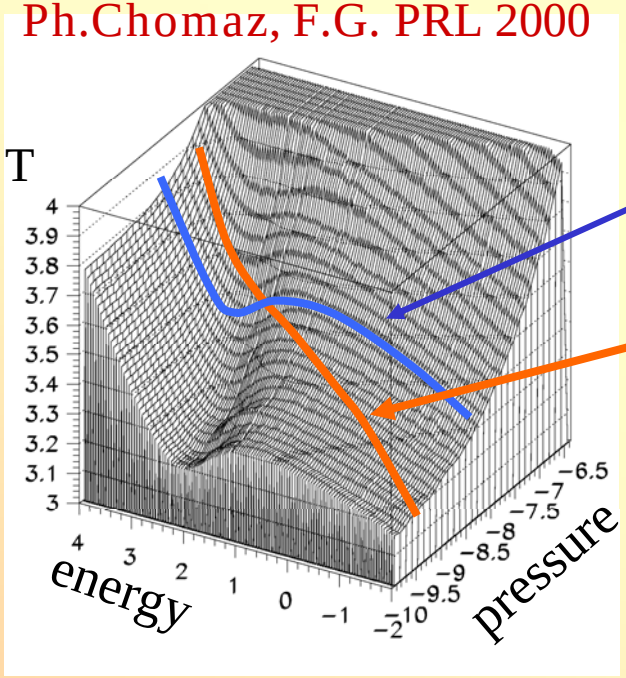


	Au	Liquid-Gas
τ	2.2±0.1	2.196 ±0.024
σ	0.71±0.02	0.647 ±0.006
γ	1.12±0.05	1.24 ±0.01
β	0.3 ±0.1	0.305 ±0.005


Caloric Curve
Aladin PRL1995
Texas A&M PRC2003
Temperature (Degrees)
Heat (Calories per grams)
120°C
100°C
80°C
60°C
40°C
20°C
0°C
-20°C
0
80
160
240
320
400
480
560
640
720
T, MeV
A = 60-100
A = 100-140
A = 140-180
A = 180 - 240
Ex/A, MeV/u

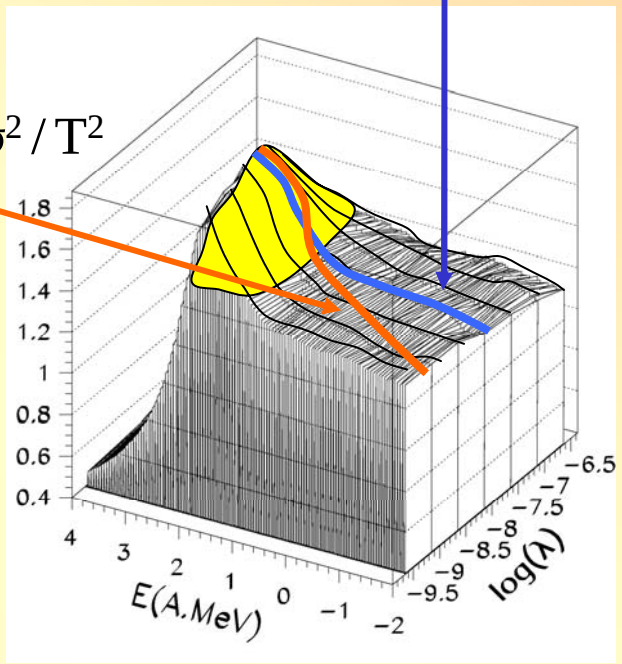
Abnormal fluctuations

Ph.Chomaz, F.G. PRL 2000



p = cte

V = cte

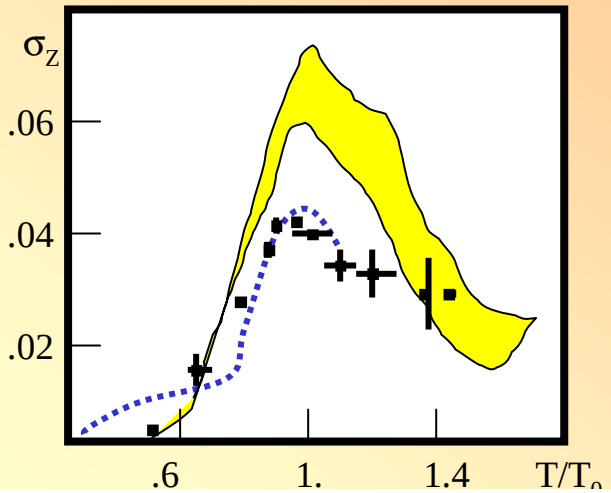


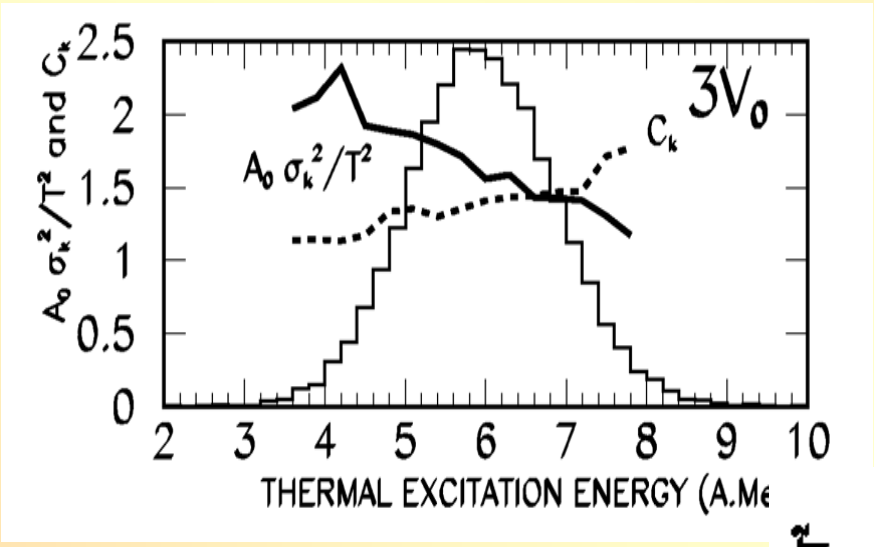
The caloric curve
depends on the transformation

Fluctuations are unique

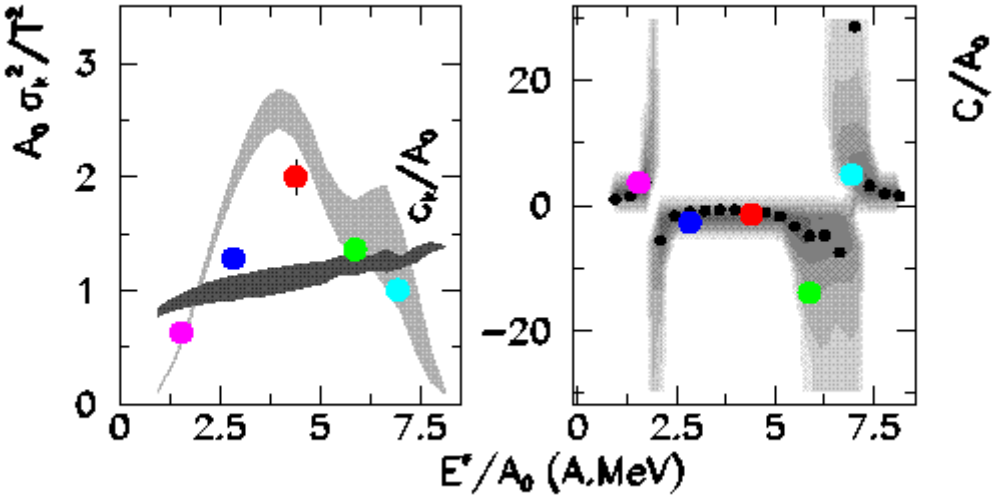
fluctuations and negative heat capacity

NIMROD PRC 2004



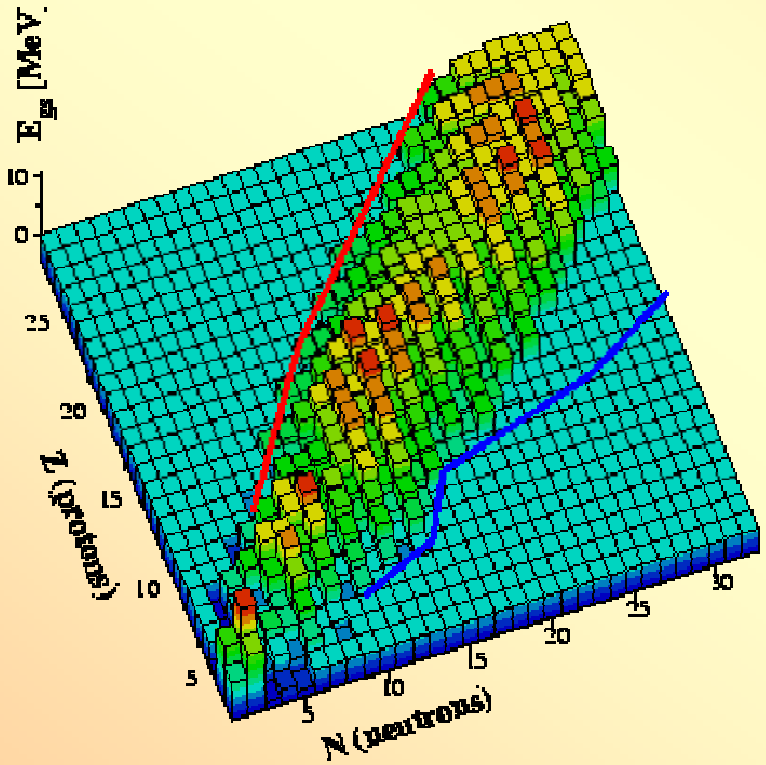


INDRA NPA 2002



Multics NPA 2003

The phase transition with exotic beams

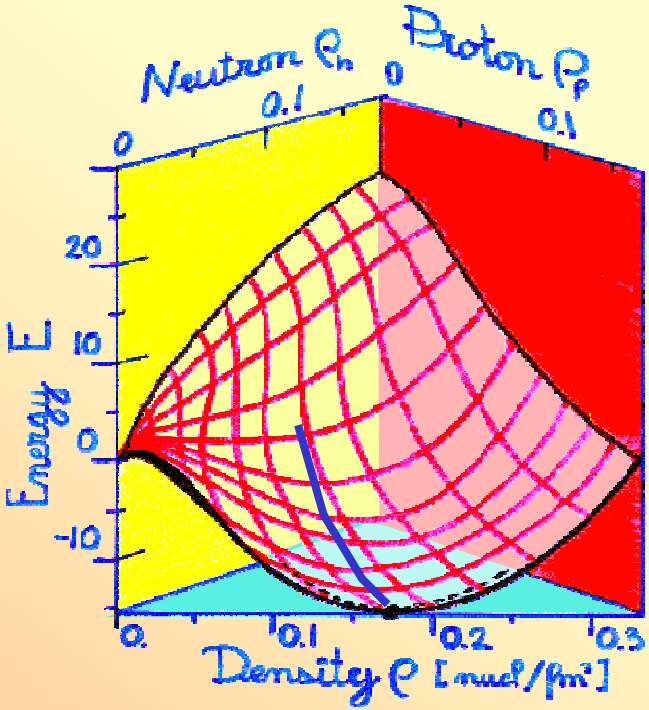


Changing

- the isospin content (N/Z)
- the Coulomb properties

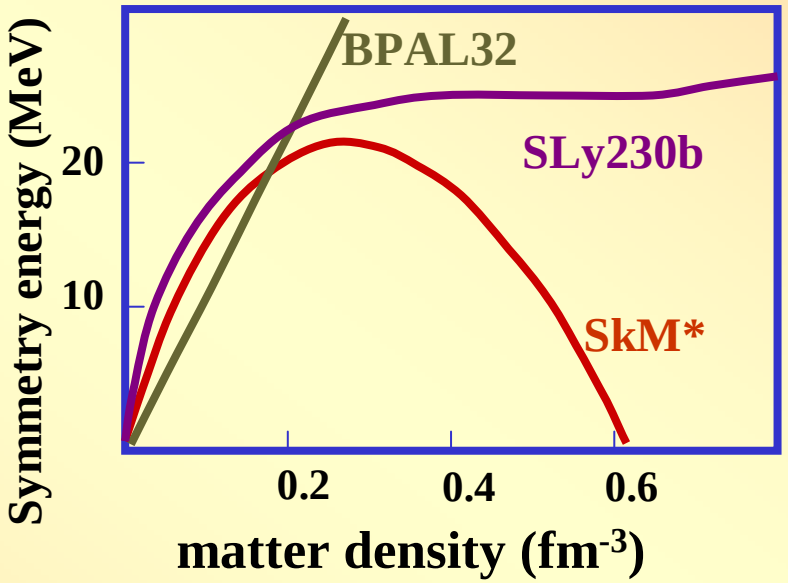
of the fragmenting source: an extra dimension

Equation of state at T=0: symmetry energy



Muller Serot PRC 1995

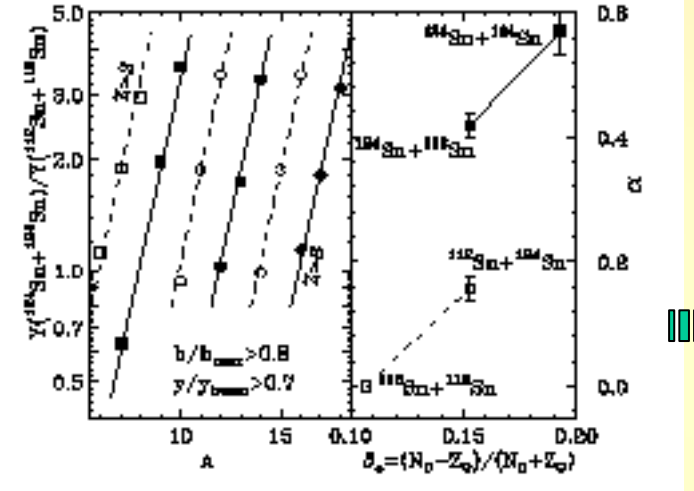
$$E=E_1(\rho) + E_{sym}(\rho)\,(\rho_n-\rho_p)^2/\rho^2$$



Theoretical uncertainty on the density dependence

symmetry energy and isospin diffusion

$^{112}_{124}Sn + ^{112}_{124}Sn$
50 A.MeV



LASSA-Miniball PRL 2004

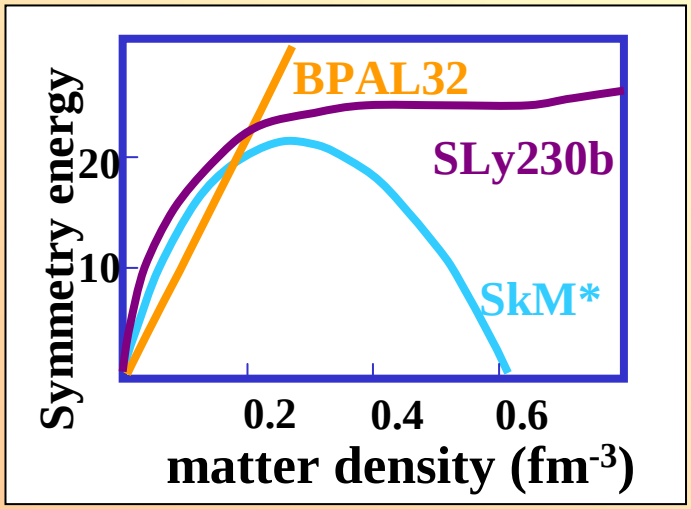
Better agreement with asy-stiff

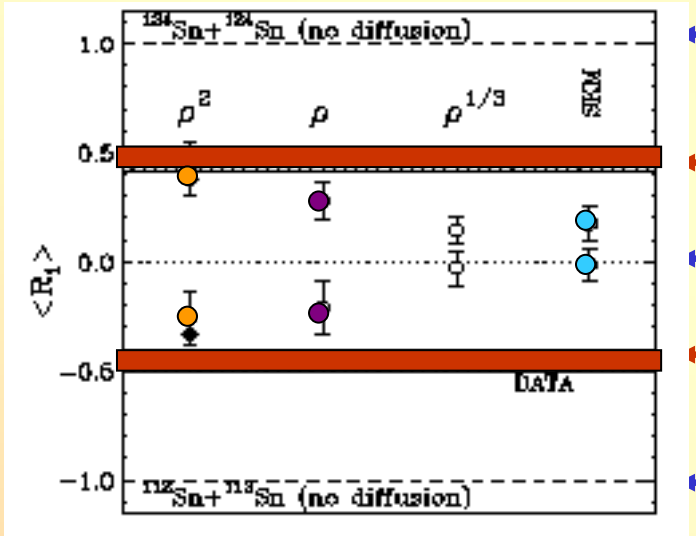
isospin transport ratio

$$R_i = \frac{2\alpha_i - \alpha_{124+124} - \alpha_{112+112}}{\alpha_{124+124} - \alpha_{112+112}}$$

scales:

correlations needed!





no diffusion

data

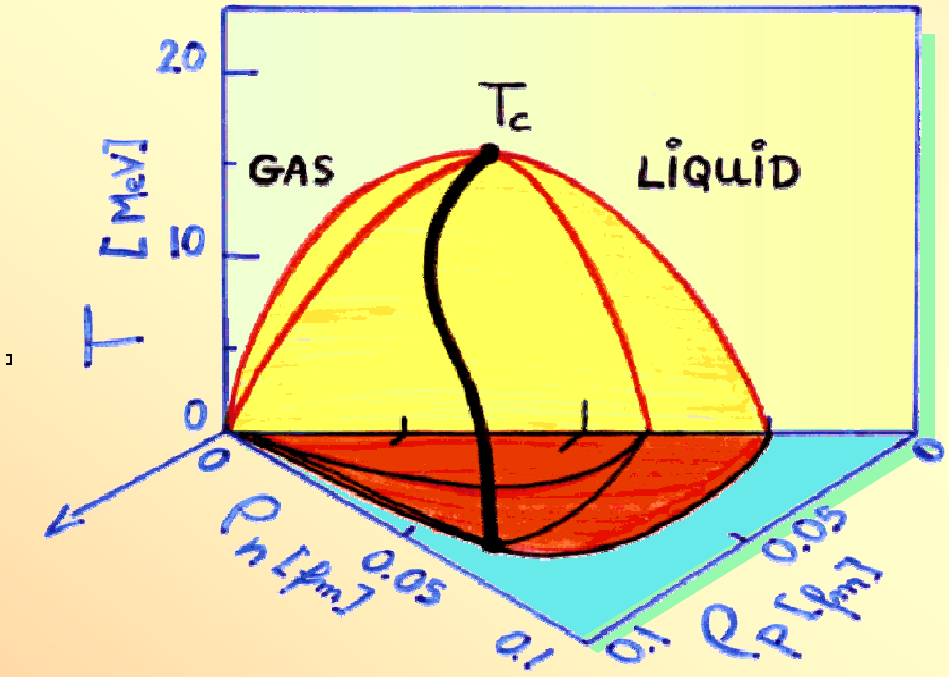
equilibration

data

no diffusion

Equation of state at T>0: phase transition

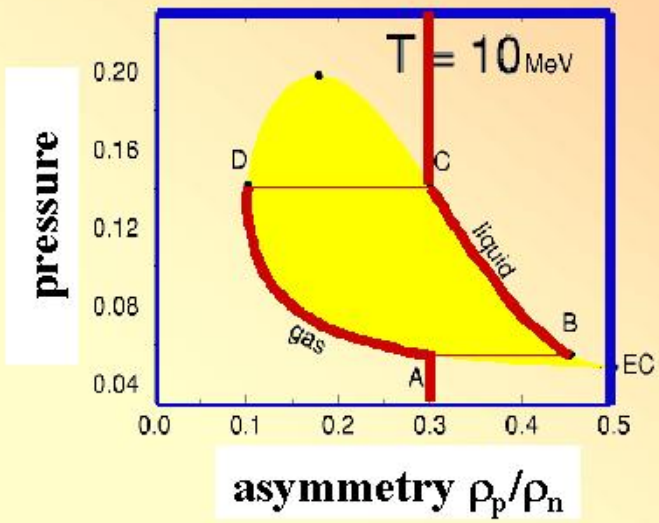
Muller Serot PRC 1995



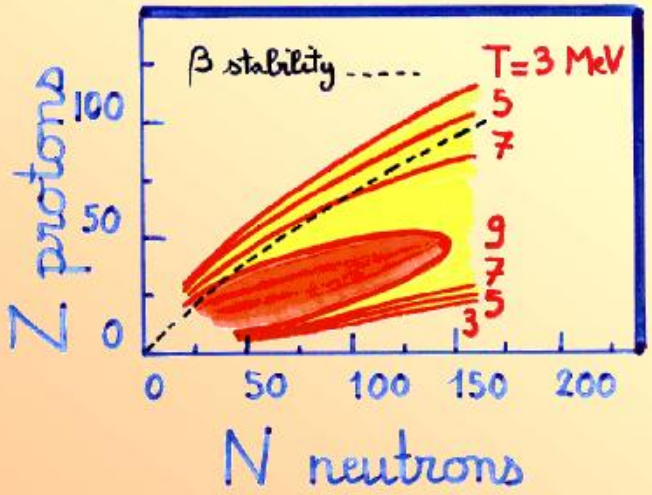
Phase transition: observables

A neutron rich gas:
isospin distillation

Muller Serot PRC 1995



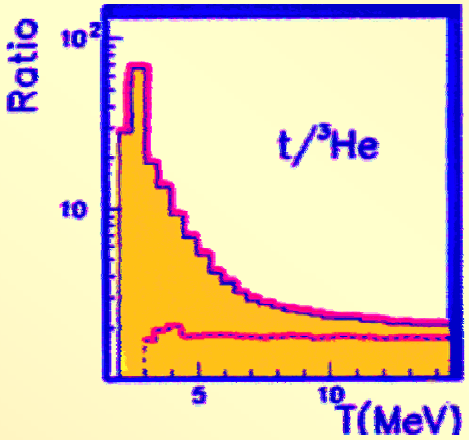
Bonche Vautherin NPA 1984



Proton rich nuclei:
vanishing limiting temperatures

Isospin distillation

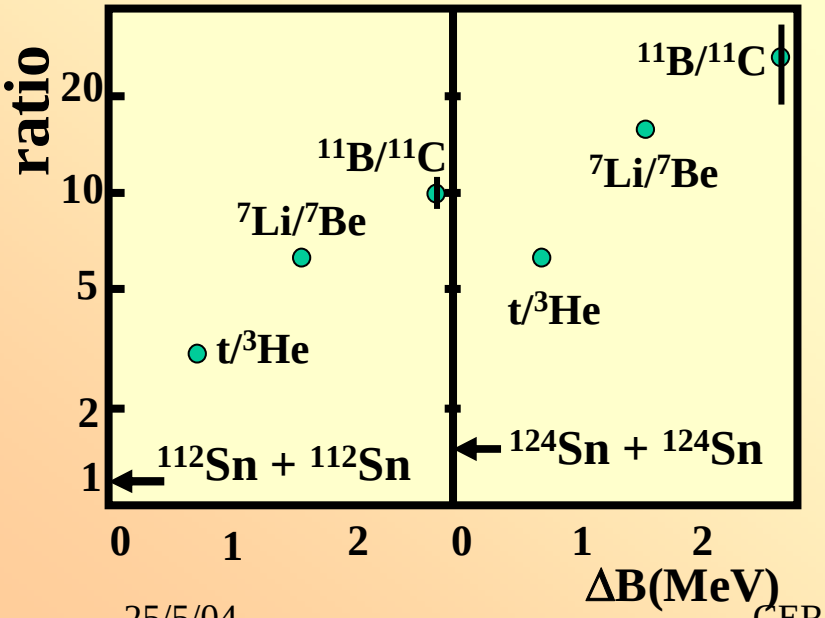
Lattice Gas Model



Ph.Chomaz, F.G. PLB 1999

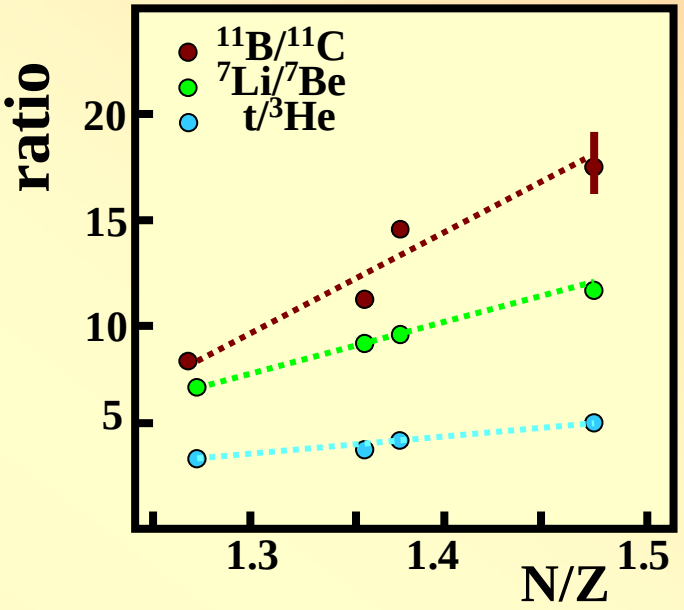
LASSA + Miniball PRL 2000

Sn+Sn 50 A.MeV



NIMROD PRC 2003

Sn+Sn 28 A.MeV



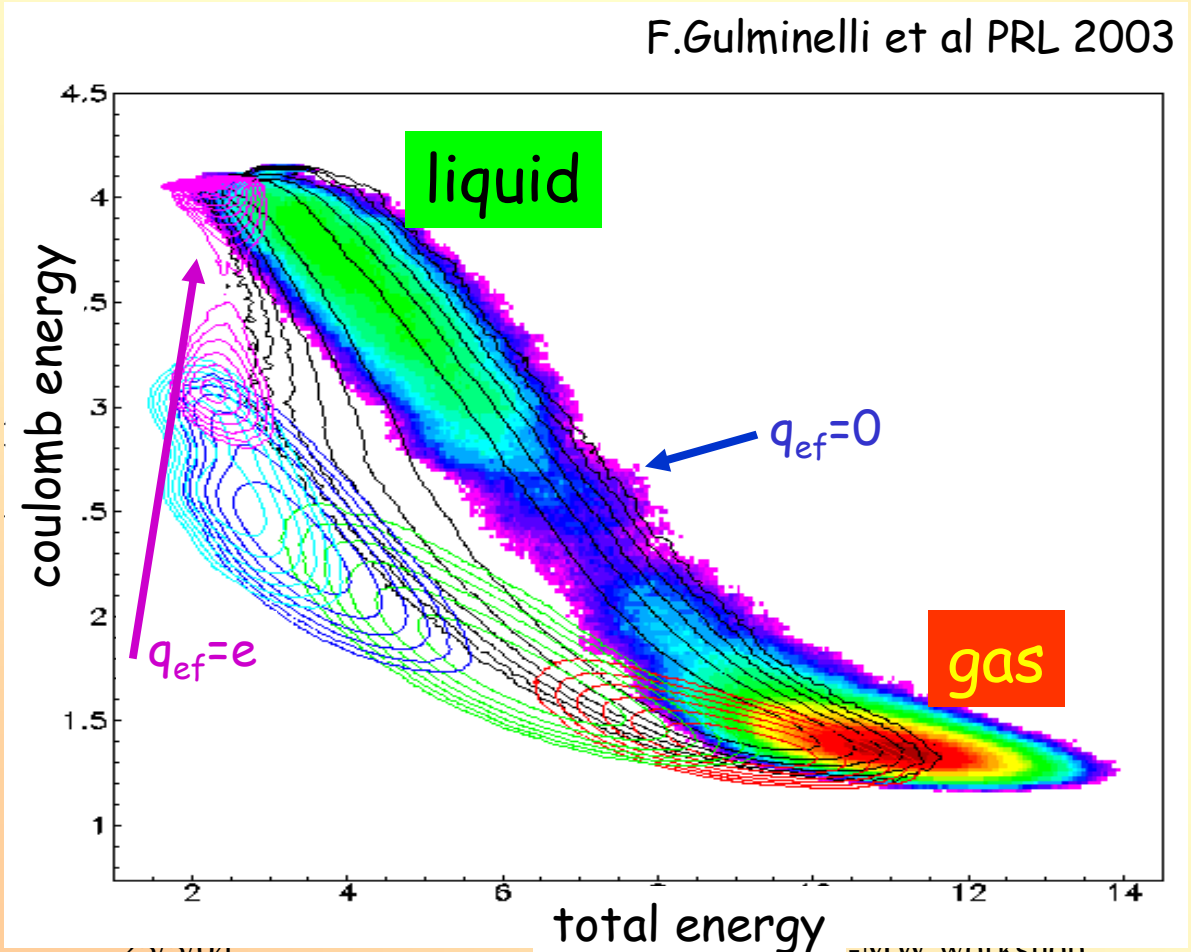
$\rho_n/\rho_p \approx 5.5$ for N/Z=1.48

but

thermodynamic characterization needed

Coulomb effects on the phase transition

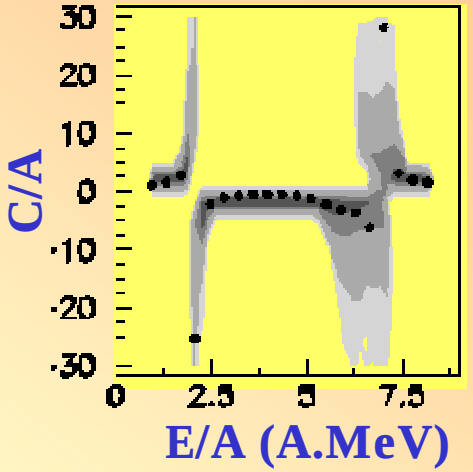
Statistical Multifragmentation Model



From nuclear matter to heavily charged nuclei, the first order phase transition is expected to become a cross over

conclusions

Multics NPA 2003



- **The physics of hot nuclei**
  - a unique laboratory for the thermodynamics of open, finite, off-equilibrium systems
  - a quantitative nuclear metrology

WCI 2004

world-wide review of the field of dynamics and thermodynamics with nucleonic degrees of freedom

http://cyclotron.tamu.edu/sjygroup/wci2004/

Multics	E_1=2±0.3	E_2=6.5±0.7
Isis	E_1=2.5	E_2=7.
Indra		E_2=6.±0.5

- **What do we need**
  - 4π mass and charge detection (AZ4π collaboration - FAZIA concept of the EURISOL report)
  - 20-50 A.MeV radioactive beams