Nuclear Science (Chemistry&Physics)

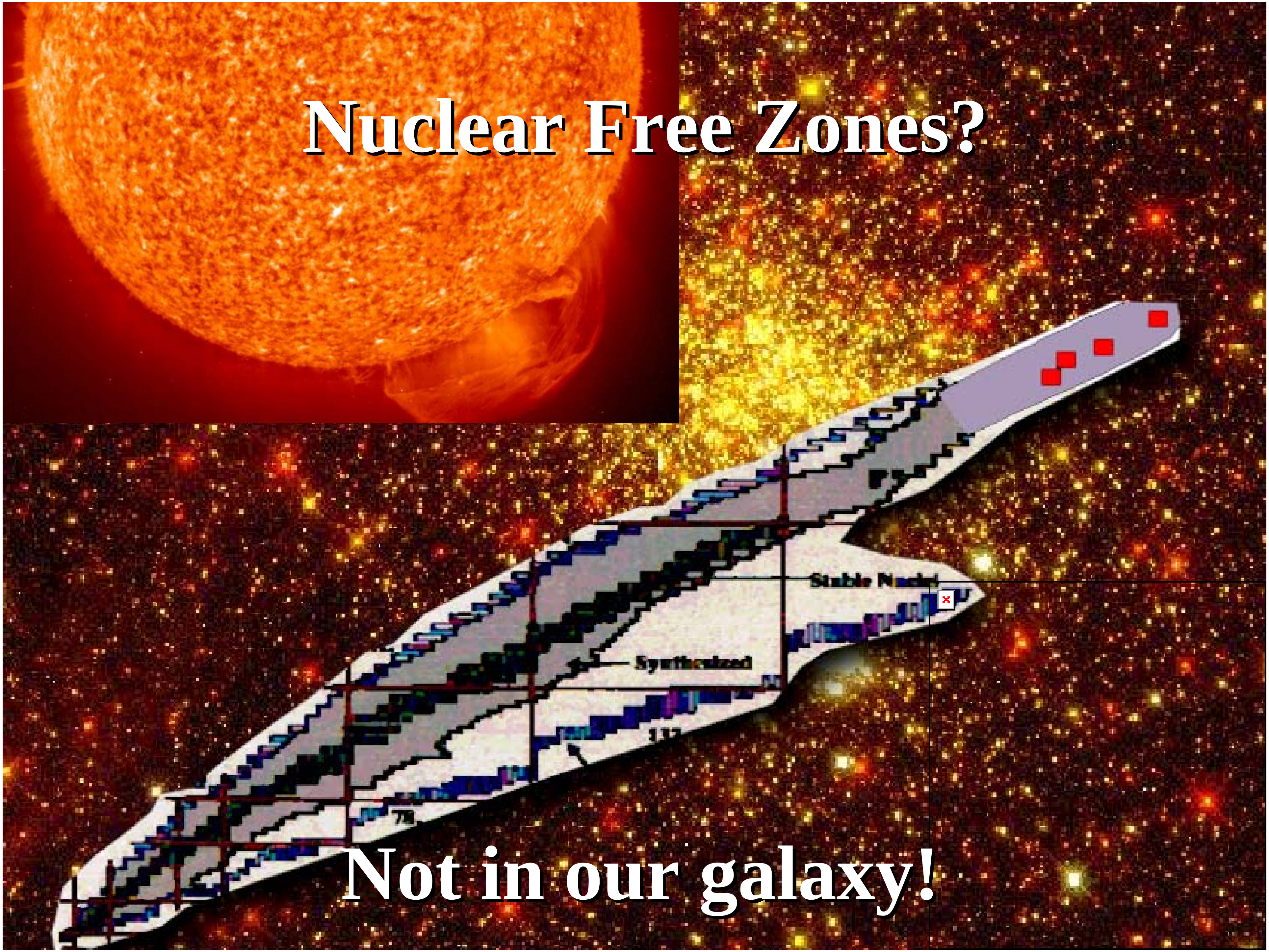
Objectives of Basic Science:

- **Structure and Interactions of Nuclear Matter (99.95%)**
- **Synthesis and Transformation of Elements**

Applications:

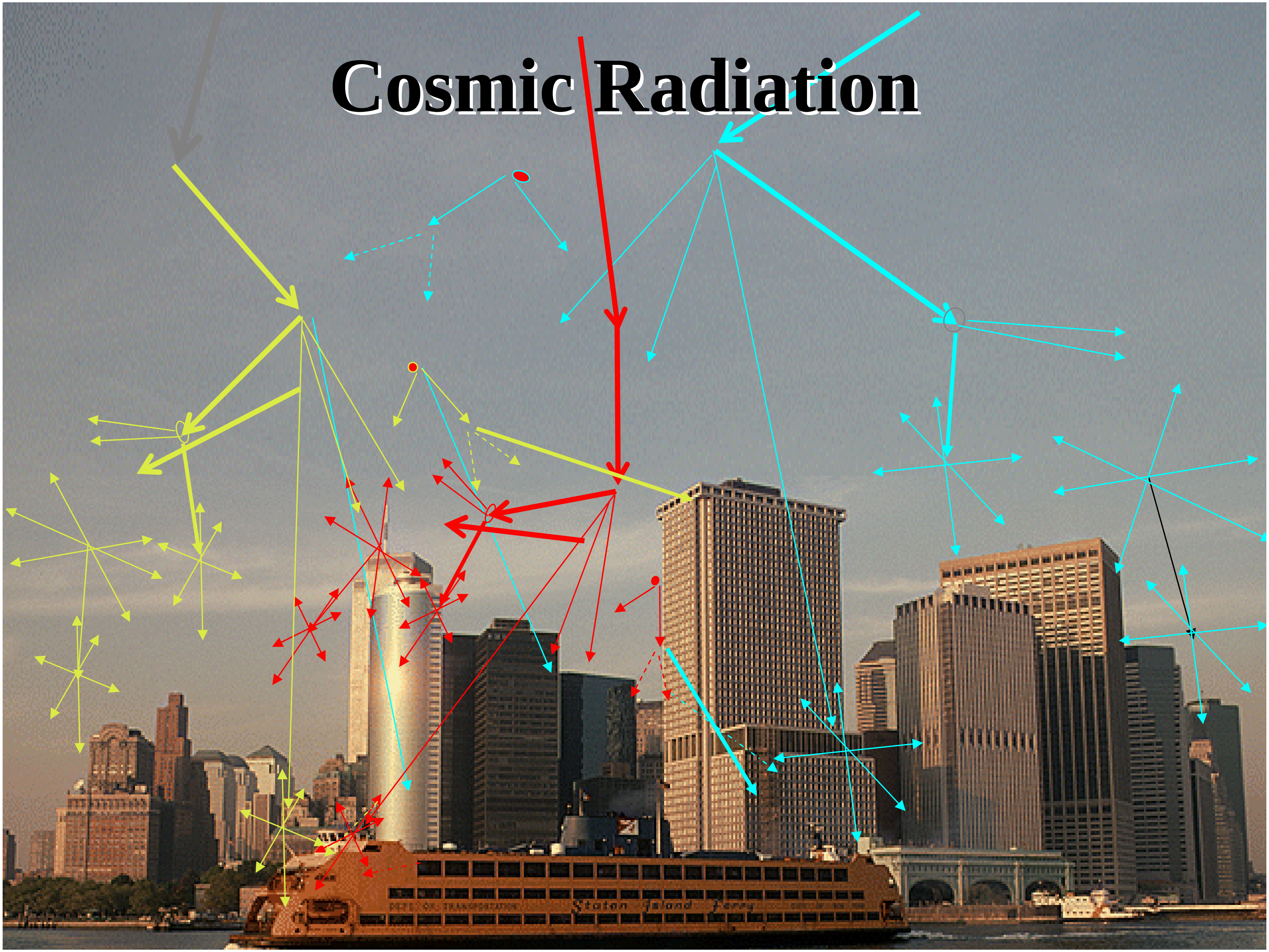
- **Environmental studies**
- **Earth and planetary science**
- **Life science (nuclear medicine)**
- **Material science**
- **Separation technology**
- **Hot-atom chemistry**
- **Cosmology (chemistry&physics)**
- **Nuclear power industry**

Nuclear Free Zones?



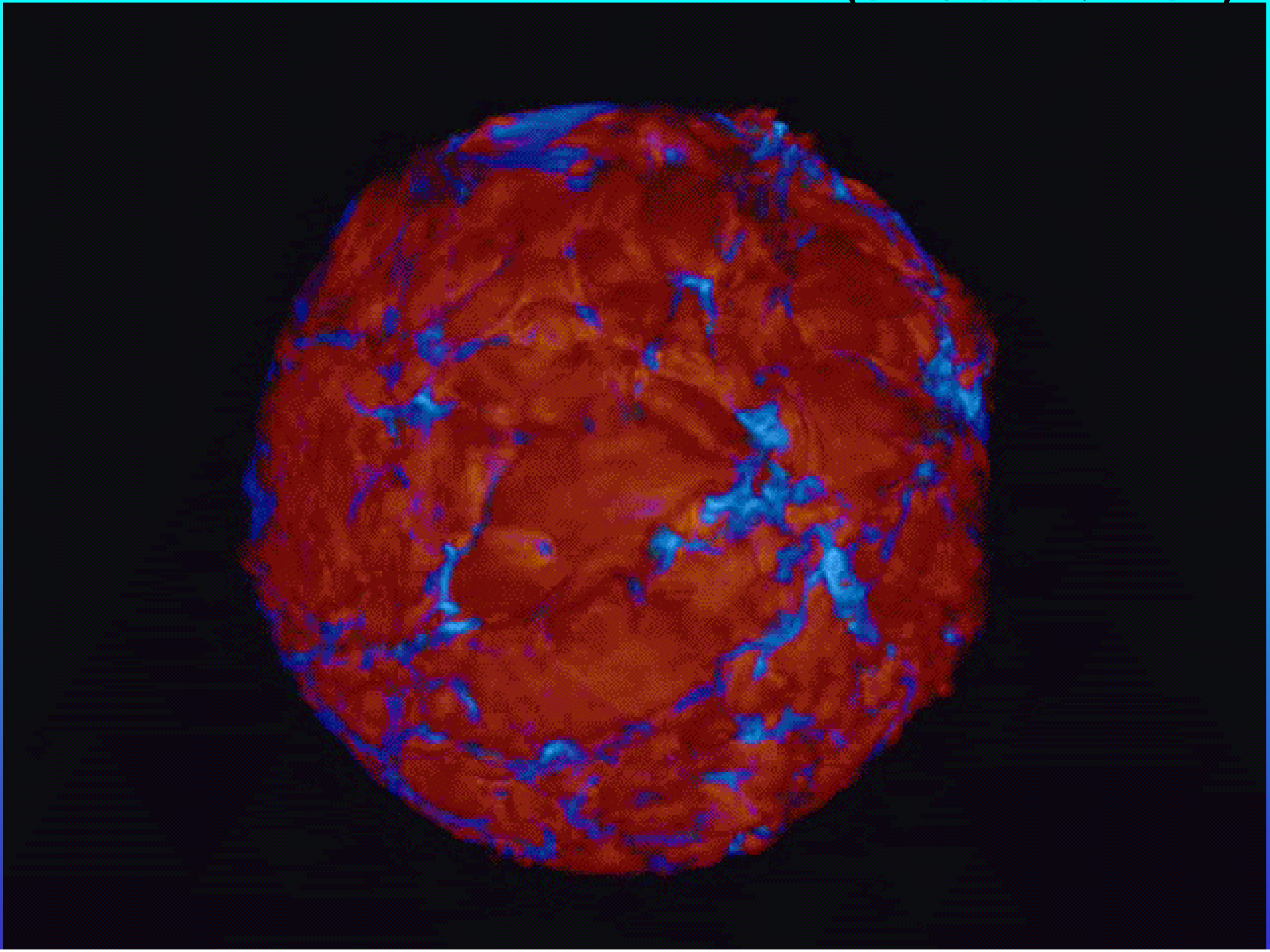
Not in our galaxy!

Cosmic Radiation

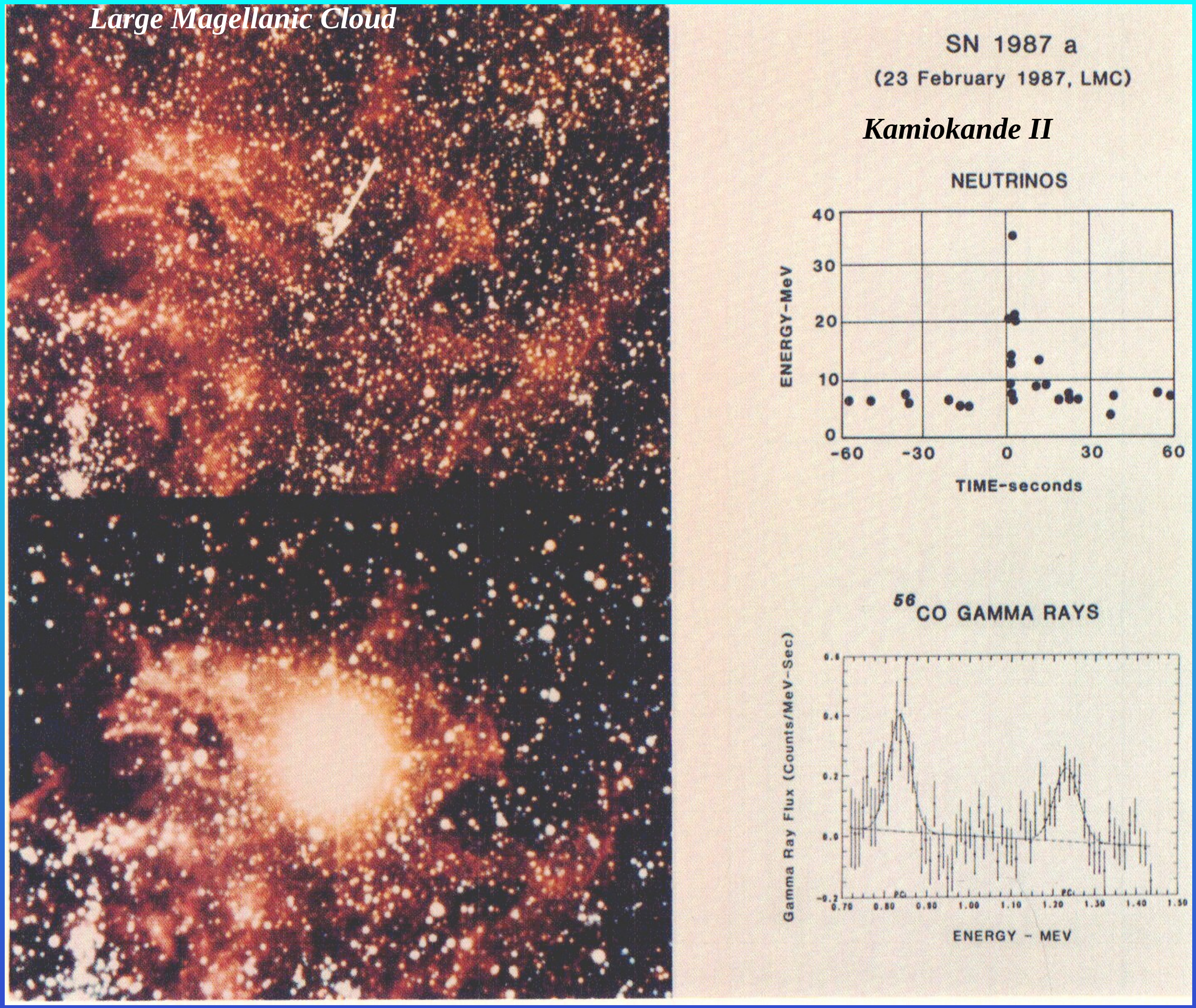


Collapse and Explosion of a Star

(Simulation:NASA)



Studying Nuclear Reactions in Supernova Explosions



Time-of-flight spectrum of neutrinos, measured relative to γ-rays.

0.85 MeV and 1.24 MeV γ-rays from ^{56}Co synthesized in the SN.

Nuclear Interactions

Task of nuclear theory and experiment:

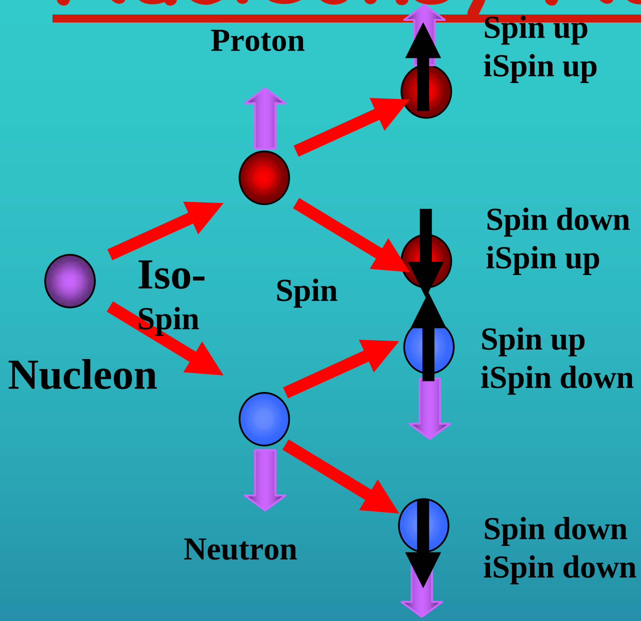
Explain

a) the internal structure of nuclei

b) the interactions of nuclei (collisions)

c) the abundance and origin of elements

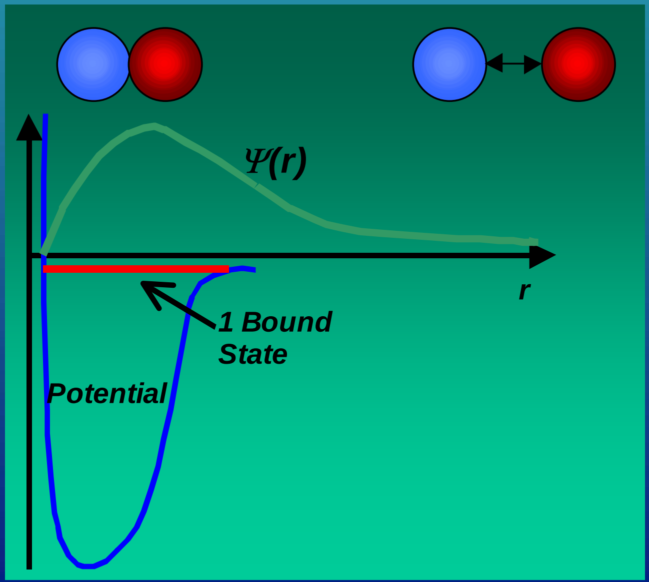
Nucleons, Nucleonic Interactions, Bonding



Nucleons:

p,n similar properties, interactions (exc. charge), = different "iso-spin" states of nucleon

p,n: magnetic moments, mechanical spins. Spin-Isospin statistics causes different effective nuclear interactions (nn,pp), np

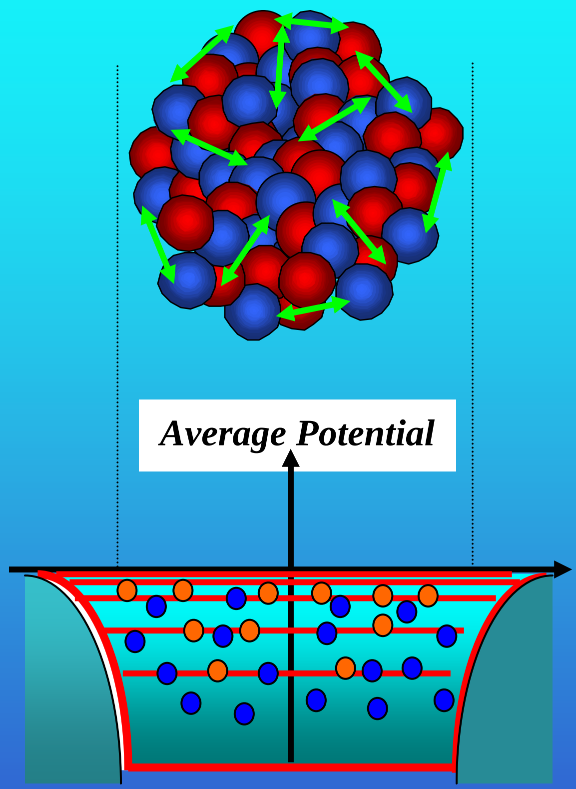


Approximate interaction:

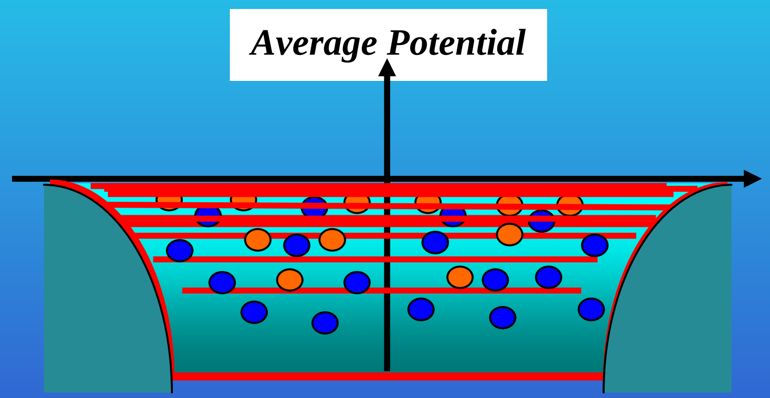
Potential depth = 50 MeV,
minimum at r ≈ 1 fm
Repulsive core ("Lennard-Jones")
The 2-nucleon system has <u>only one</u> (weakly) bound state,
E_B = 2.2 MeV

The Nuclear Shell Model

The nucleus is a "dense-pack" of A nucleons with surface tension
Volume $\approx A \cdot$ Volume of 1 Nucleon. Somewhat like water drops.

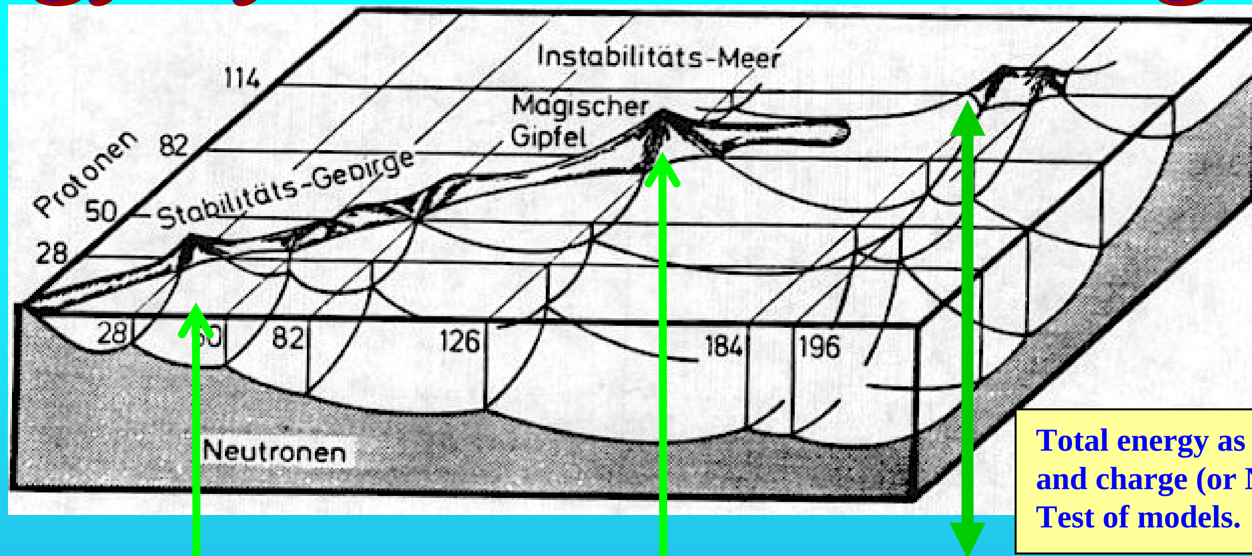


***Aufbau Principle*: Fill nucleonic shells successively to construct heavier nuclei.**
Closed shells - "Magic" nuclei
Stability problem: disruptive Coulomb repulsion of protons

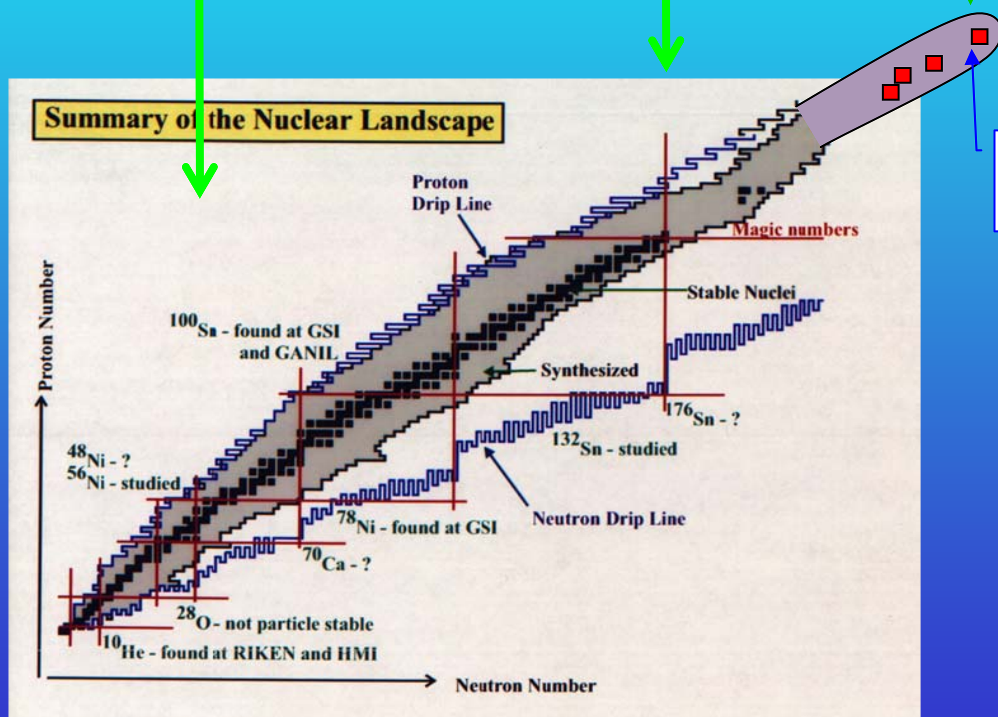


Mutual nucleonic interactions generate a mean field (potential), their own holding field. Neutrons and protons occupy discrete energy states of this potential: Nuclear Shell Model

Energy Systematics of Existing Nuclei



Total energy as function of mass and charge (or N and Z).
Test of models.



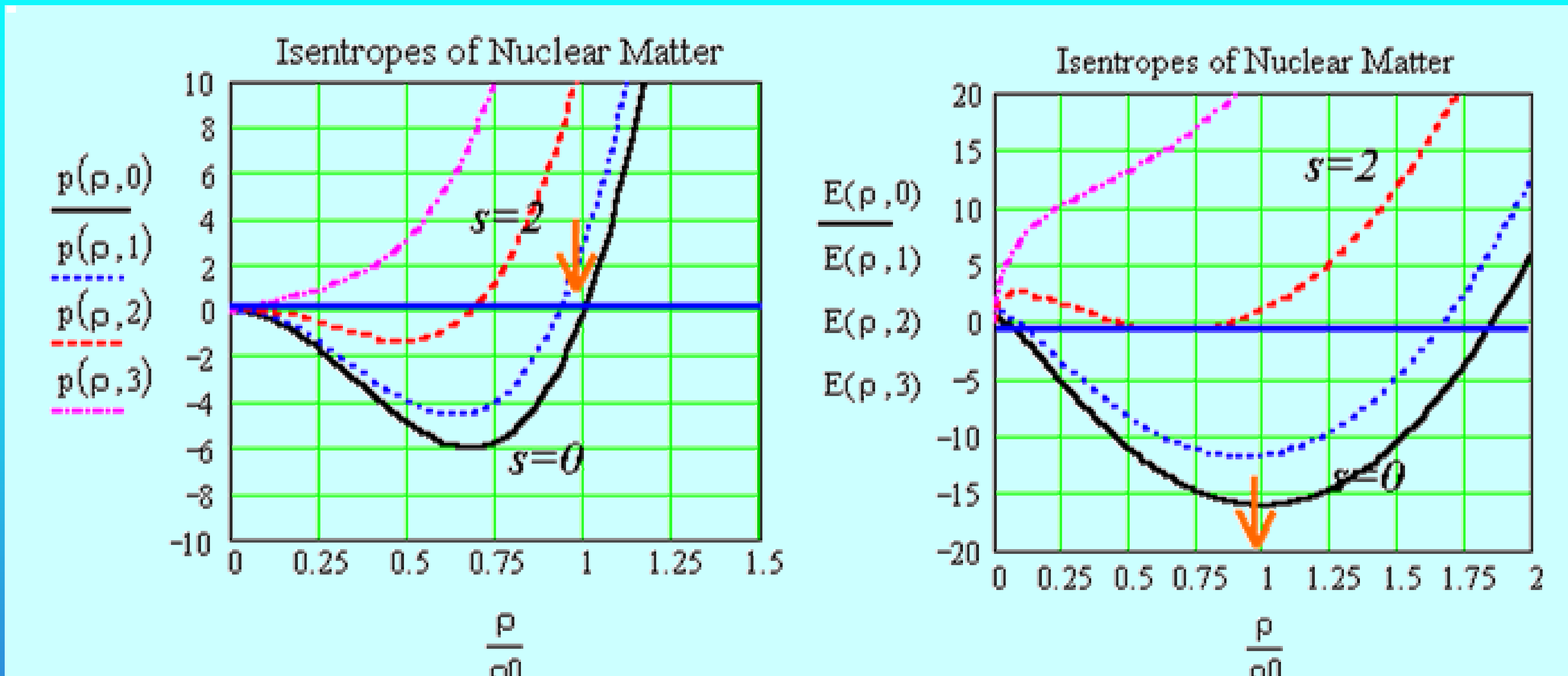
Z=114
GSI

Questions: Limits of stability of nuclear ground states.

a) Is there a SHE island of stability?

b)Where are the *n* and *p* "drip lines"?

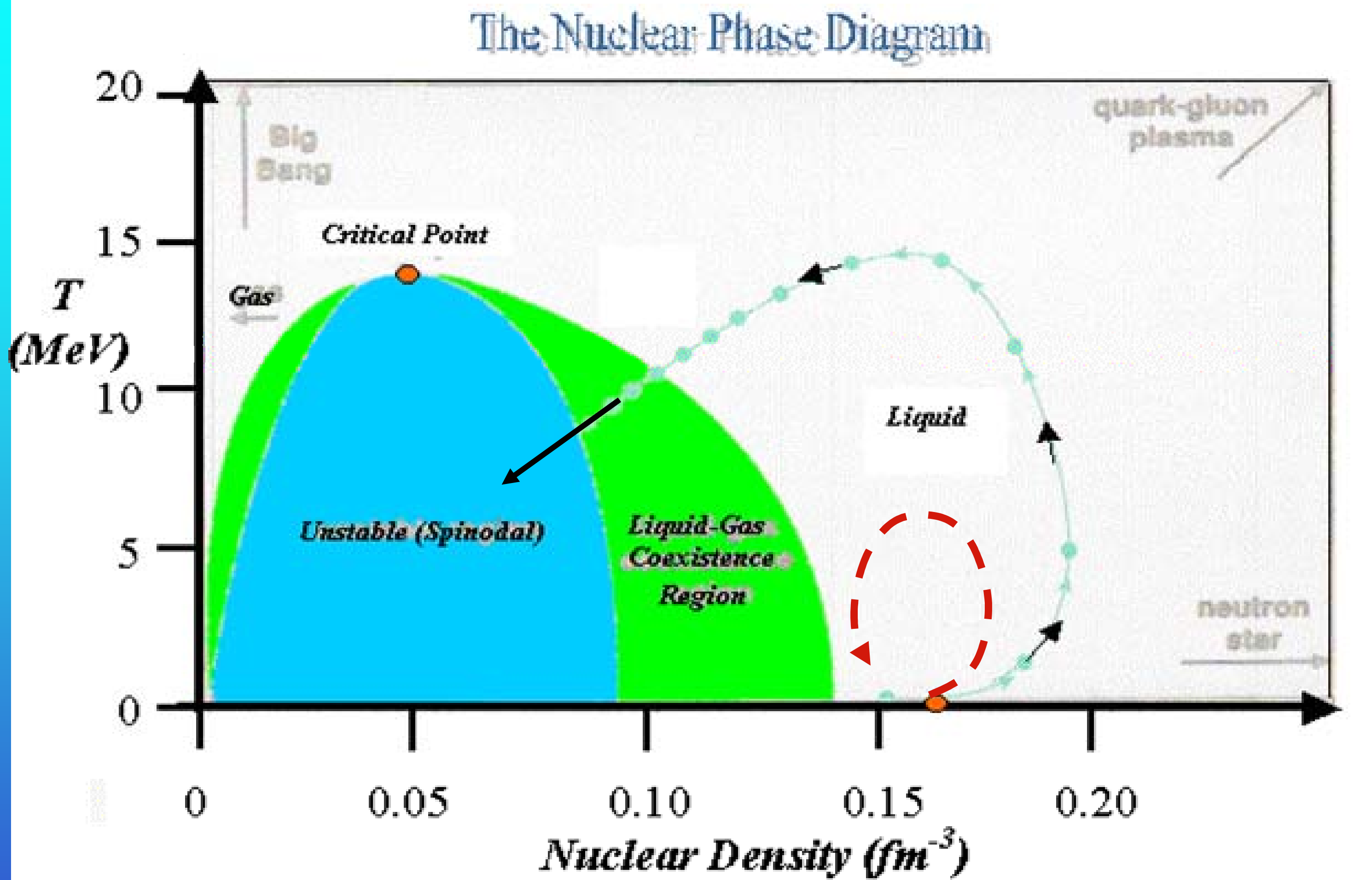
Bulk Properties: The Nuclear Equation of State



(after Bertsch & Siemens (*PL 126B,9*): Skyrme interaction)

This is one of several reasonable theoretical estimates. Needs experimental verification/falsification.

Consequences of the Nuclear EOS



Attempt to reach unstable (spinodal) region with nuclear reactions → *cluster decay*.

Nuclear Interactions

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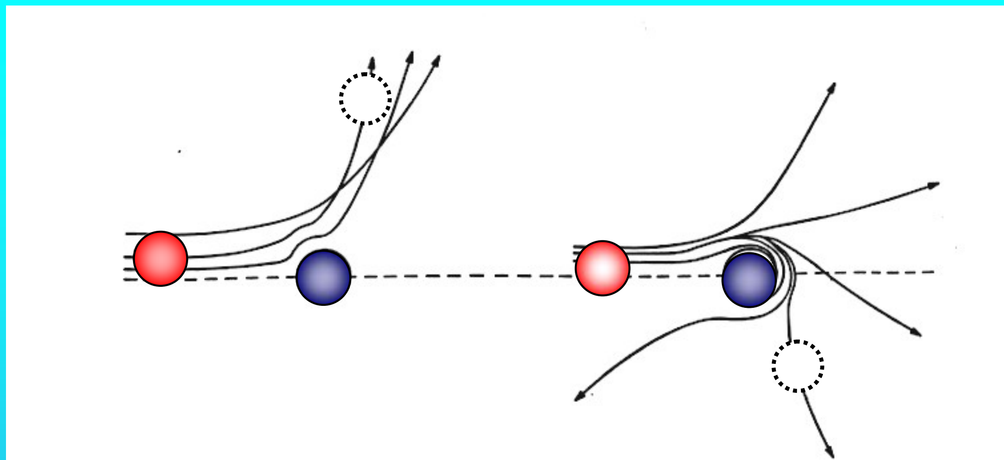
Reaction Scenarios

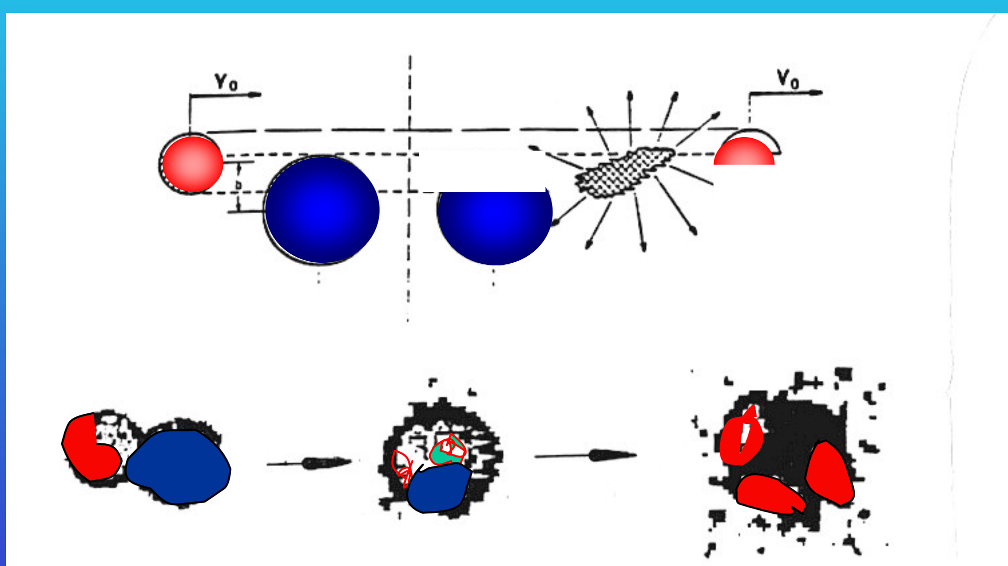
Reaction Scenarios



Near the Barrier

Dissipative Collisions leading to Focussing and Orbiting

2 possible emitters: PLF, TLF



Fermi Energies: Peripheral

Participant-Spectator Scenario (Fireball)

3 emitters: PLF, TLF, IVS

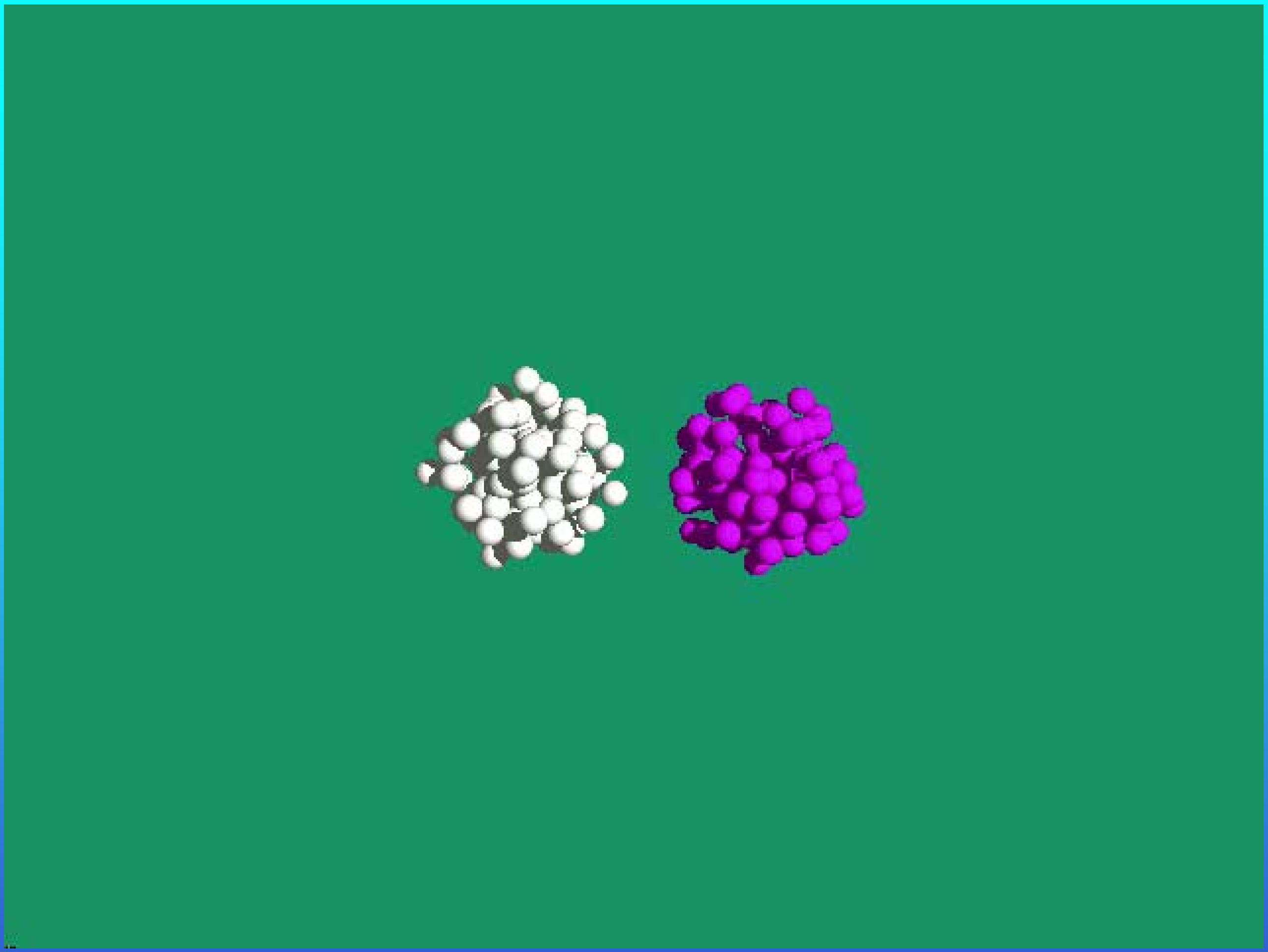
Fermi Energies: Central

Multi-Fragmentation (Fireball at high energies)

1 emitter: CN

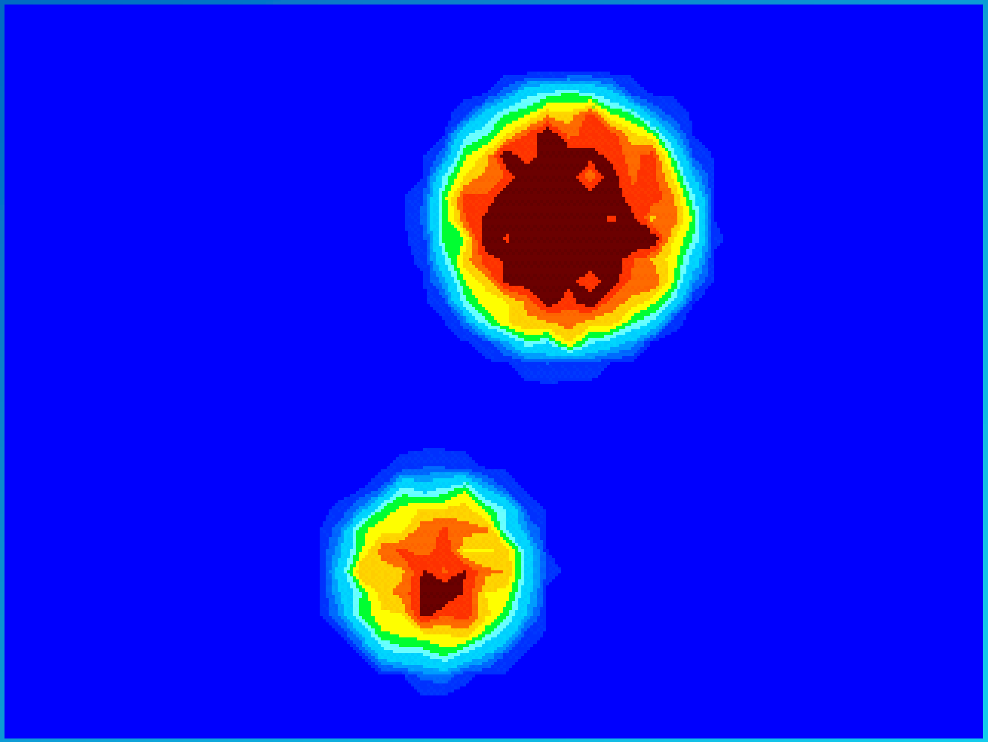
Sn+Xe Collision at E/A = 50 MeV

(QMD: Aichelin)



Fast particles and clusters emitted at the same early times? Non-statistical, dynamical process?

Nuclear Liquid:
The Boltzmann-Uehling-Uhlenbeck Approach



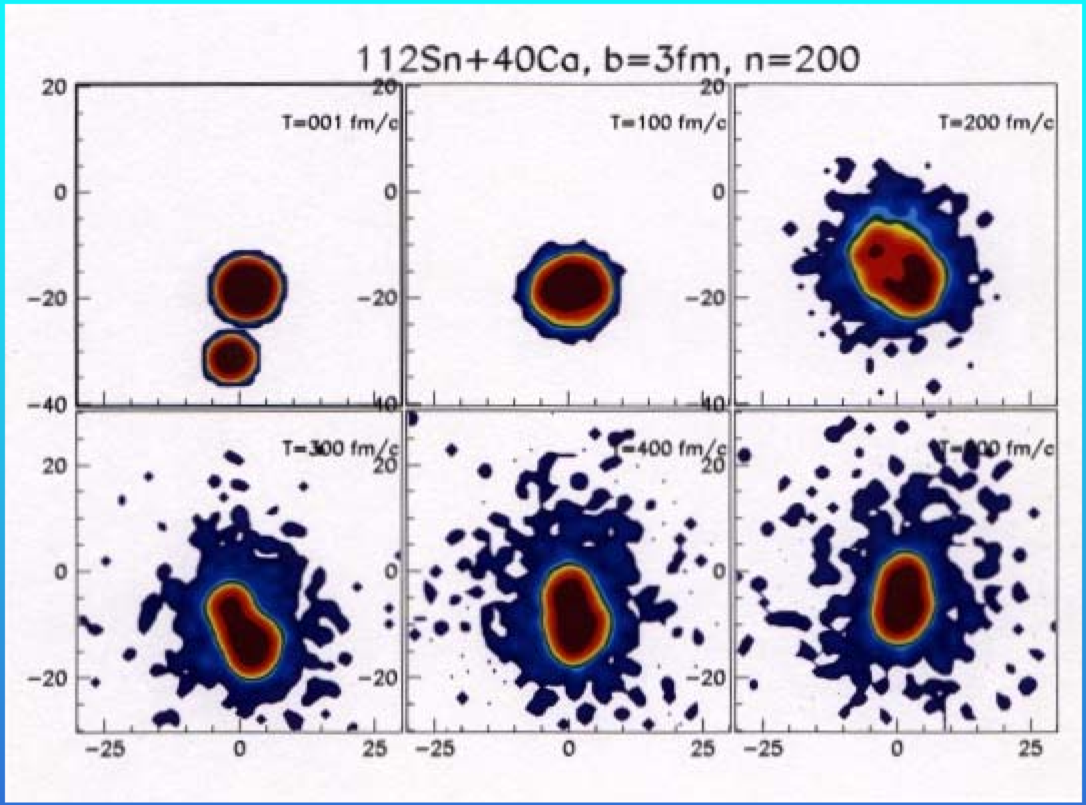
Transport equation for s.p. distribution function *f*.

***U:* Mean field, v: velocity; collision term due to residual interactions**

Test particle method

Making New Elements:

BUU Predictions for compound nucleus formation (Code: Bauer).



Time sequence of a Sn+Ca fusion collision at E/A=35 MeV.

Fusion-like process relatively gentle, not many fast particles emitted in the approach phase. Complete stopping, mixing, and damping.

Nuclear Interactions

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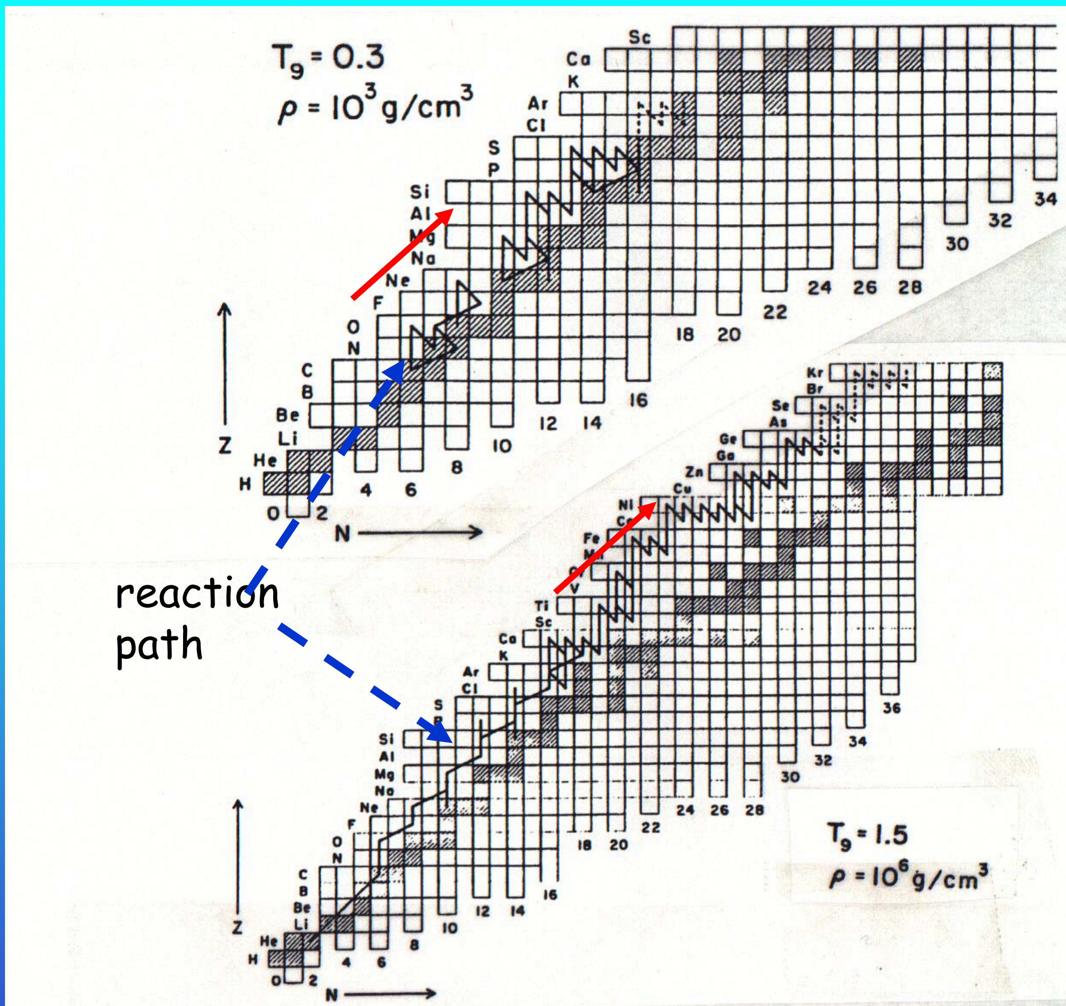
Nucleosynthesis in Stellar Reaction Networks



r-p process (rapid-proton capture) produces heavy elements.

r process (rapid-neutron capture)

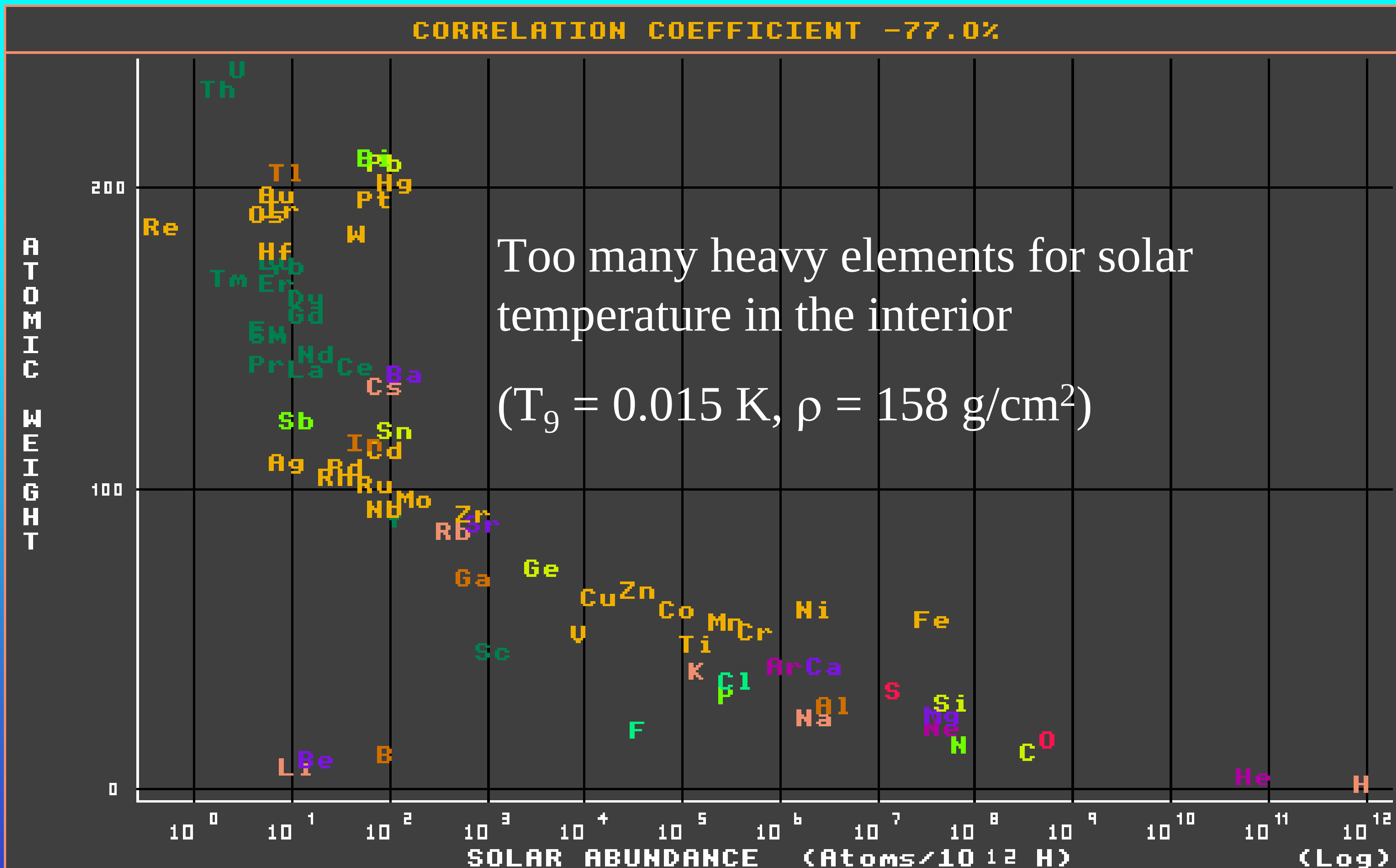
Strong T dependence

Details of nuclear structure and stability and the conditions at formation (star, Big Bang) account for the natural abundance of elements.

Much of the information needed is not yet known

→ Task of future experiments.

Solar Abundance of Elements



Too many heavy elements for solar temperature in the interior

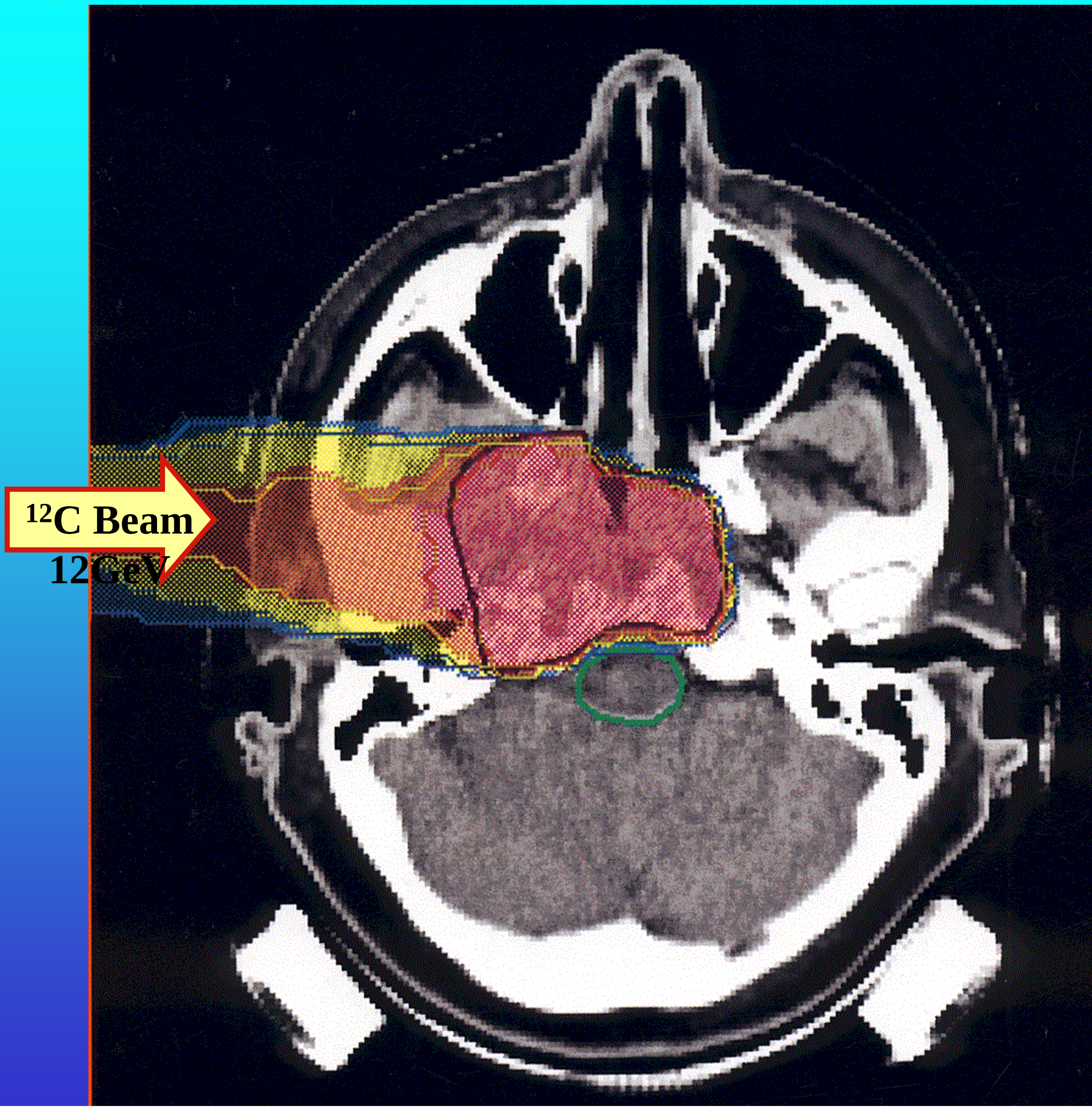
(T_9 = 0.015 K, ρ = 158 g/cm^2)

Applications

Use nuclear instruments

and nuclear methods

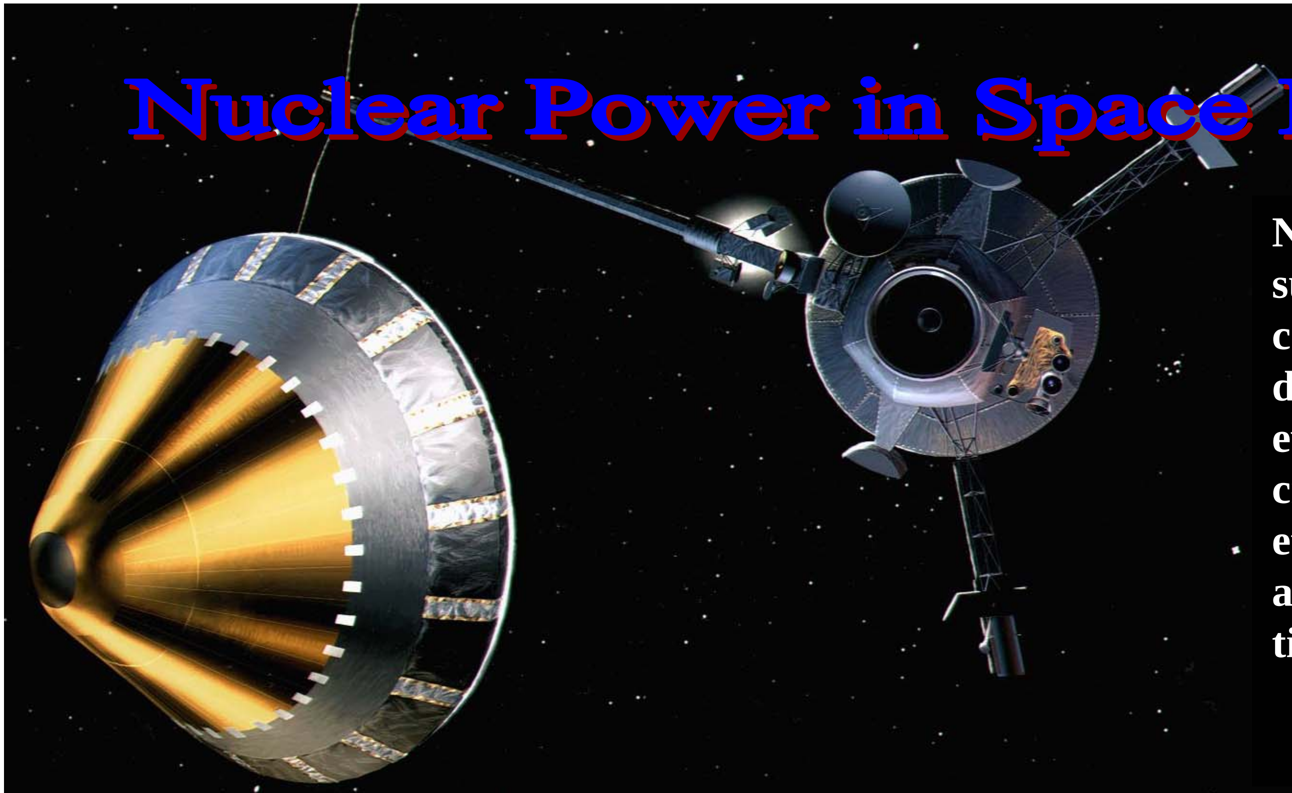
Heavy-Ion Radio-Therapy: Non-Intrusive Brain Surgery



Heavy ions (here ^{12}C) have a well-defined range in materials. They lose much of their kinetic energy shortly before complete stopping, leading to a radiation dose concentrated at the end of their range. This provides a non-intrusive surgical tool

Nuclear Power Generators

Nuclear Power in Space Exploration



Nuclear energy is used to power submarines, ice-breakers, aircraft carriers, extra-terrestrial craft, deep space probes, i.e., everywhere where power has to be created very reliably and efficiently, in order to maintain autonomous operations for long time periods.

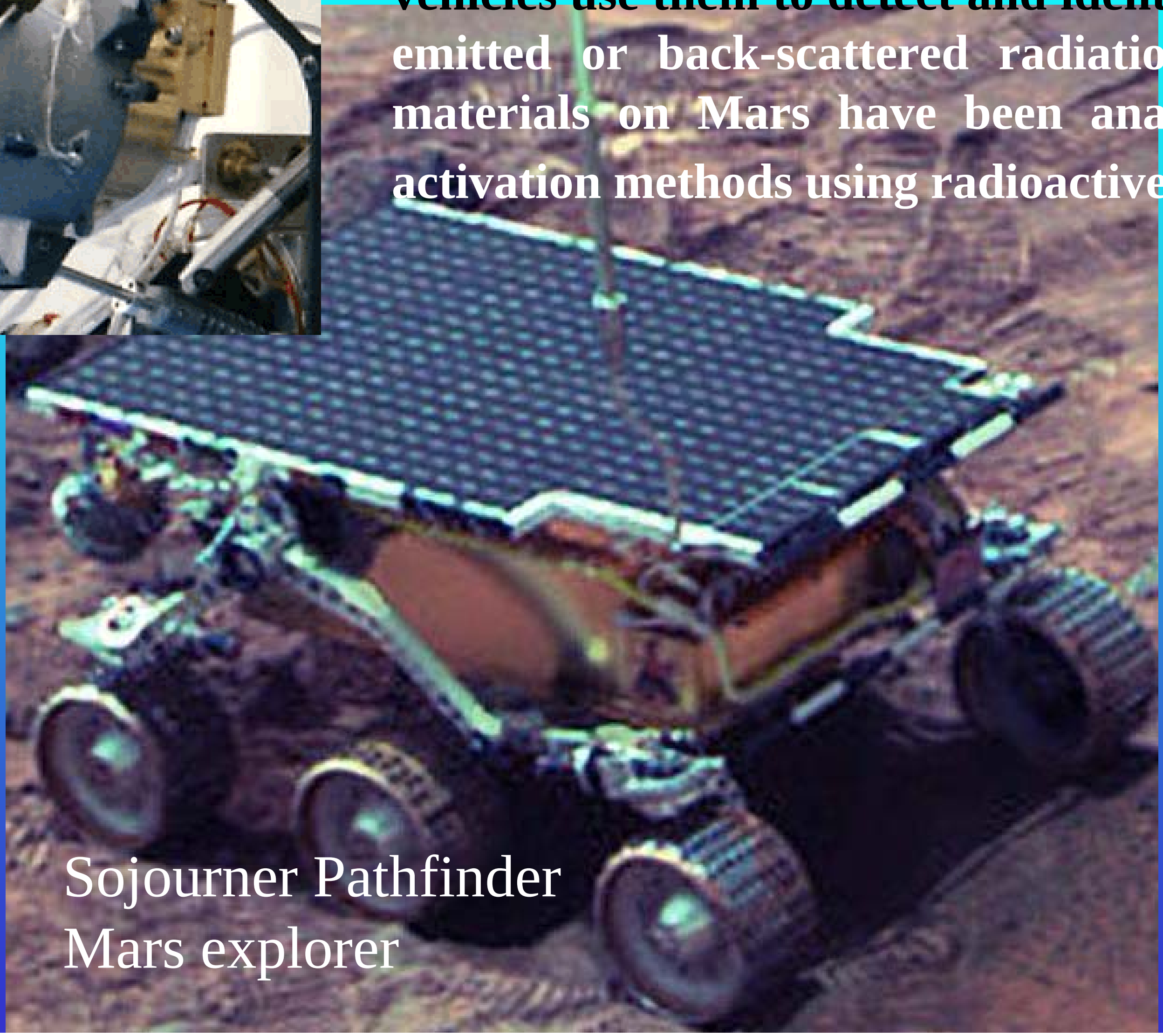
Galileo spacecraft

Voyager spacecraft

Nuclear Space Technology

Nuclear radiation detectors are used in explorations of the sun and its planets. Space vehicles use them to detect and identify directly emitted or back-scattered radiation. Surface materials on Mars have been analyzed with activation methods using radioactive sources.

Radiation detector



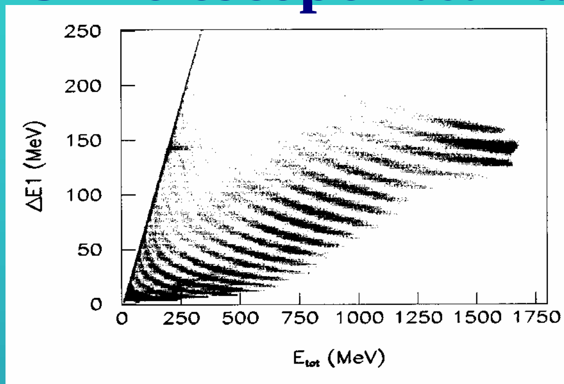
Sojourner Pathfinder
Mars explorer

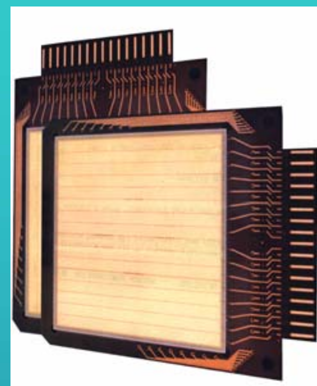
Pushing the Envelope:
Instruments of Nuclear Research

A glimpse into the future. What are now methods and instrumentation of advanced, basic nuclear research could tomorrow see application in a variety of areas in society and economy, from medicine (diagnostics and therapy) to materials research.

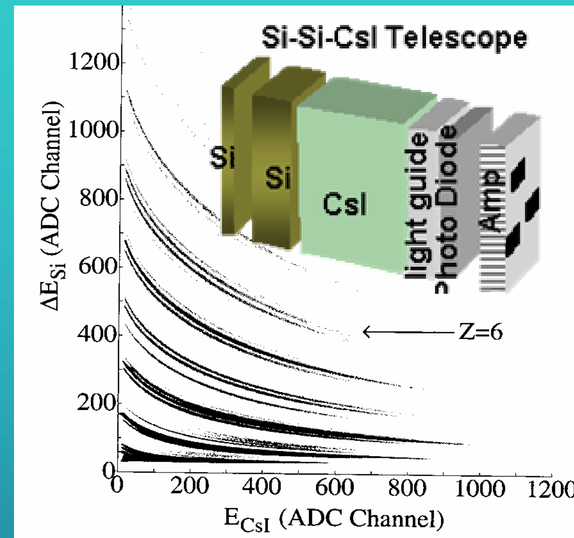
Nuclear Radiation Detectors

Si Telescope Fast Reaction Products

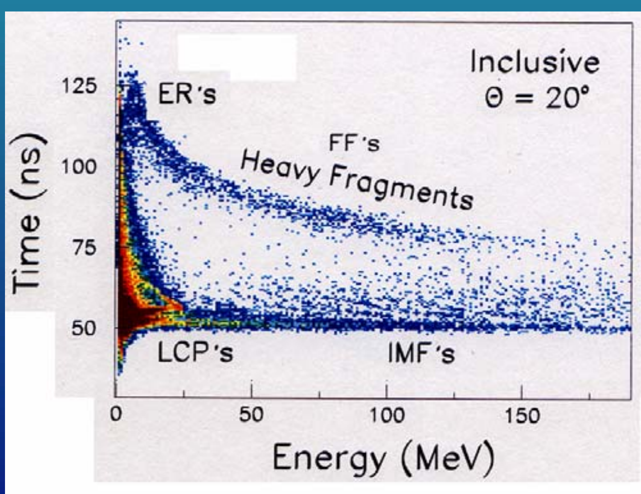




SiSiCsI Telescope (Light Particles)



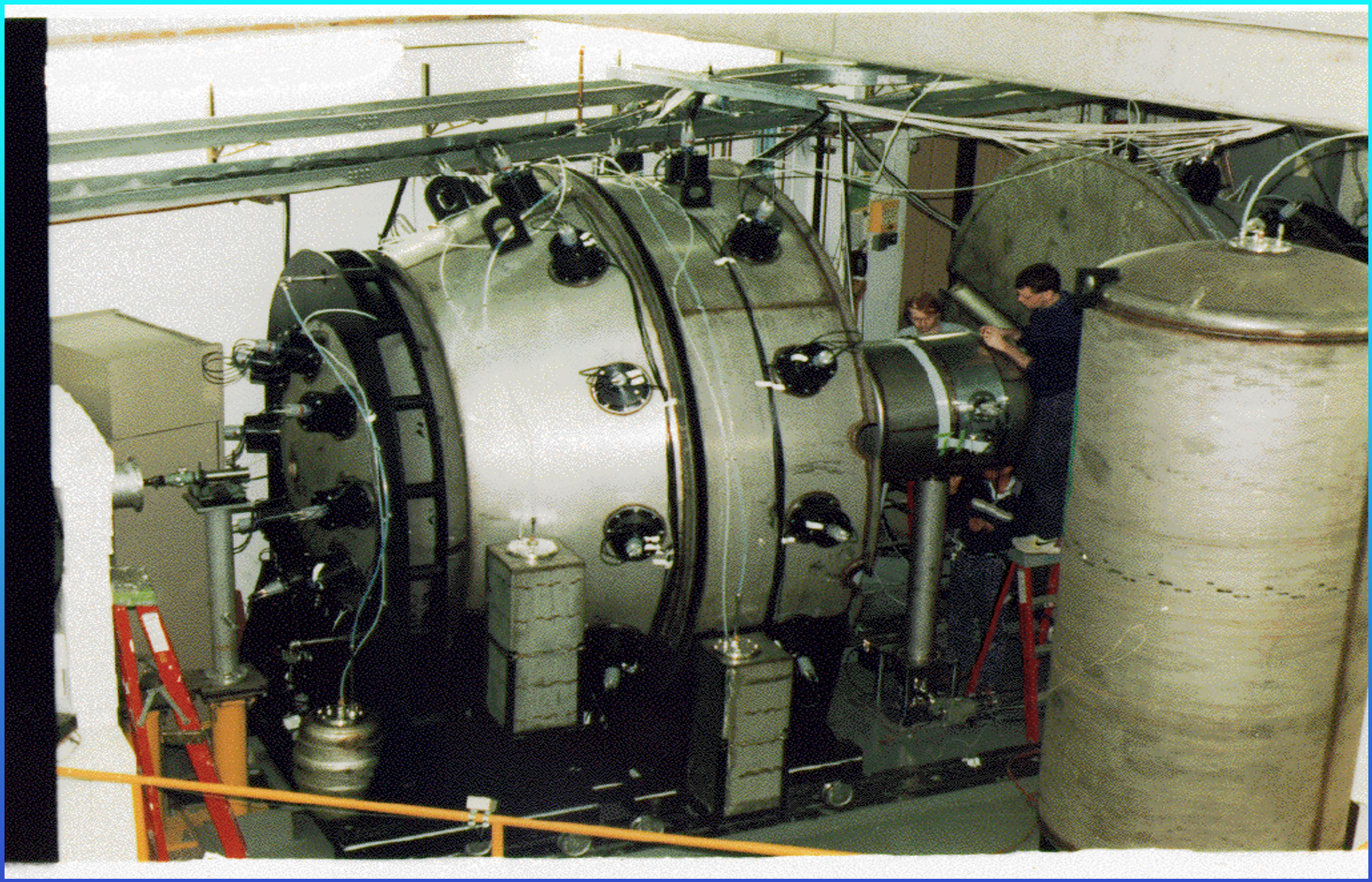
Si Strip Detectors for slow products



- Z Resolution
- A Resolution
- Particle ID

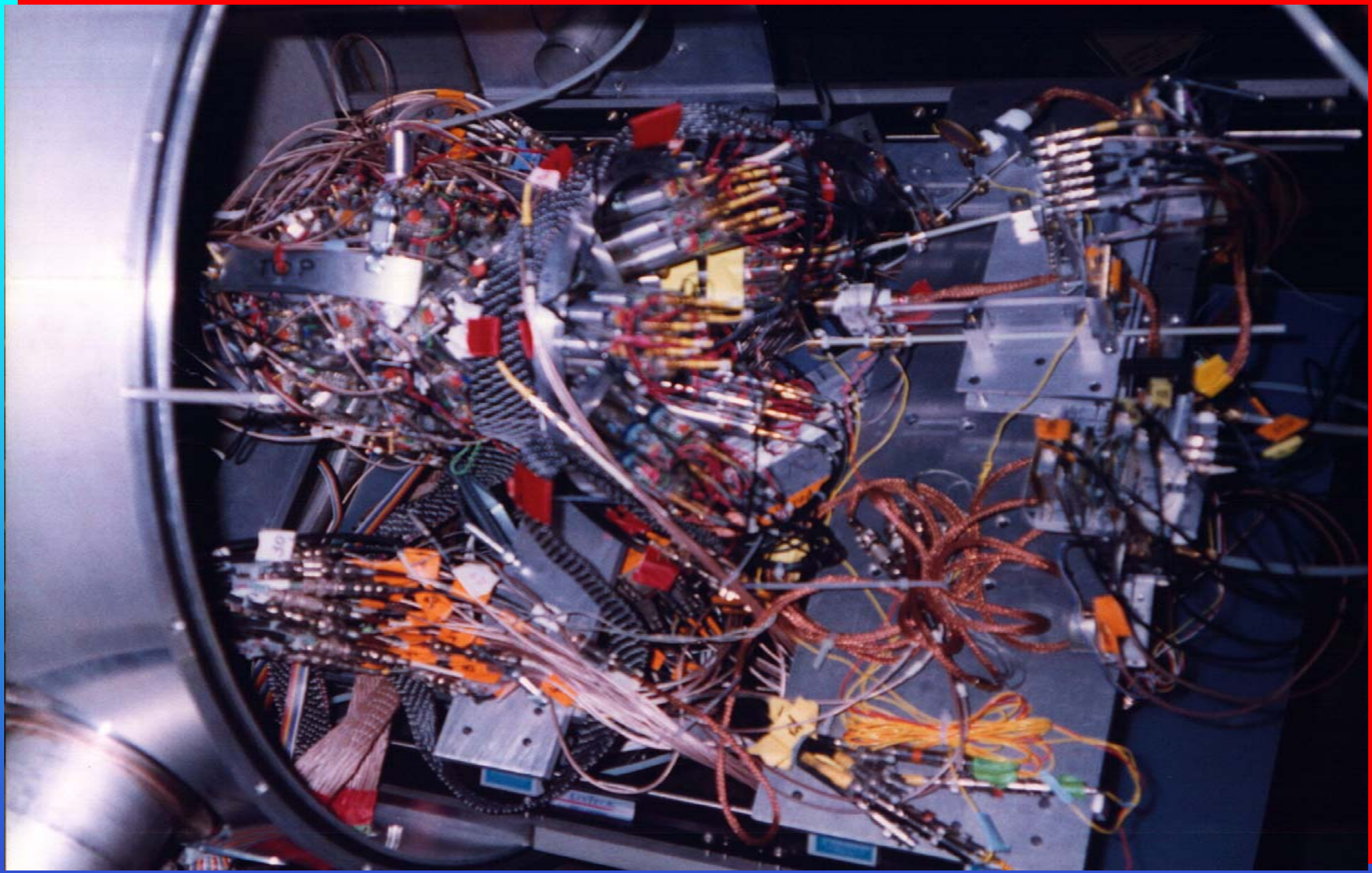
Efficient Radiation Detection

SuperBall **Calorimeter: *4π* measurement of neutrons**
→ excitation energy, impact parameter



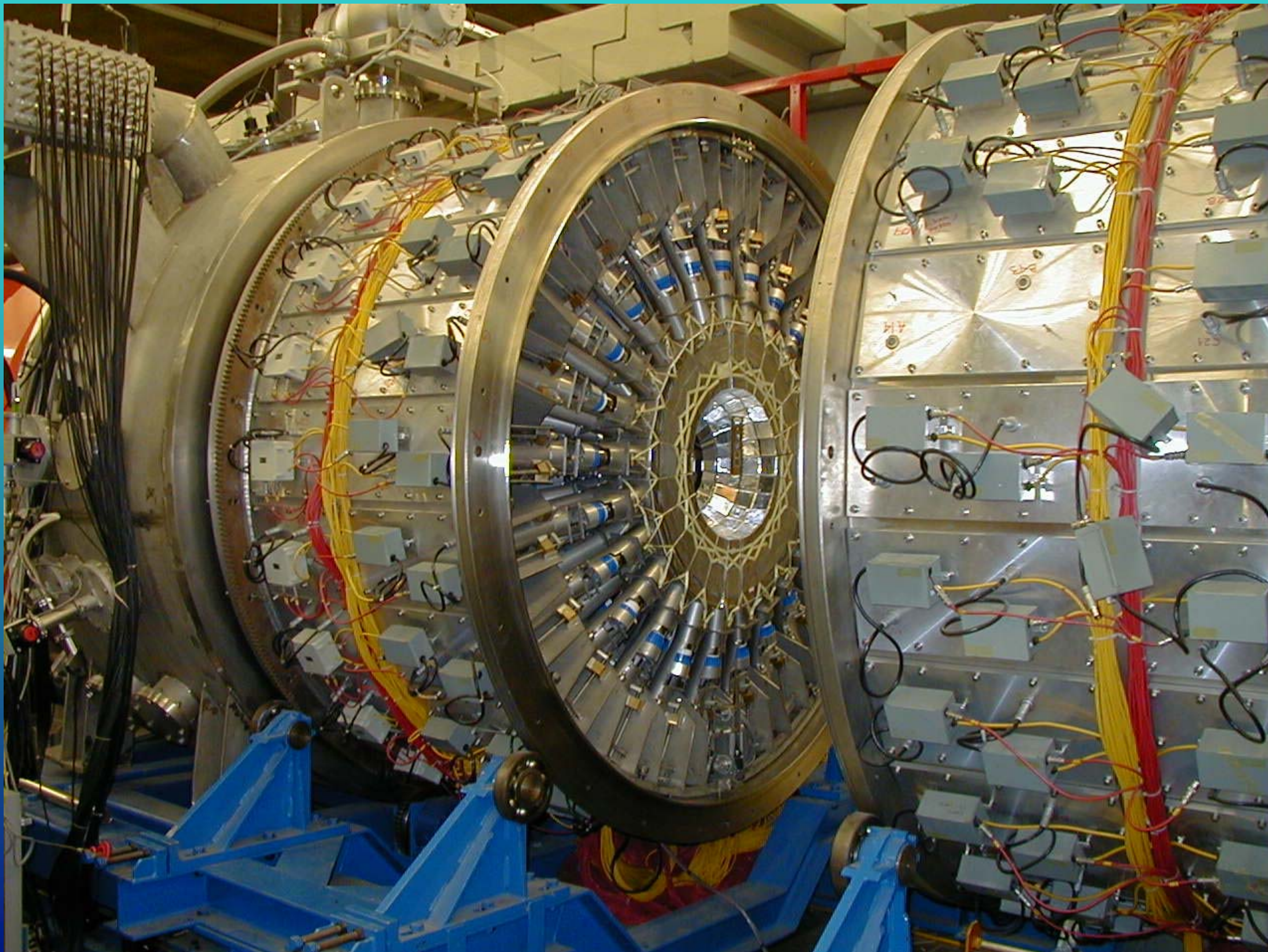
Versatility

DwarfBall/Wall: *4π* measurement of charged particles



In addition: Si detector telescopes for PLFs, IMFs, HRs

MEDEA Multi-Detector Array at LNS Catania



The End (for now)

Next: Discovery of the Nucleus