Title: Nuclear Theory/Heavy Ions 7

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Abstract:

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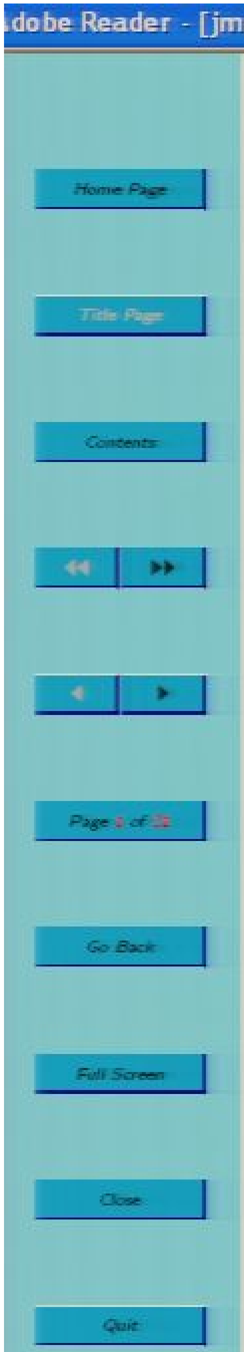
7. Concluding remarks



Hartree-Fock-Bogoliubov Mass Models for Astrophysics

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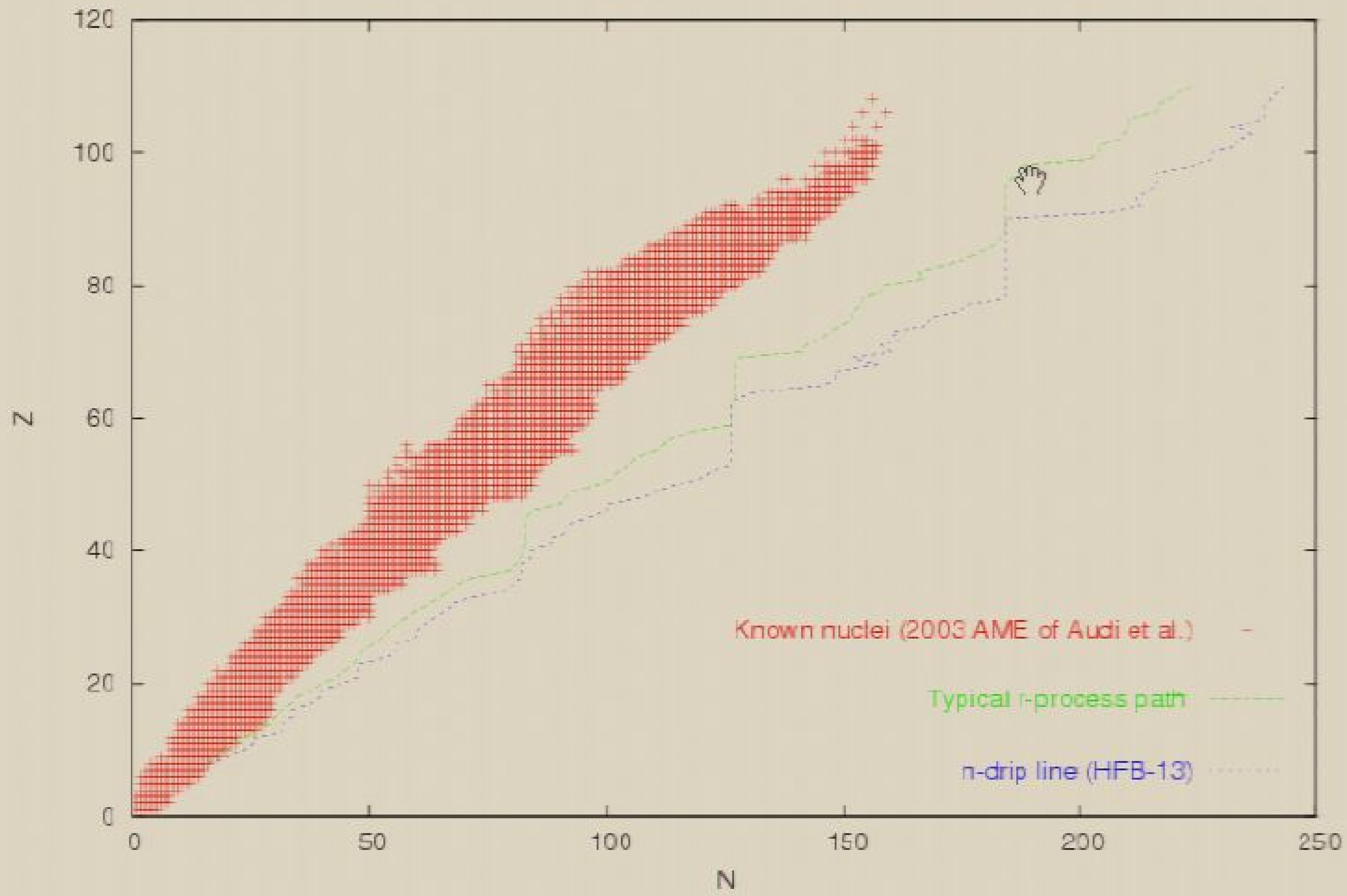

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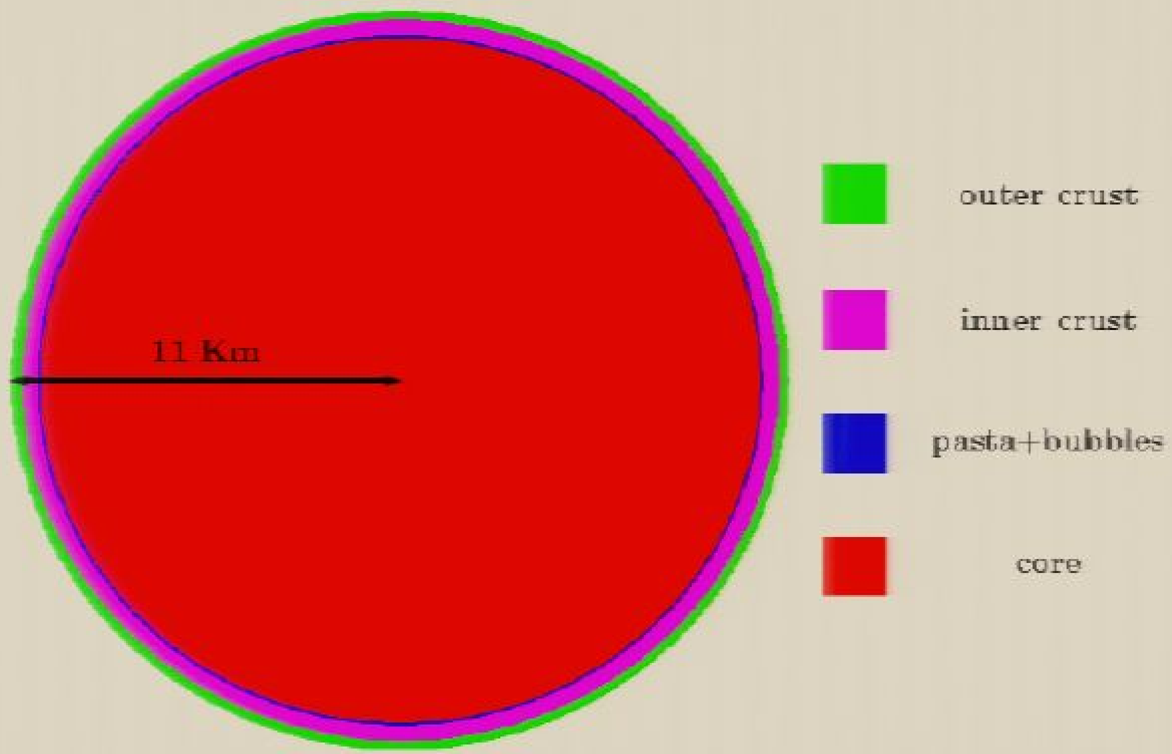

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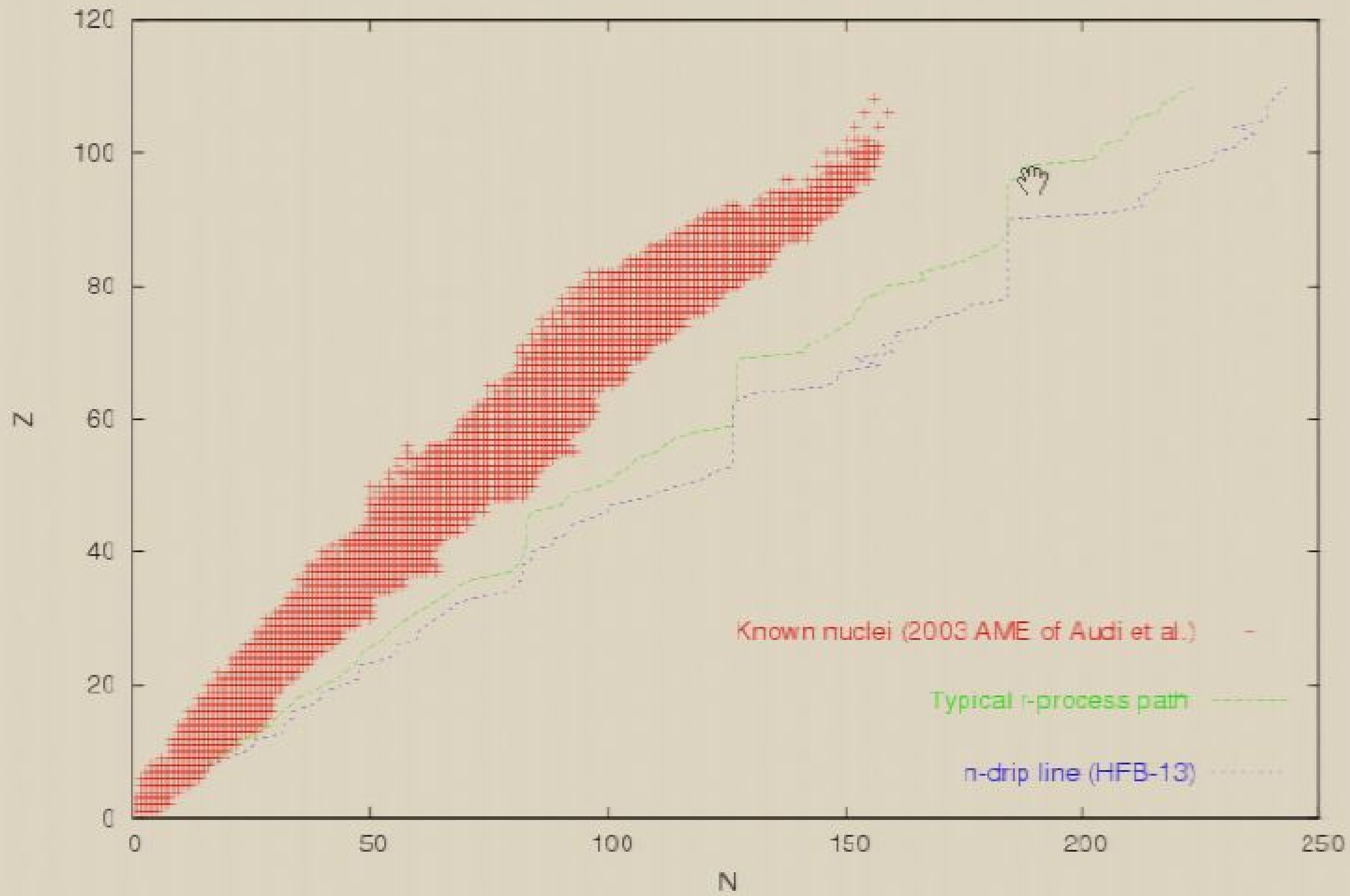

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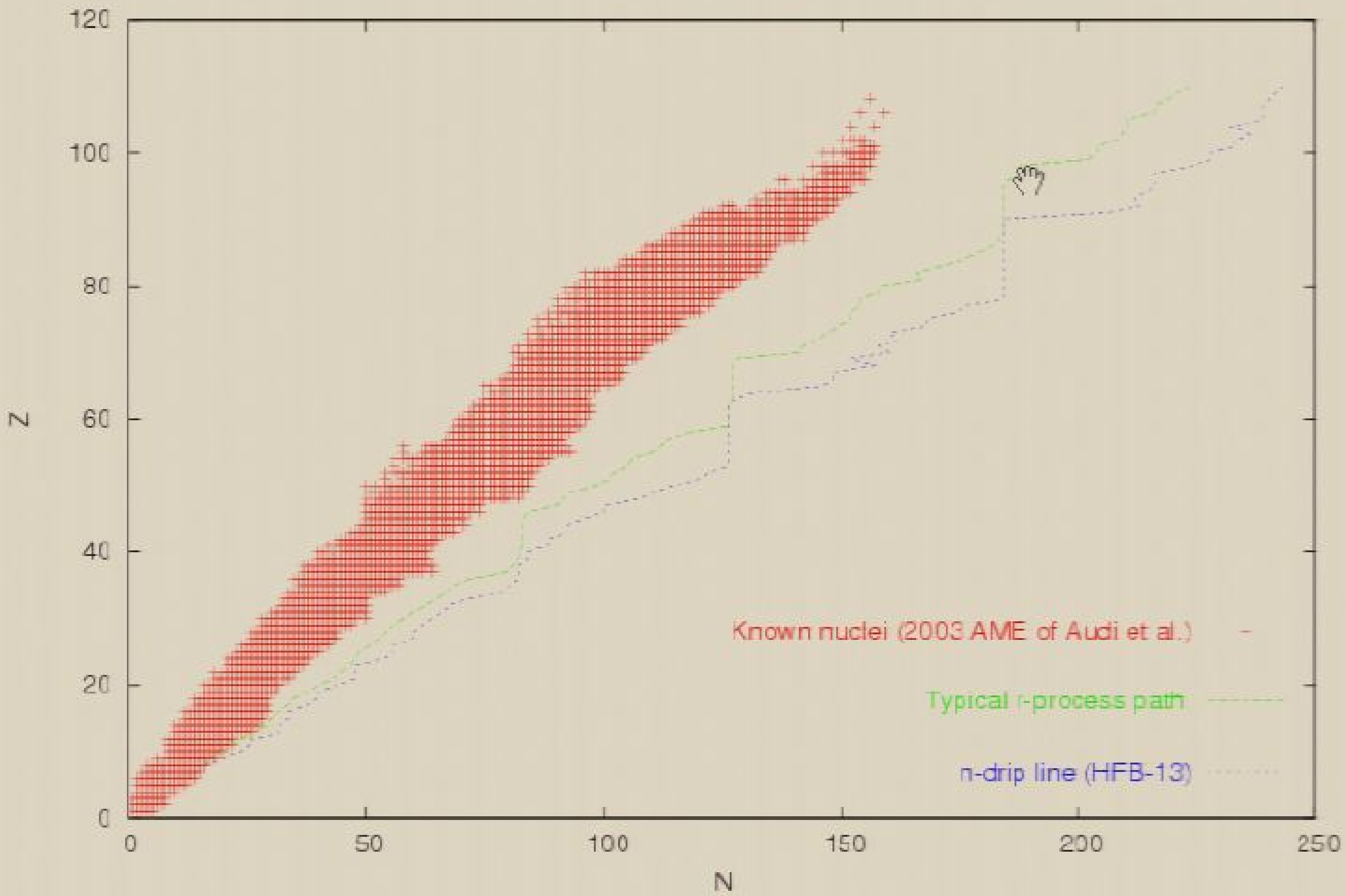

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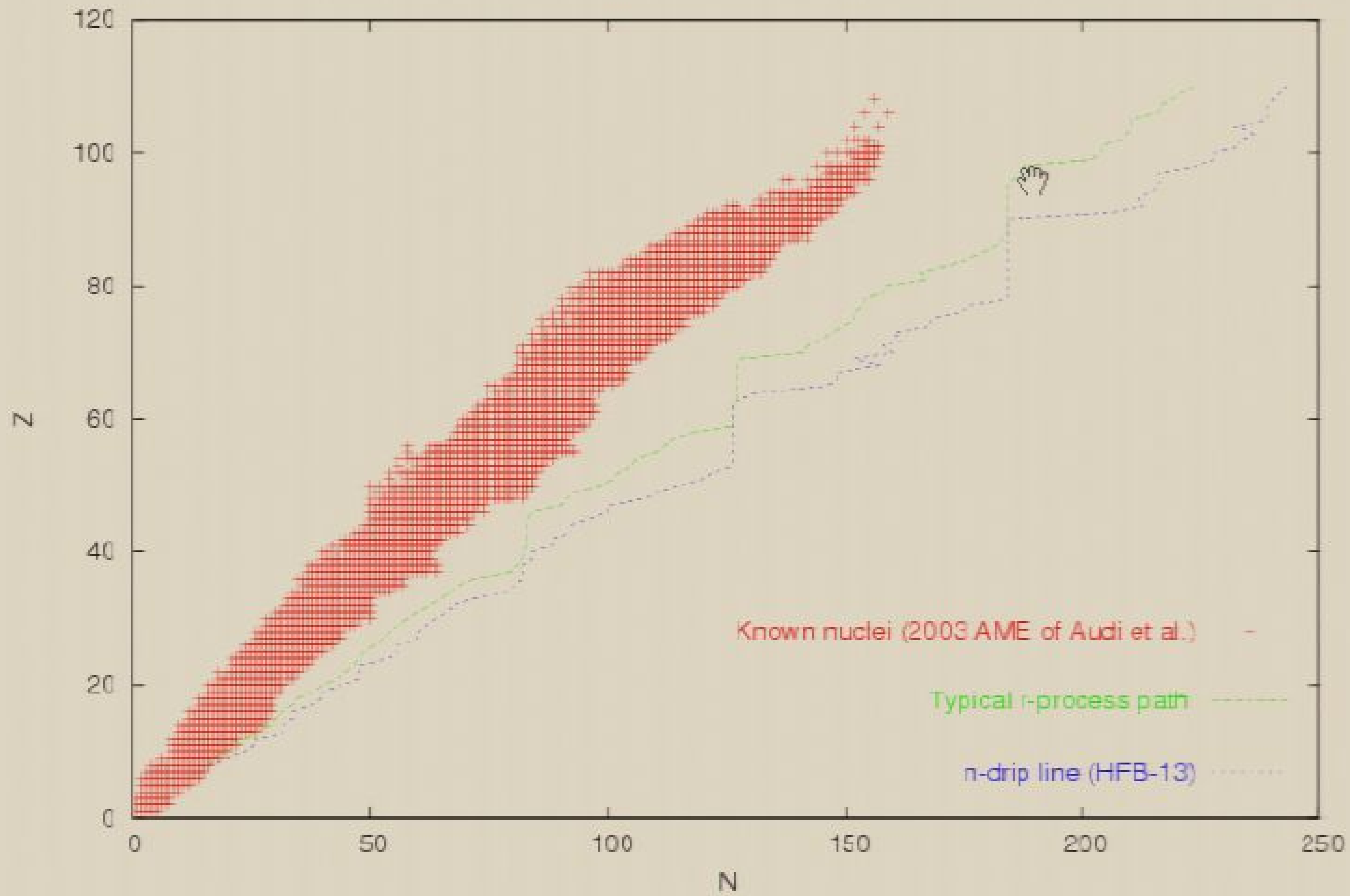

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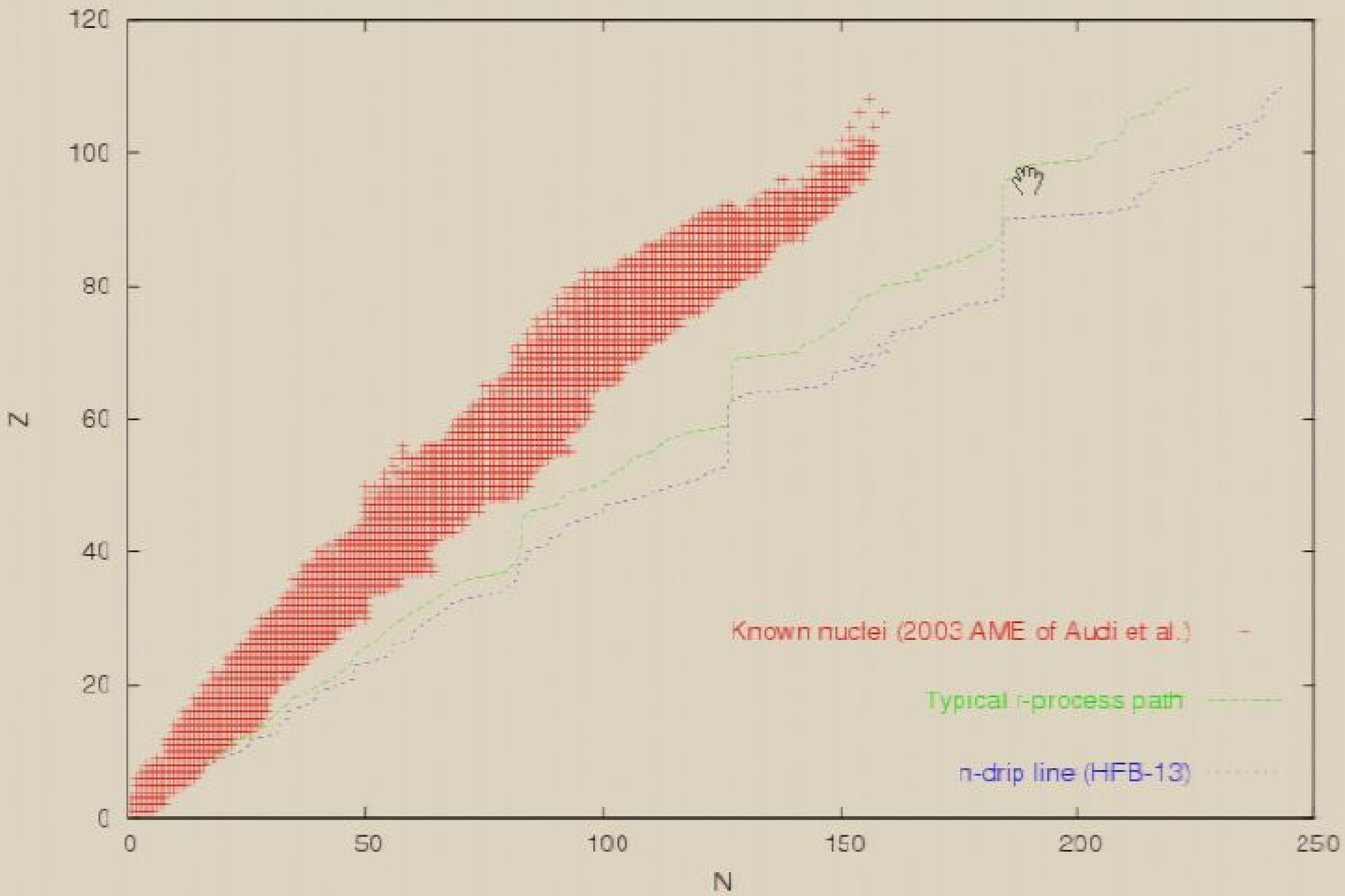

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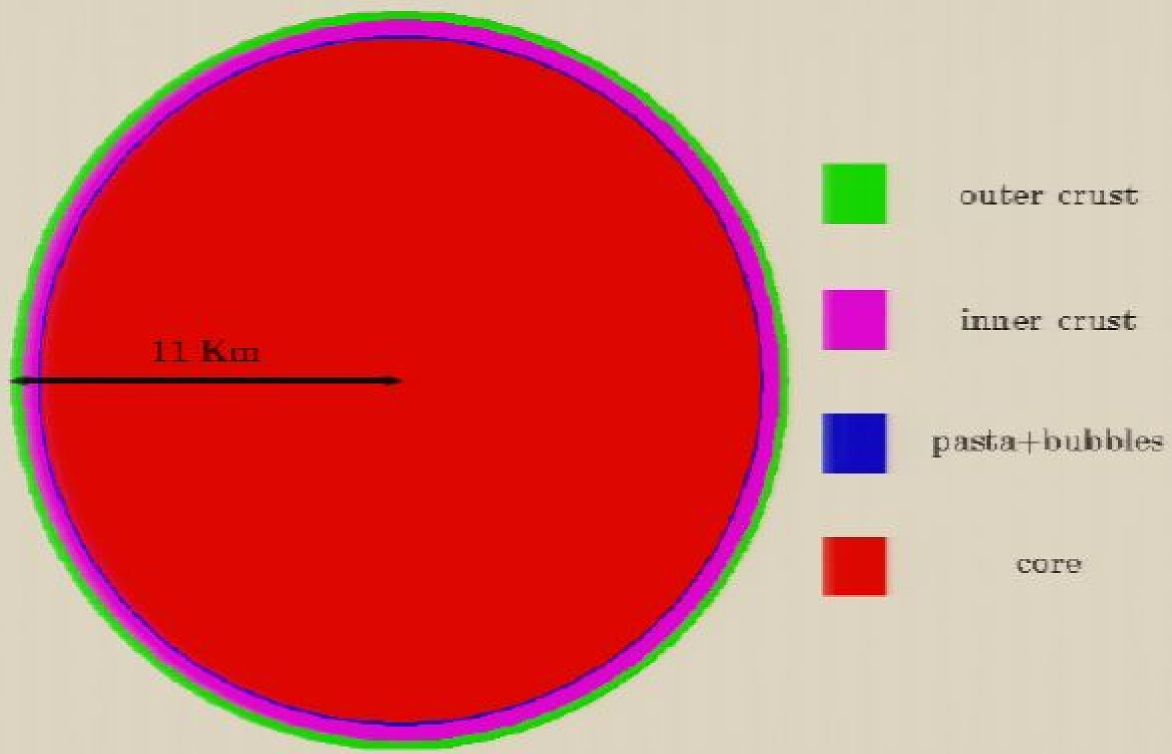

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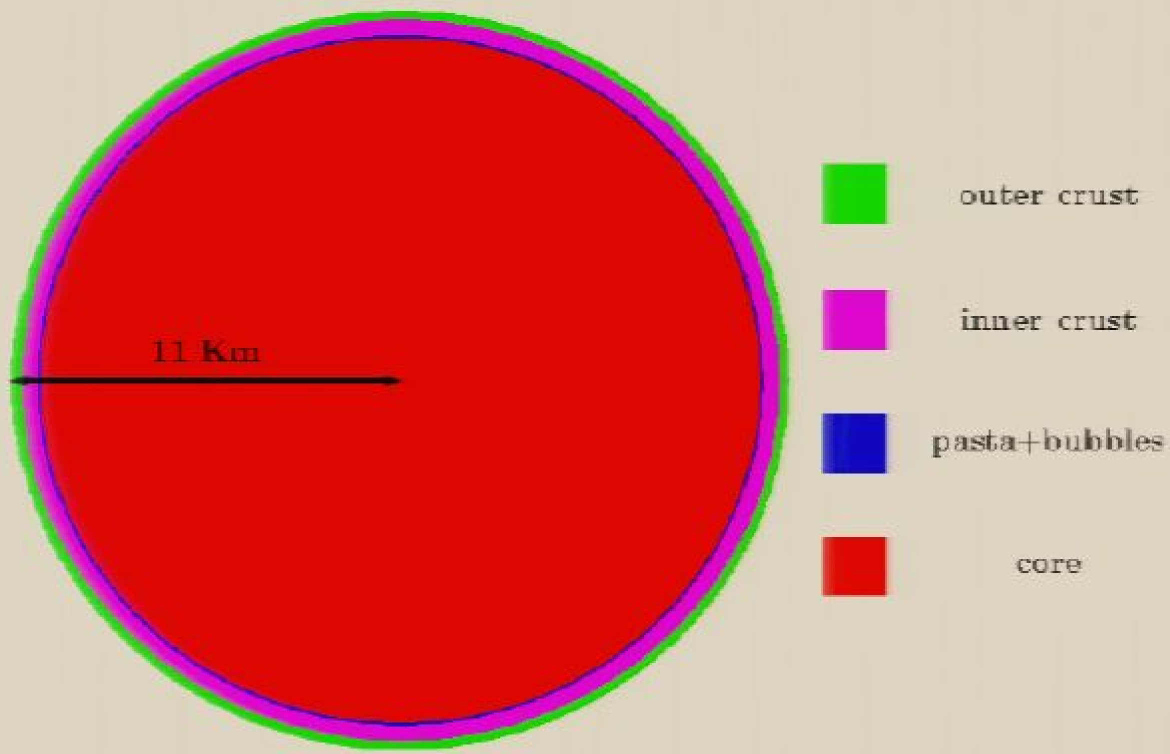

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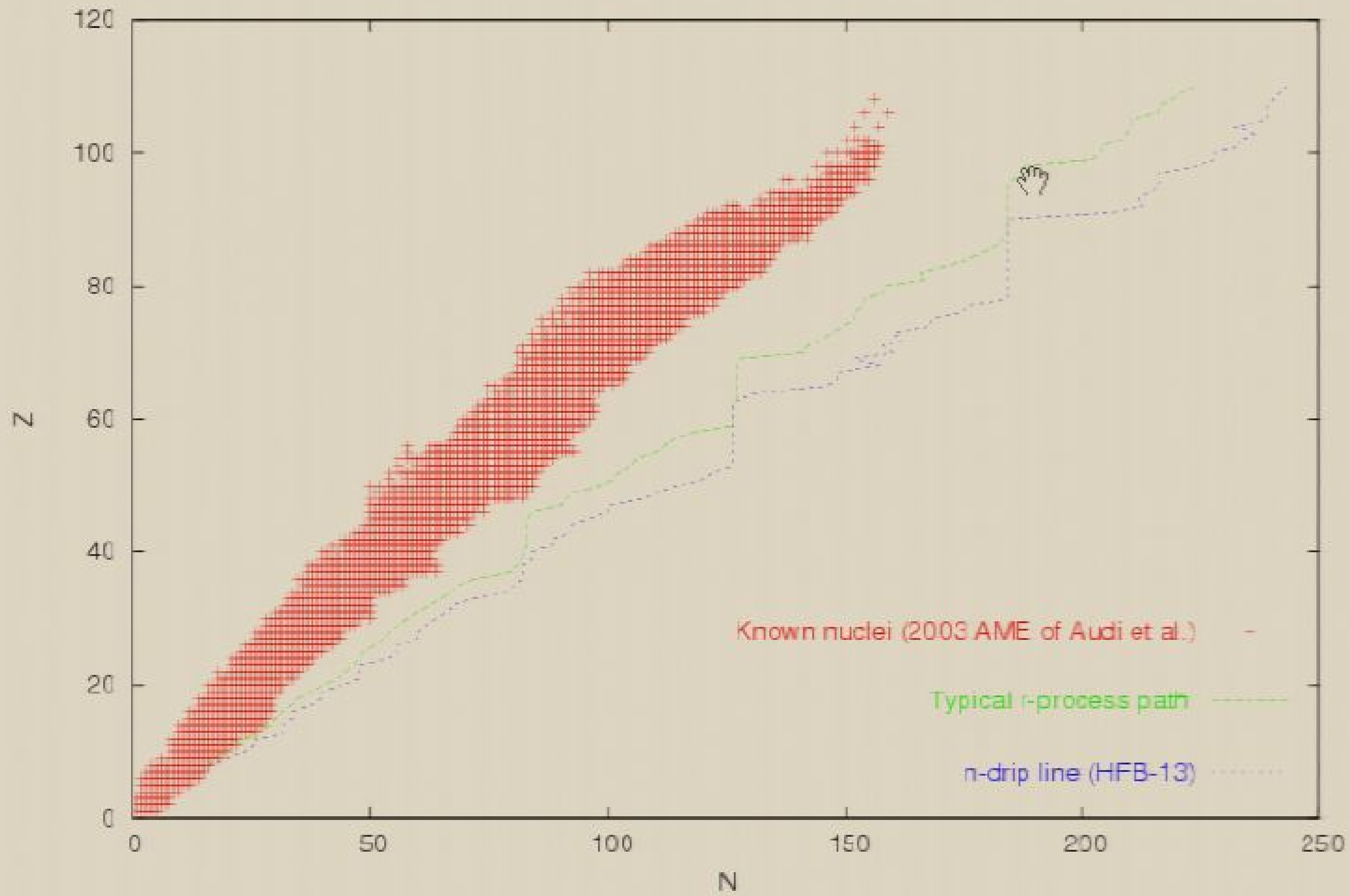

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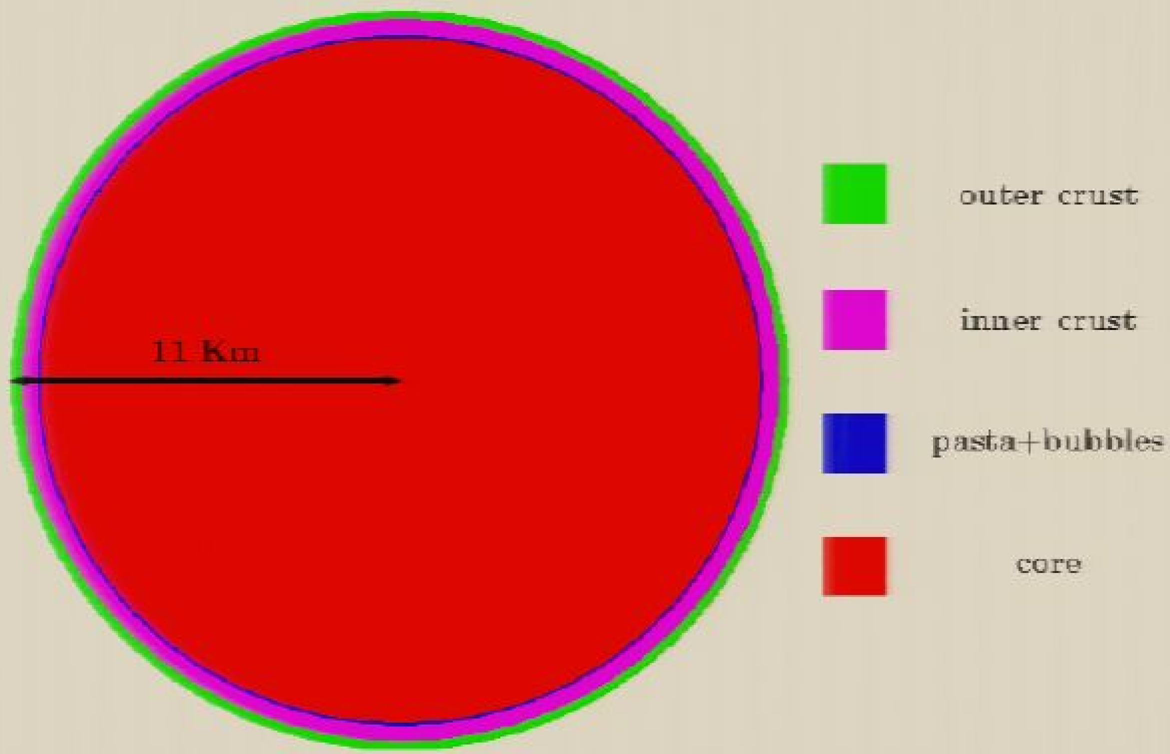

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2. HFB model

Skyrme force

$$
\begin{aligned}
v_{ij} = {} & t_0(1 + x_0 P_\sigma)\delta(\mathbf{r}_{ij}) \\
& + t_1(1 + x_1 P_\sigma)\frac{1}{2\hbar^2}\{p_{ij}^2 \delta(\mathbf{r}_{ij}) + h.c.\} \\
& + t_2(1 + x_2 P_\sigma)\frac{1}{\hbar^2}\mathbf{p}_{ij}.\delta(\mathbf{r}_{ij})\mathbf{p}_{ij} \\
& + \frac{1}{6}t_3(1 + x_3 P_\sigma)\rho^\alpha \delta(\mathbf{r}_{ij}) \\
*** \quad & + \frac{1}{2\hbar^2}t_4(1 + x_4 P_\sigma)\{p_{ij}^2 \rho(\mathbf{r}_i)^\beta \delta(\mathbf{r}_{ij}) + h.c.\} \\
& + \frac{i}{\hbar^2}W_0(\boldsymbol{\sigma}_i + \boldsymbol{\sigma}_j).\mathbf{p}_{ij} \times \delta(\mathbf{r}_{ij})\mathbf{p}_{ij} \\
*** \quad & + \frac{i}{\hbar^2}W_1(\boldsymbol{\sigma}_i + \boldsymbol{\sigma}_j).\mathbf{p}_{ij} \times \rho(\mathbf{r}_i)^\gamma \delta(\mathbf{r}_{ij})\mathbf{p}_{ij}
\end{aligned}
$$

*** non-conventional

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Pairing force

$$v_{pair}(\boldsymbol{r}_{ij}) = V_{\pi q} \left[1 - \eta \left(\frac{\rho}{\rho_0} \right)^{\sigma} \right] \delta(\boldsymbol{r}_{ij})$$

cutoff: $E_F - \varepsilon_\Lambda \leq \varepsilon_i \leq E_F + \varepsilon_\Lambda$

Generalized Wigner term for nuclei with $N \simeq Z$

$$E_W = V_W \exp\left\{ -\lambda \left(\frac{N-Z}{A} \right)^2 \right\} + V_W' |N-Z| \exp\left\{ -\left(\frac{A}{A_0} \right)^2 \right\}$$

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Mass data from 2003 Atomic Mass Evaluation

Audi, Wapstra, Thibault, Nucl. Phys. **A729** (2003) 337.

Fit to all 2149 measured masses for $Z, N \geq 8$.

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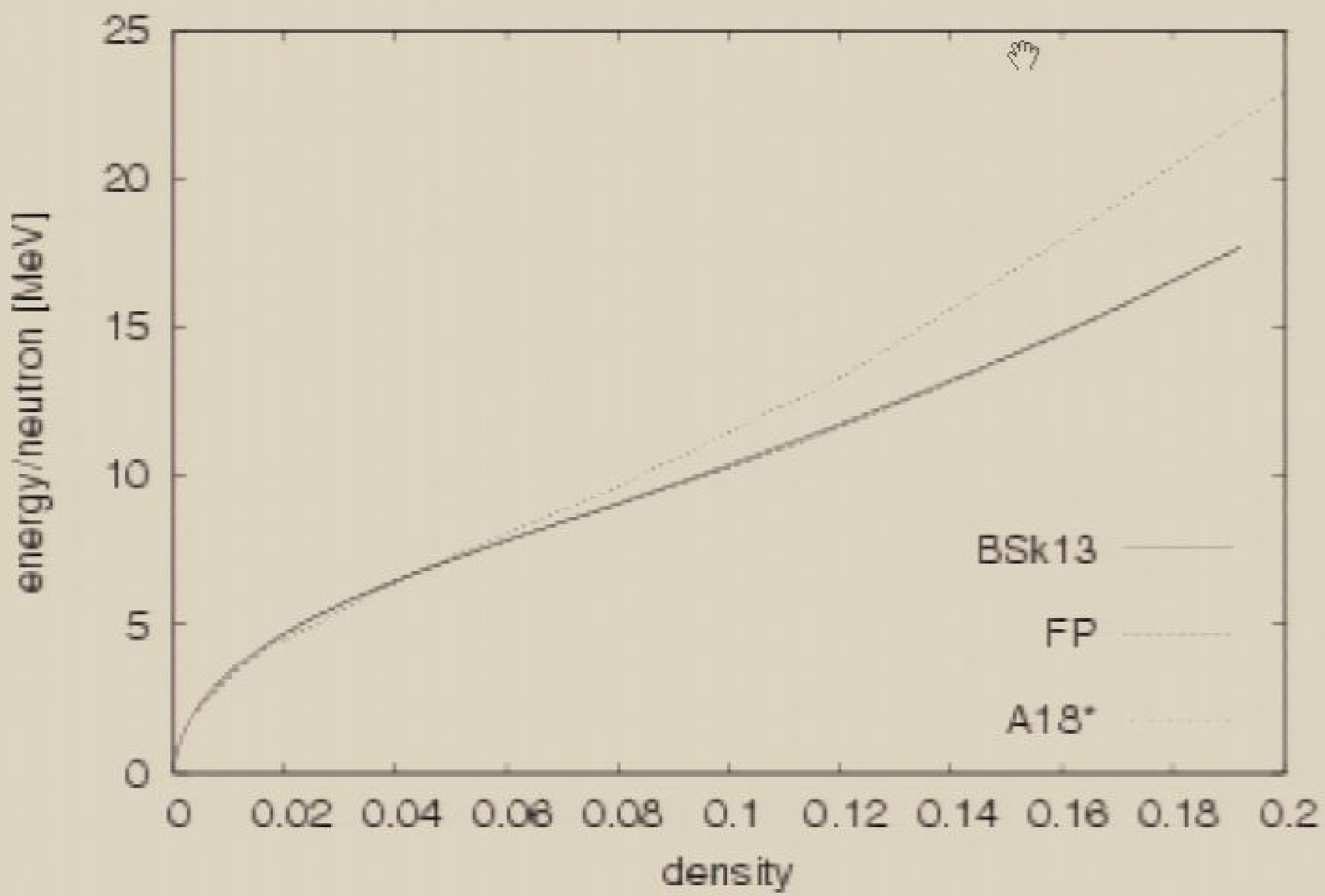

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A force that fits the masses and satisfies this condition will be highly suitable not only for extrapolation to the neutron-rich nuclei involved in the r-process but also for extrapolating still further, beyond the neutron drip line, out to inner-crust matter of neutron star.

Role of mass fit for inner-crust matter of neutron star is two-fold:

ties down $T = 0$ force - neutron star contains some protons

ties down surface properties - crust of neutron star inhomogeneous

These Skyrme forces, which have been fitted to ordinary nuclei, $\rho \leq \rho_0$, cannot be used for core of neutron star, where $\rho \geq \rho_0$.

Best fit so far is parameter set BSk13:

$$\sigma = 0.717 \text{ MeV}.$$

Without neutron-matter constraint can get a much better fit to mass data (force BSk8):

$$\sigma = 0.635 \text{ MeV}.$$

But neutron matter much too soft.

Complete mass table with $Z \leq 110$, going from one drip line to the other has been constructed for force BSk13 : mass table HFB-13.

This serves both for r-process and composition of outer crust of neutron star.

4. Fission barriers

- Most interesting application is to neutron-rich nuclei: termination of r-process path determined by fission barriers.

- HFB calculations force still in progress. So look at our old ETFSI results: Extended Thomas-Fermi plus Strutinsky integral, a semi-classical approximation to HF, with shell corrections added perturbatively; pairing treated in BCS.

5. Extrapolation beyond neutron-drip line

inner crust of neutron star: n-p clusters in neutron vapour – uniform electron gas

Calculations:

Wigner-Seitz model; 4th-order Extended Thomas-Fermi

Onsi et al. Phys. Rev. C **55** 3139 (1997)

Calculate optimal cell composition at each density ($T = 0$).

6. Results for neutron-star crust

$T = 0$

but nuclear statistical equilibrium (star initially very hot)

so unique N, Z at each density

outer crust

nuclear masses from computed table (if not measured)

crucial role of electron gas

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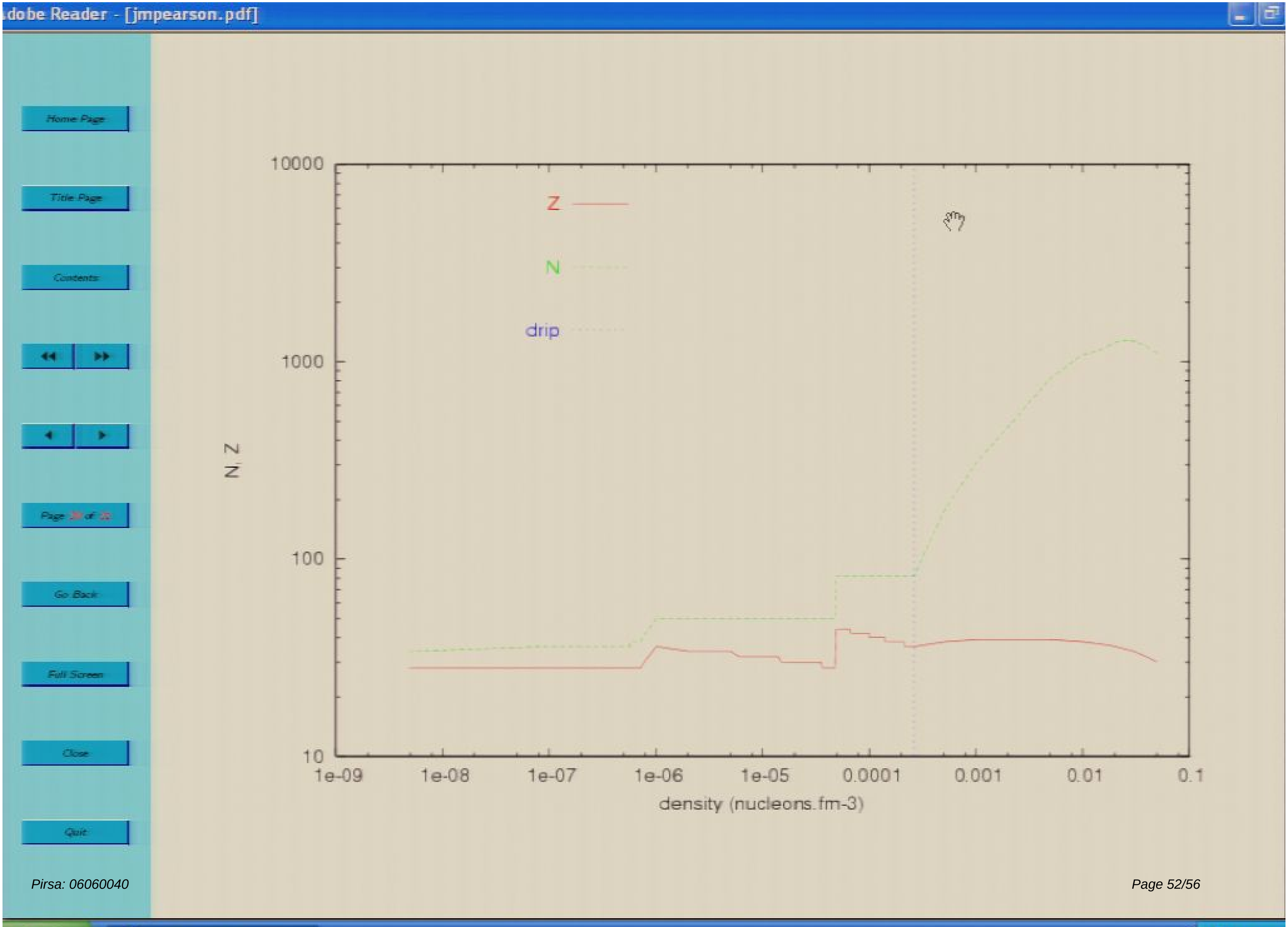
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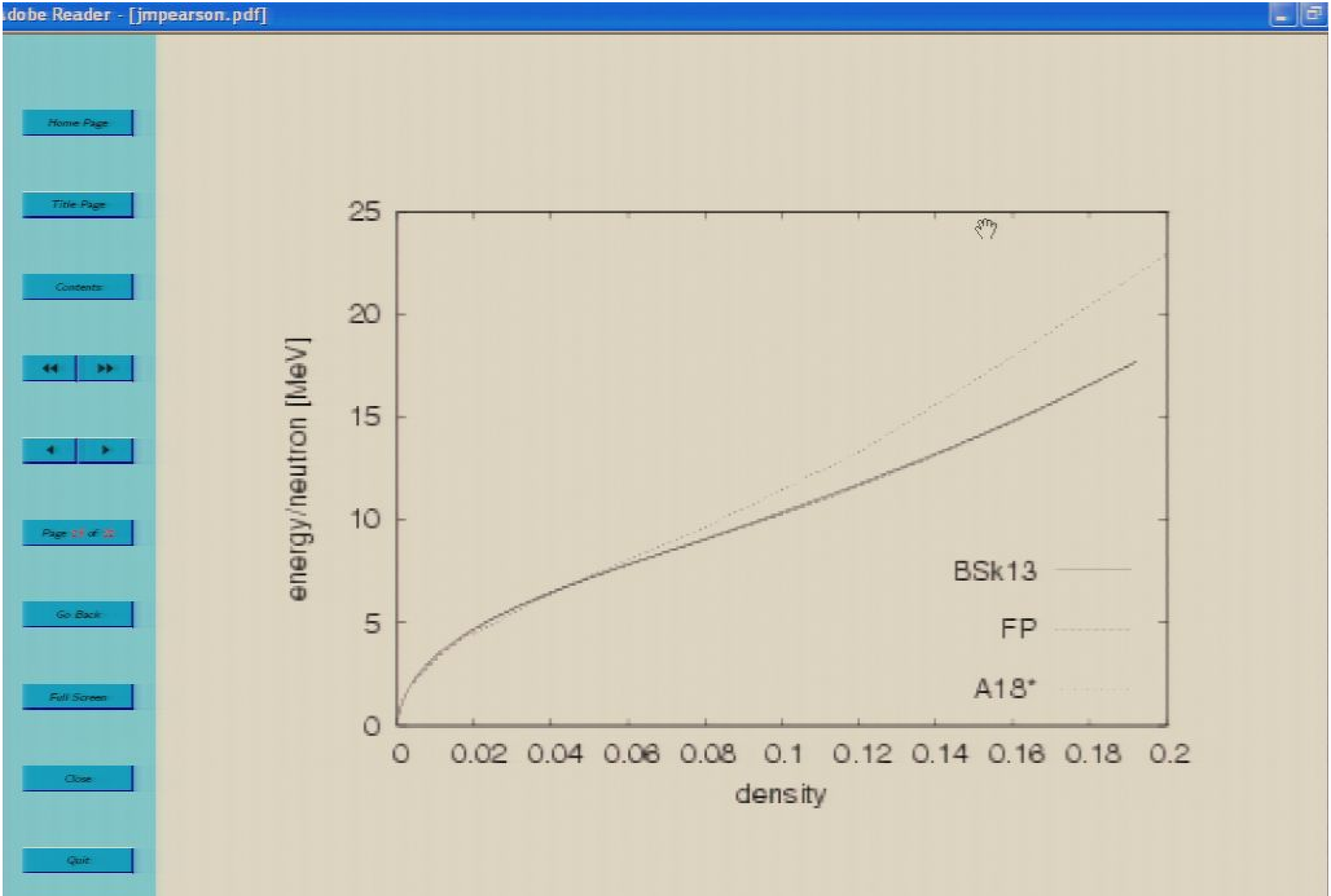

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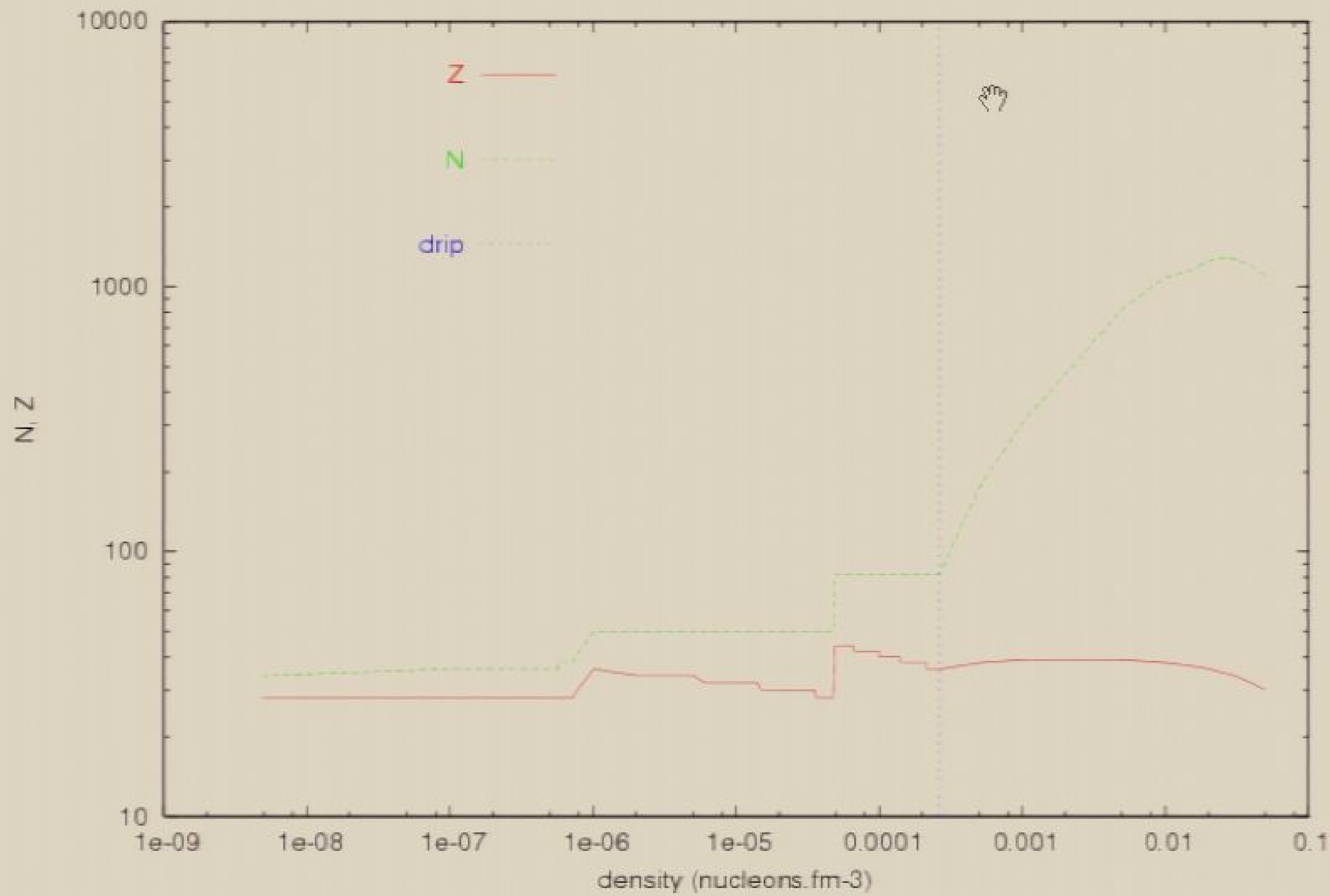

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7. Concluding remarks

- Mass models based on the Skyrme-HFB method have been made, with high quality fits to the mass data, and to neutron matter.

- Tables constructed for $N, Z \geq 8$ from one drip line to the other – used for both r-process and outer crust of neutron stars.

- Can be extrapolated *beyond* the drip line to give EOS for inner crust of neutron stars.

- Fission is problematical – but important for r-process.

- Note that our models are not yet completely microscopic: Wigner term.

- Will want to go beyond Skyrme + δ-function pairing to get closer to "real" forces.