Tensor Force Effects in Nuclear Reactions

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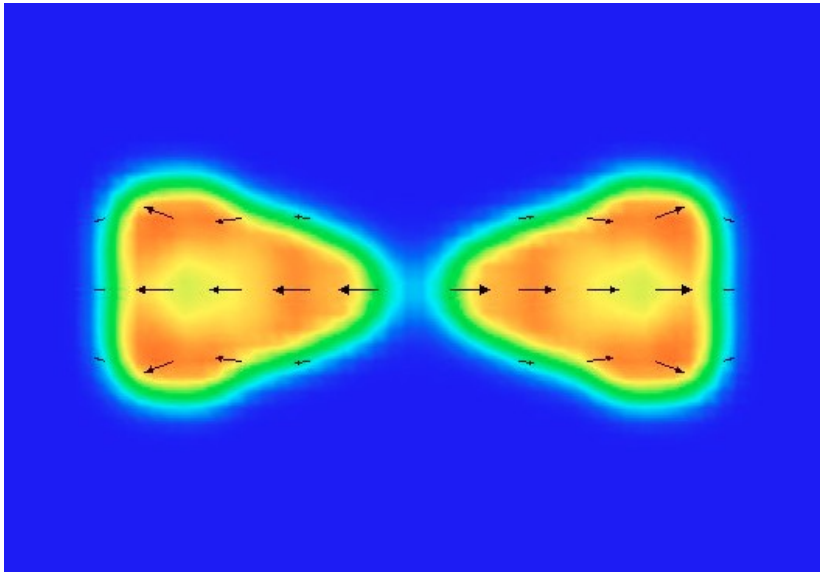

Skyrme forces

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THE EFFECTIVE NUCLEAR POTENTIAL

T. H. R. SKYRME
Atomic Energy Research Establishment, Harwell, Didcot, Berks.

Received 18 October 1958

Skyrme forces

comparison with the scattering matrix we have expressed them as

$$t_{12} = \delta(\mathbf{r}_1 - \mathbf{r}_2) t(\mathbf{k}', \mathbf{k})$$

where $\mathbf{k}$ is the operator corresponding to the relative wave-number,

$$\mathbf{k} = \tfrac{1}{2i}(\nabla_1 - \nabla_2);$$

It is generally believed that the most important part of the two-body interaction can be represented by a contact potential, i.e. by constant $t(\mathbf{k}', \mathbf{k})$; this suggests an expansion in powers of $\mathbf{k}'$ and $\mathbf{k}$.

$$\begin{aligned} t(\mathbf{k}', \mathbf{k}) = {} & t_0(1 + x_0 P^\sigma) + \tfrac{1}{2} t_1 (1 + x_1 P^\sigma)(\mathbf{k}'^2 + \mathbf{k}^2) \\ & + t_2[1 + x_2(P^\sigma - \tfrac{4}{5})]\mathbf{k}' \cdot \mathbf{k} \\ & + \tfrac{1}{2} T[\boldsymbol{\sigma}_1 \cdot \mathbf{k} \boldsymbol{\sigma}_2 \cdot \mathbf{k} - \tfrac{1}{3} \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2 \mathbf{k}^2 + \text{conj.}] \\ & + \tfrac{1}{2} U[\boldsymbol{\sigma}_1 \cdot \mathbf{k}' \boldsymbol{\sigma}_2 \cdot \mathbf{k} - \tfrac{1}{3} \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2 \mathbf{k}' \cdot \mathbf{k} + \text{conj.}] \\ & + V[i(\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2) \cdot \mathbf{k}' \times \mathbf{k}], \end{aligned}$$

Energy-density functional

Delta function lets us perform one integral trivially

$$\mathcal{E}_{\text{Skyrme}} =$$

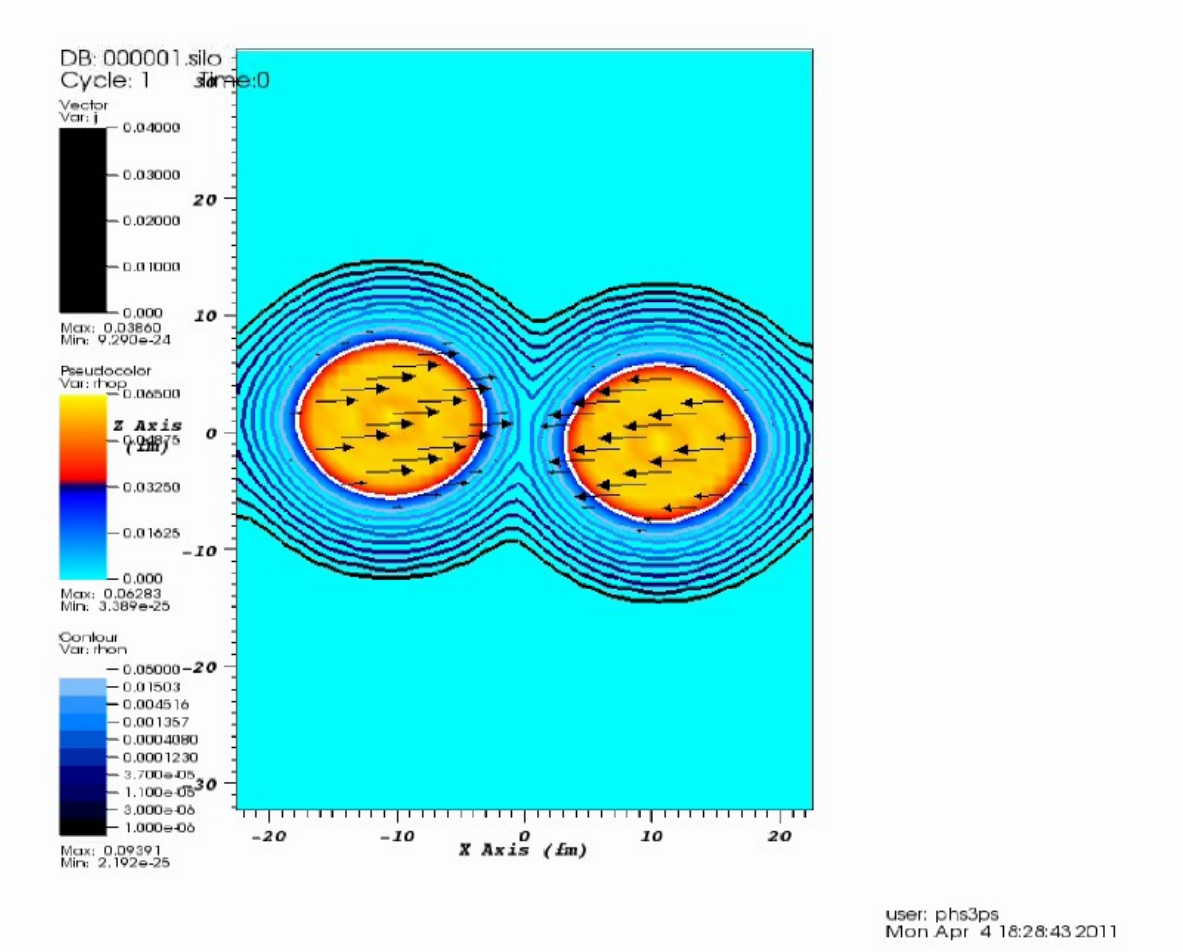
Densities

$$\rho(\boldsymbol{r},\boldsymbol{r}') = \sum_{\sigma,q}\rho_q(\boldsymbol{r}\sigma,\boldsymbol{r}'\sigma) = \sum_{i,\sigma,q}\phi_i^*(\boldsymbol{r}',\sigma,q)\phi_i(\boldsymbol{r},\sigma,q),$$

$$\boldsymbol{S}(\boldsymbol{r},\boldsymbol{r}') = \sum_{\sigma,\sigma',q}\rho_q(\boldsymbol{r}\sigma,\boldsymbol{r}'\sigma')\langle\sigma'|\hat{\boldsymbol{\sigma}}|\sigma\rangle = \sum_{i,\sigma,\sigma',q}\phi_i^*(\boldsymbol{r}',\sigma',q)\hat{\boldsymbol{\sigma}}\phi_i(\boldsymbol{r},\sigma,q),$$

$$\begin{aligned}
\rho(\boldsymbol{r}) &= \rho(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},\\
\tau(\boldsymbol{r}) &= \boldsymbol{\nabla}\cdot\boldsymbol{\nabla}'\rho(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},\\
\boldsymbol{S}(\boldsymbol{r}) &= \boldsymbol{S}(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},\\
T_\mu(\boldsymbol{r}) &= \boldsymbol{\nabla}\cdot\boldsymbol{\nabla}'S_\mu(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},\\
\boldsymbol{j}(\boldsymbol{r}) &= -\frac{i}{2}\left(\boldsymbol{\nabla}-\boldsymbol{\nabla}'\right)\rho(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},\\
J_{\mu\nu}(\boldsymbol{r}) &= -\frac{i}{2}\left(\nabla_\mu-\nabla'_\mu\right)S_\nu(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},\\
F_\mu(\boldsymbol{r}) &= \frac{1}{2}\sum_{\nu=x}^{z}\left(\nabla_\mu\nabla'_\nu+\nabla'_\mu\nabla_\nu\right)S_\nu(\boldsymbol{r},\boldsymbol{r}')|_{\boldsymbol{r}'=\boldsymbol{r}},
\end{aligned}$$

$^{238}U+^{238}U$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Pseudocolor
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Contour
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1.000e-06
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X Axis (fm)
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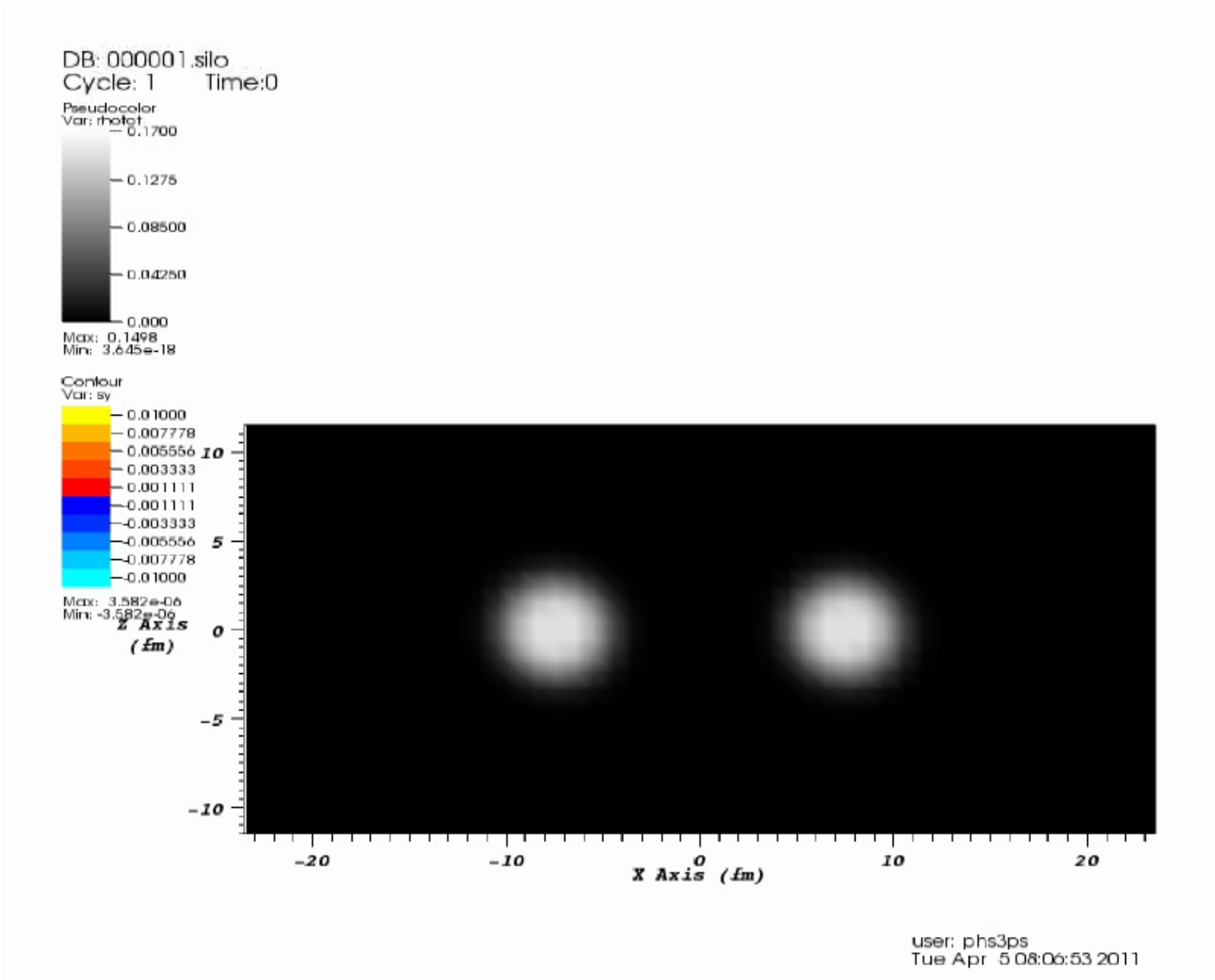
$^{16}O+^{16}O$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Contour
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0.003333
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20
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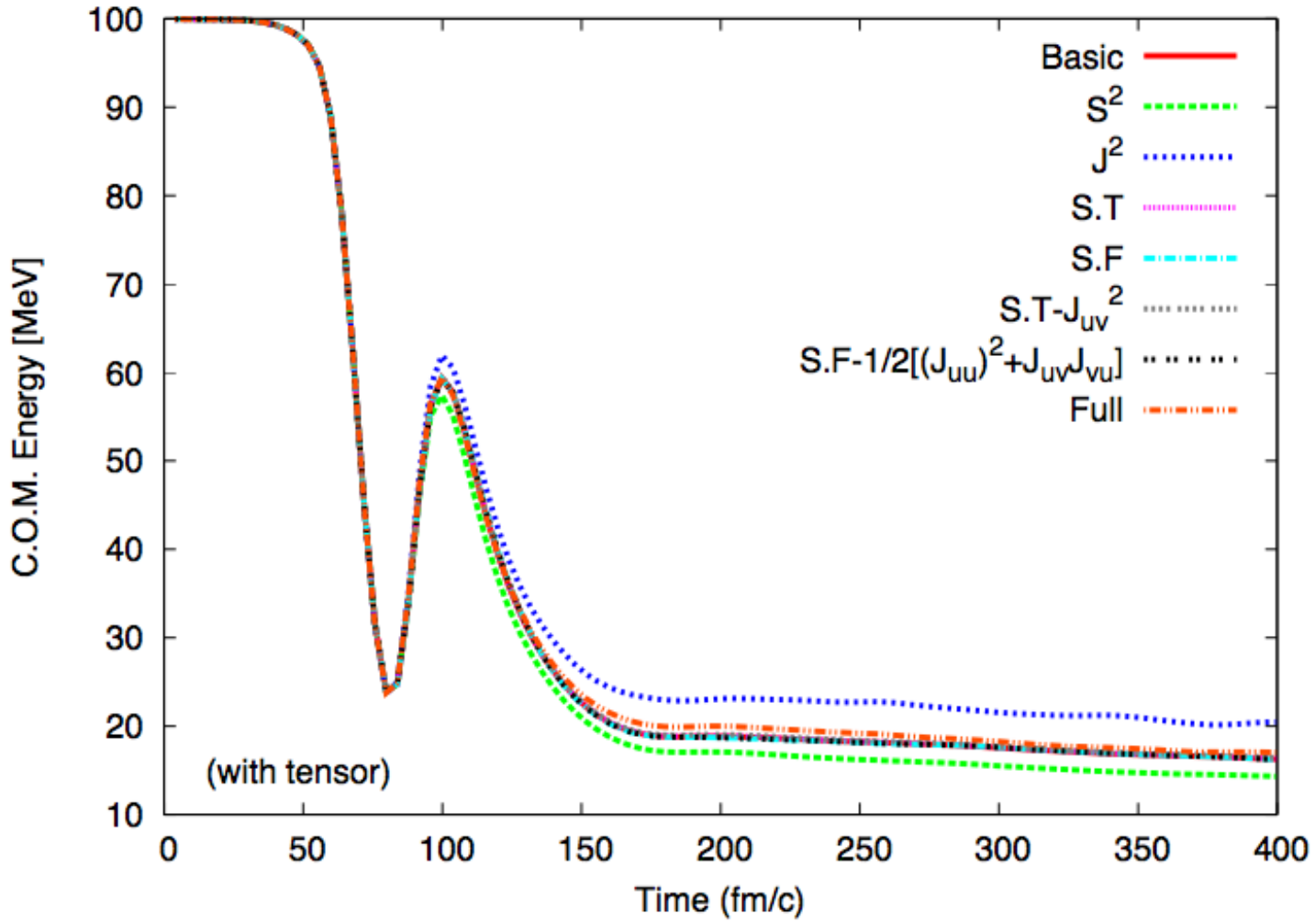
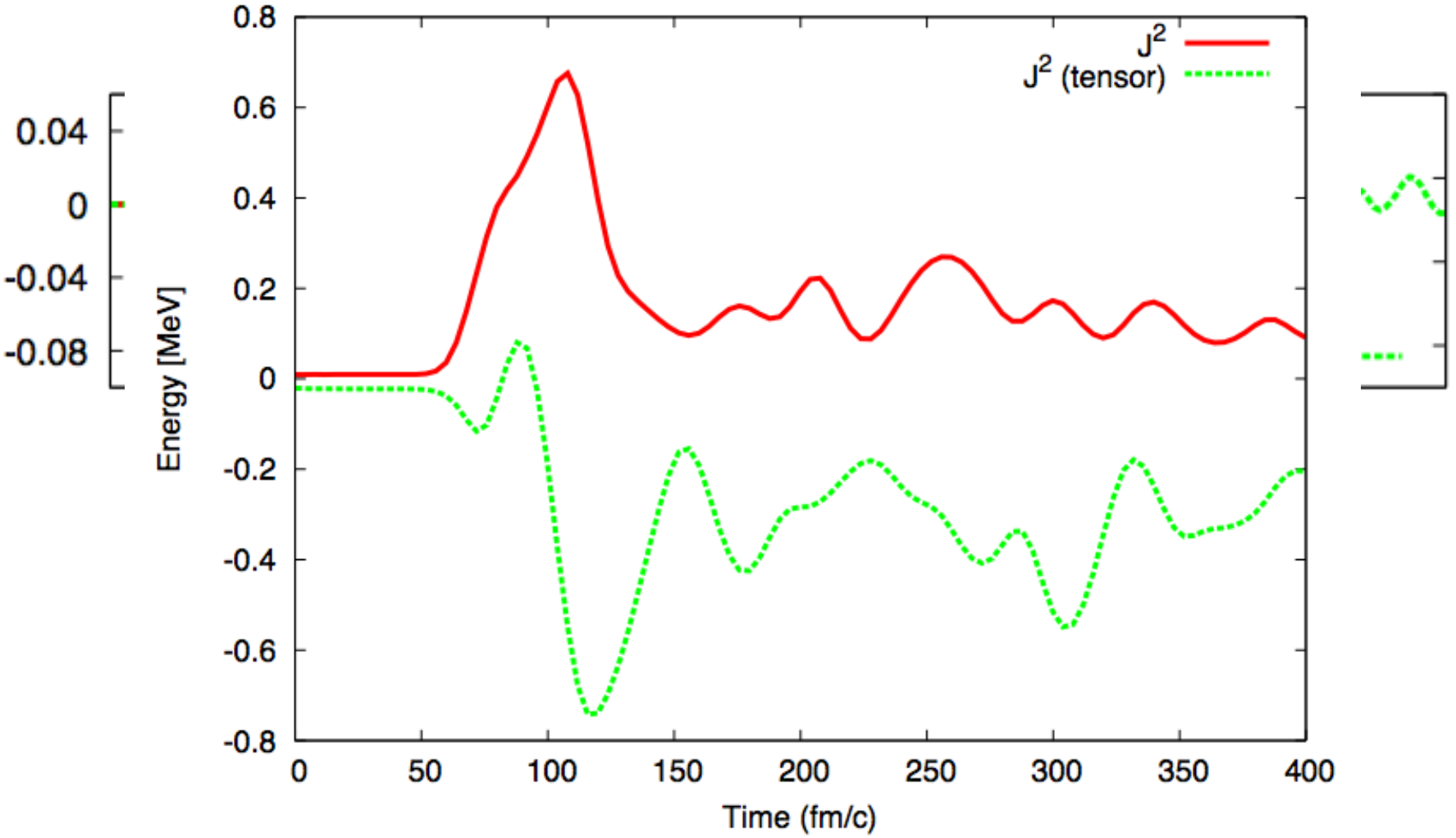
Tue Apr 5 08:06:53 2011

$^{16}O+^{16}O$

SLy5 with tensor as in Coló et al, PL**B646**, 227 (2007)



Energy density terms



$^{16}O+^{16}O$

Force	Barrier [MeV]	Threshold [MeV]	Thresh/Umar [MeV]*
SkM* (basic)	9	77	77
SkM* + full t_{odd}	9	73	73
SLy5 + full t_{odd}	10	68	68
SLy5 + tensor	10	65	-
T12	9	60	-
T14	9	70	-
T22	9	62	-
T24	9	71	-
T46	9	85	-

* A. S. Umar and V. E. Oberacker, *Phys. Rev.* **C 73**, 054607 (2006)

Summary

- We have performed symmetry-unrestricted 3D Time-dependent Hartree Fock
- Skyrme force includes all time-odd and tensor parts
- Tensor force fits taken from the literature show a range of results for fusion windows for $^{16}O+^{16}O$
- “New” parts of functional have finite effect. J^2 term dominant change in tensor fits