Interaction-dependence and independence in low-energy $E1$ excitations of neutron-rich nuclei

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Contents :

I. Introduction

"L parameter" — a key to nuclear symmetry energy

$\Longleftarrow$ nuclear structure ?

- n-skin thickness
- (low-energy) $E1$ strength

} — how good ?

$\leftarrow$ EDF approach ("MFA", "RPA")

$\cdots$ naturally connected to infinte matter

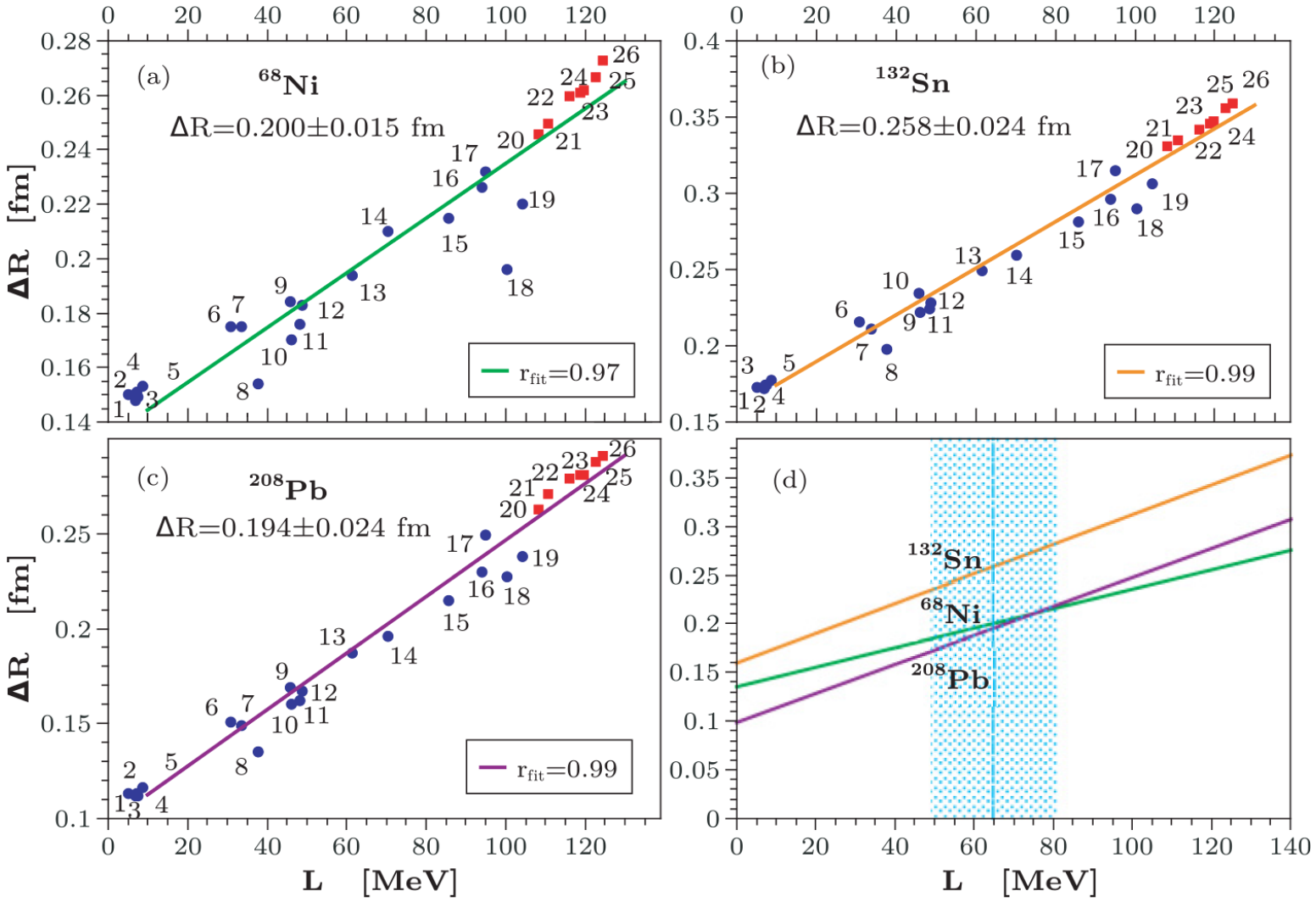
- reference to droplet picture ? $\rightarrow$ numerically testable
- empirical law ?

{ model-dependence ? (many-body effects ?)
{ interaction (functional)-dependence ?
{ nucleus-dependence ?

$\rightarrow$ careful assessment needed !

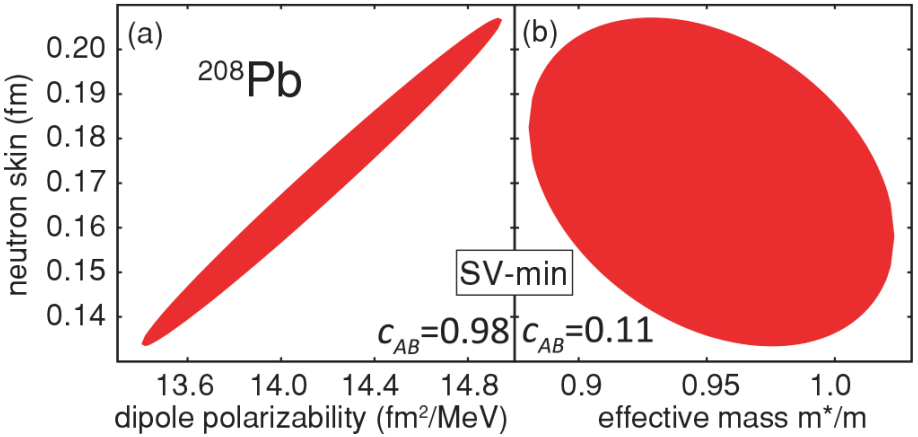
II. L parameter *vs.* dipole polarizability α_D

- L ***vs.*** Δr_{np}

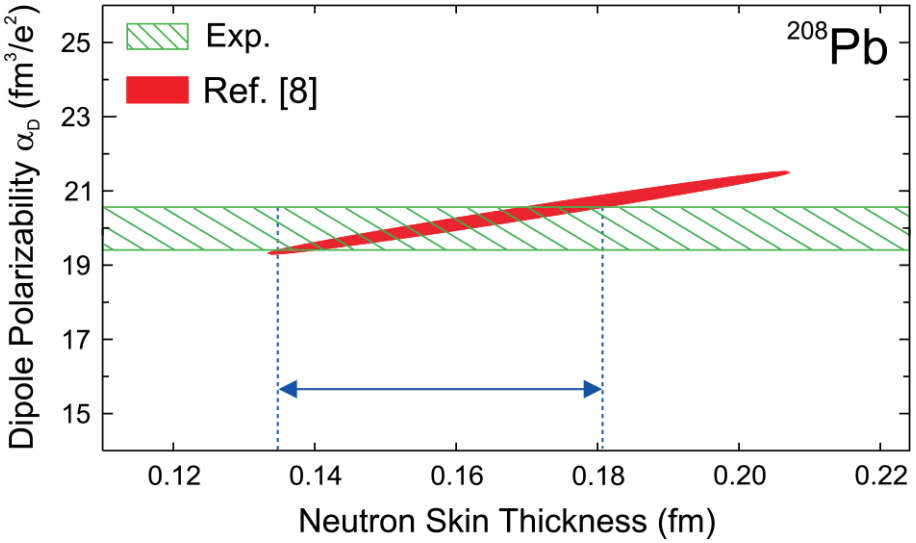


A. Carbone *et al.*, P.R.C 81, 041301(R) ('10)

- Δr_{np} ***vs.*** α_D



P.-G. Reinhardt & W. Nazarewicz,
P.R.C 81, 051303

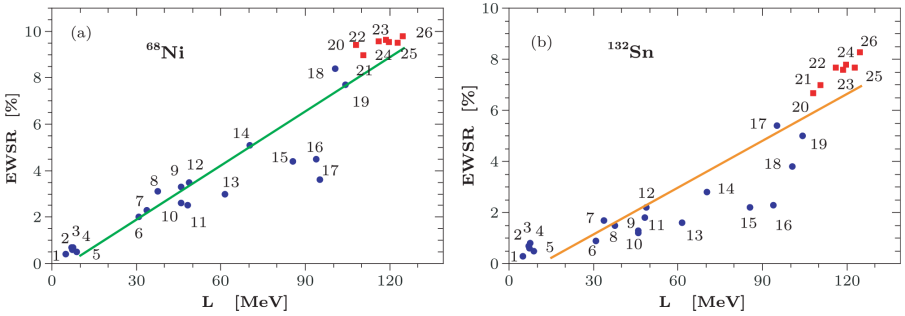


A. Tamii *et al.*,
P.R.L. 107, 062502

if $\left.\begin{array}{l} L \leftrightarrow \Delta r_{np} \\ \Delta r_{np} \leftrightarrow \alpha_D \end{array}\right\} \Rightarrow \quad L \leftrightarrow \alpha_D$

$\cdots$ **fully empirical**
$\rightarrow$ **foundation ? model-dep. ?**

cf. L ***vs.*** **PDR**

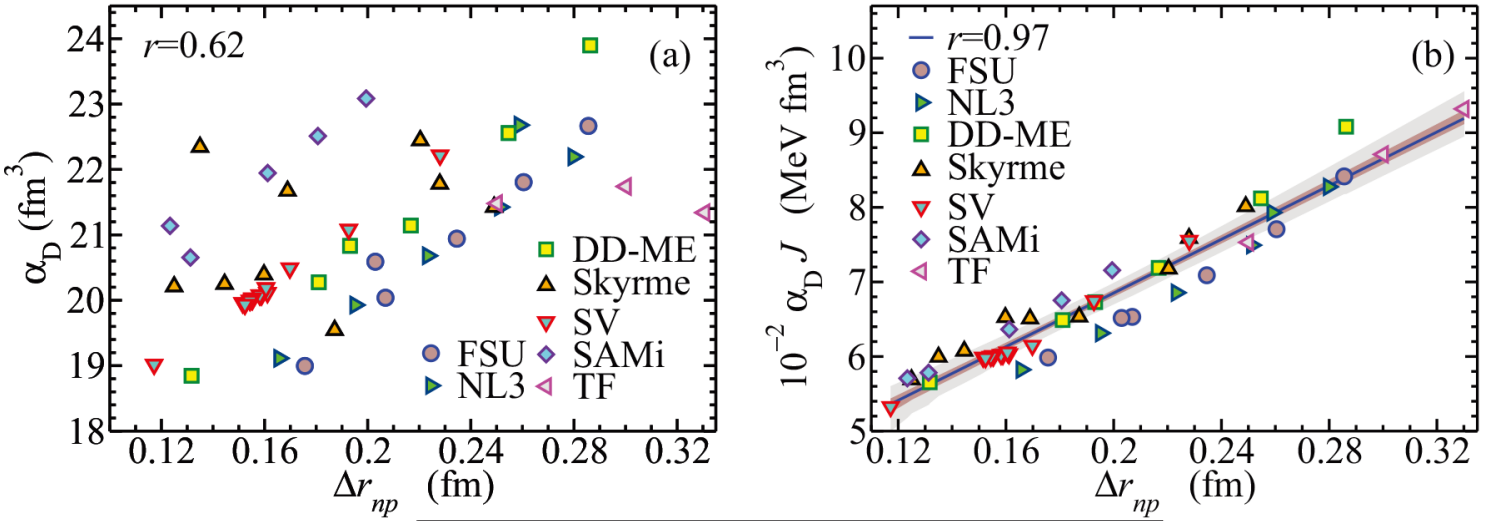


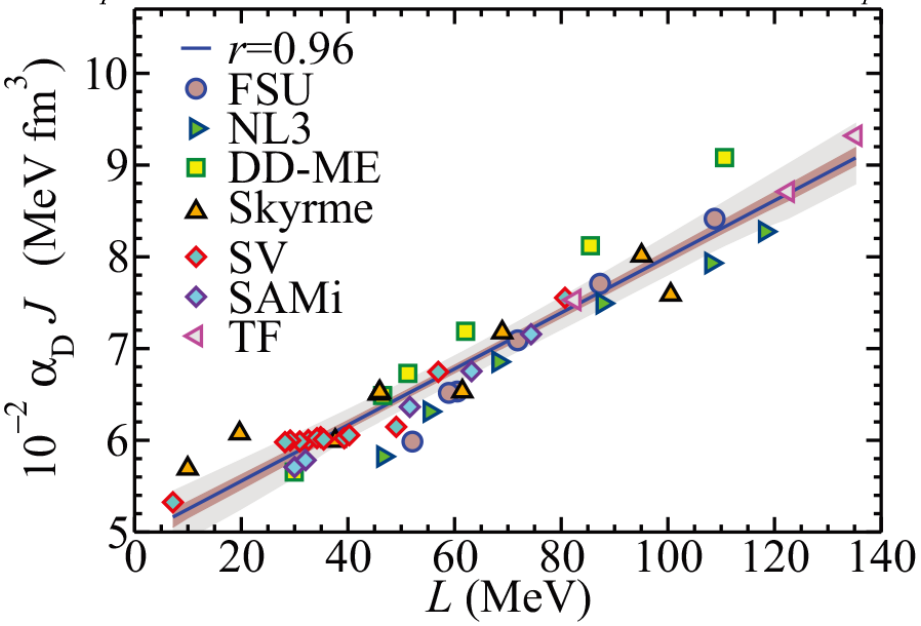
A. Carbone *et al.*,
P.R.C 81, 041301(R) ('10)

- L ***vs.*** $S_0\alpha_D$

X. Roca-Maza *et al.*, P.R.C 88, 024316 ('13)

droplet model $\rightarrow$ $S_0\alpha_D \approx \frac{\pi e^2}{54} A\langle r^2\rangle \left[1 + \frac{5(\rho_0 - \rho_A)}{9\rho_0}\frac{L}{S_0}\right]$





Further test of interaction- and nucleus-dependence

T. Inakura & H.N., in preparation

For interaction-dep.

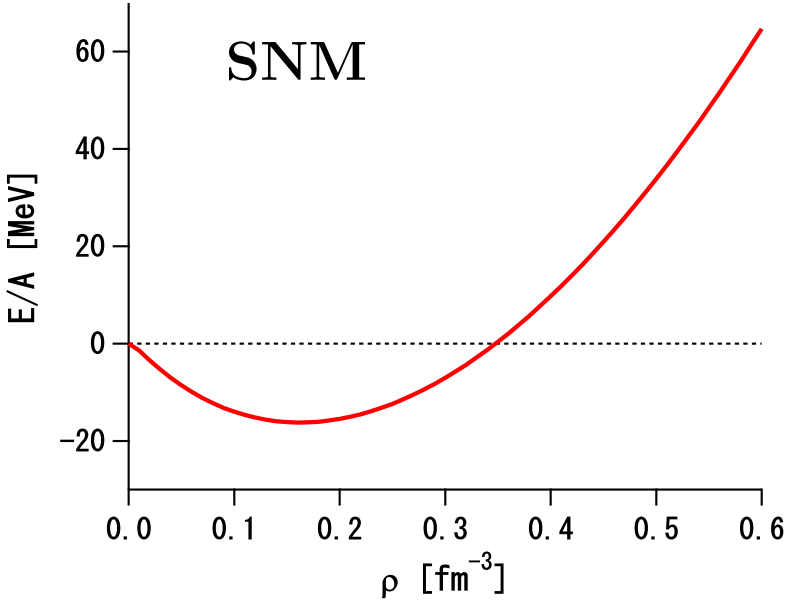
$$\hat{H}_{\rm Sky} \quad \rightarrow \quad \hat{H}_{\rm Sky} + \hat{V}_{\rm add}\,; \qquad \hat{V}_{\rm add} = -t'_3\left[\rho(\boldsymbol{r}_1)^\alpha - \rho_0^\alpha\right] P_\sigma\, \delta(\boldsymbol{r}_1 - \boldsymbol{r}_2)$$

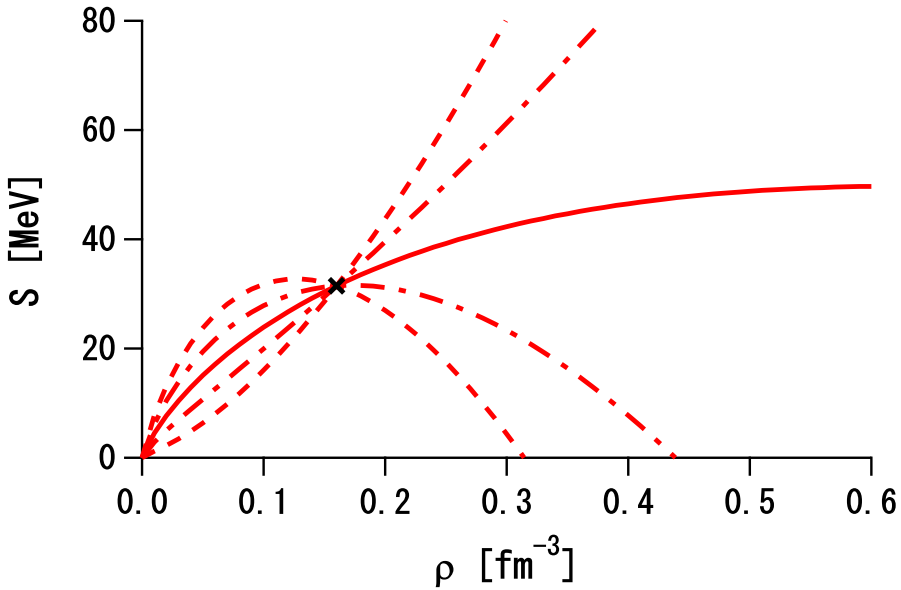
Ref.: A. Ono *et al.*, P.R.C 68, 051601(R) ('03)

i.e. $E_{\rm Sky}[\rho(\boldsymbol{r}), \cdots] \quad \rightarrow \quad E_{\rm Sky} + E_{\rm add}\,;$

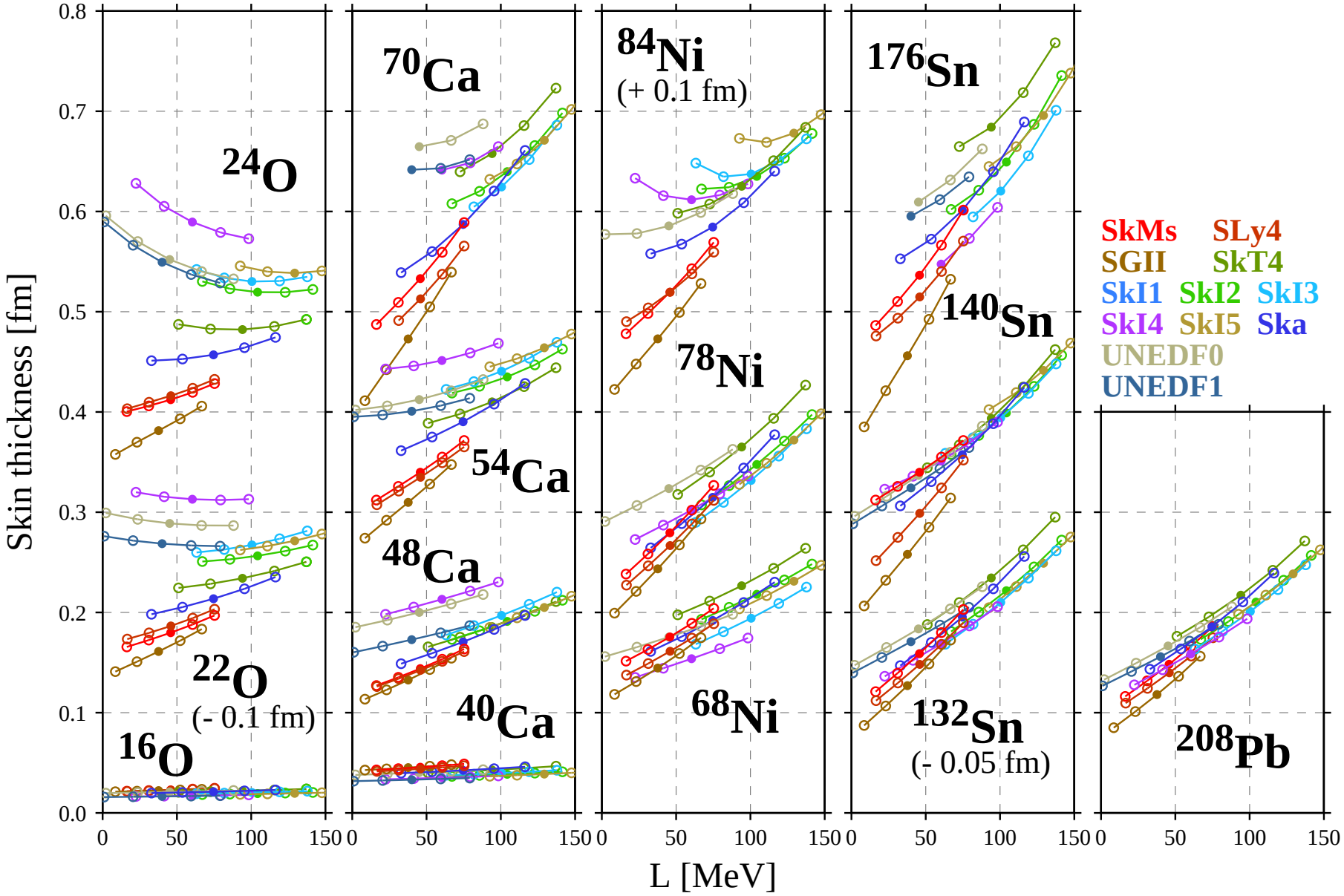
$$E_{\rm add} = \tfrac{1}{2} t'_3\left[\rho(\boldsymbol{r})^\alpha - \rho_0^\alpha\right] \cdot \left[\rho_n(\boldsymbol{r}) - \rho_p(\boldsymbol{r})\right]^2 \qquad (t'_3 = 0, \pm 1000, \pm 2000)$$

- **no influence on sym. matter** $(E/A)(\rho, \eta_t = 0)\,; \quad \eta_t := (\rho_n - \rho_p)/\rho$
- **no influence on sym. energy** S_0 $\left(:= \tfrac{1}{2}(\partial^2/\partial\eta_t^2)[(E/A)(\rho_0, \eta_t)]|_{\eta_t=0} \right)$



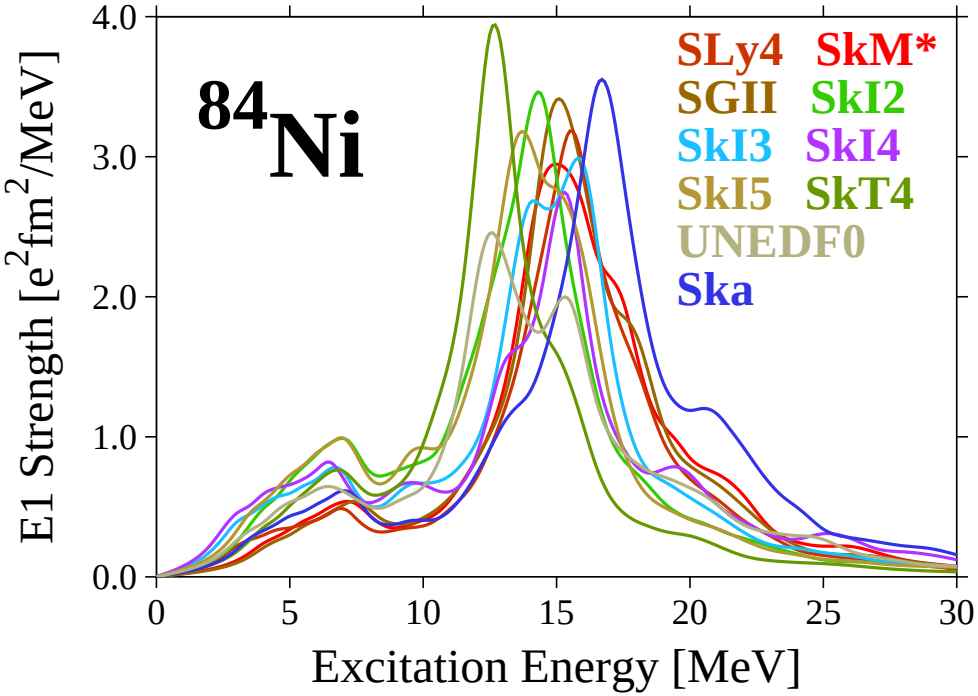


★ L *vs.* Δr_{np}

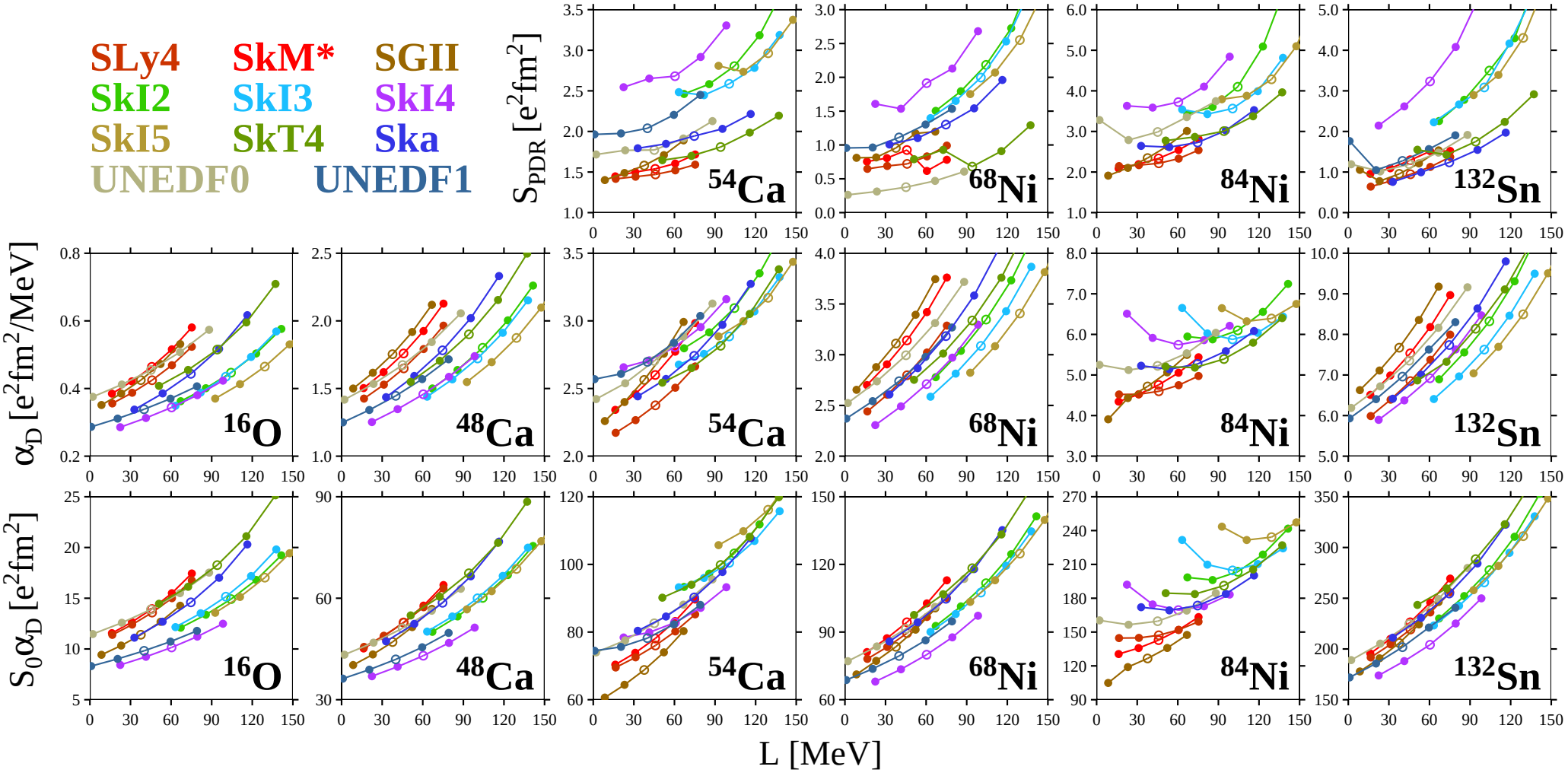


★ L ***vs.*** $S_{\rm PDR}$, α_D, $S_0\alpha_D$

$S_{\rm PDR}$:



$$S_{\rm PDR} := \int_0^{\omega_{\rm dip}} d\omega\, S^{(E1)}(\omega)$$


SLy4
SkM*
SGII
SkI2
SkI3
SkI4
SkI5
SkT4
Ska
UNEDF0
UNEDF1
S_{PDR} [e^2fm^2]
α_D [e^2fm^2/MeV]
$S_0\alpha_D$ [e^2fm^2]
^{16}O
^{48}Ca
^{54}Ca
^{68}Ni
^{84}Ni
^{132}Sn
L [MeV]

- **$S_0\alpha_D$ as well as Δr_{np} correlates to L with less interaction-dep. than $S_{\rm PDR}$ and α_D, though not always good enough.**

- **Heavy mass & well-developed PDR make their correlation more conspicuous, and therefore better in constraining L from Δr_{np} or $S_0\alpha_D$.**

  ^{68}Ni, ^{132}Sn (, ^{208}Pb) $\cdots$ not good enough !?

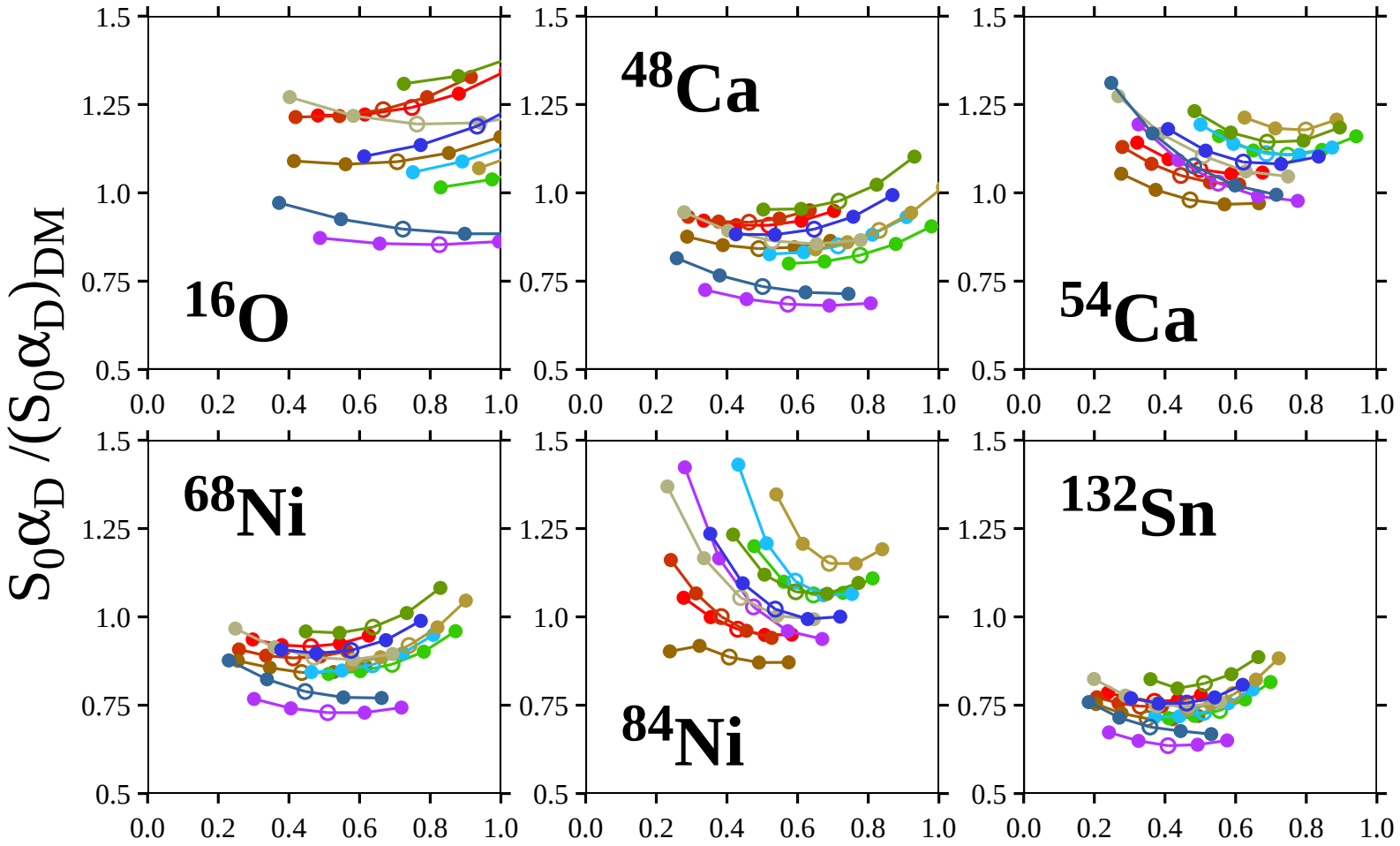
  $\rightarrow$ better candidates ? (under investigation)

- **Halo nuclei (*e.g.* ^{84}Ni) are not welcome ;**

  $\because$) strongly influenced by loosely bound orbitals.

★ Comparison to droplet-model estimate (preliminary)

$$x_A := \frac{9S_0}{4Q}A^{-1/3} \qquad \cdots \; x_A \ll 1 \text{ assumed in DM arguments}$$



not necessarily $x_A \ll 1$ nor $S_0\alpha_D/(S_0\alpha_D)_{\rm DM} \approx 1$!

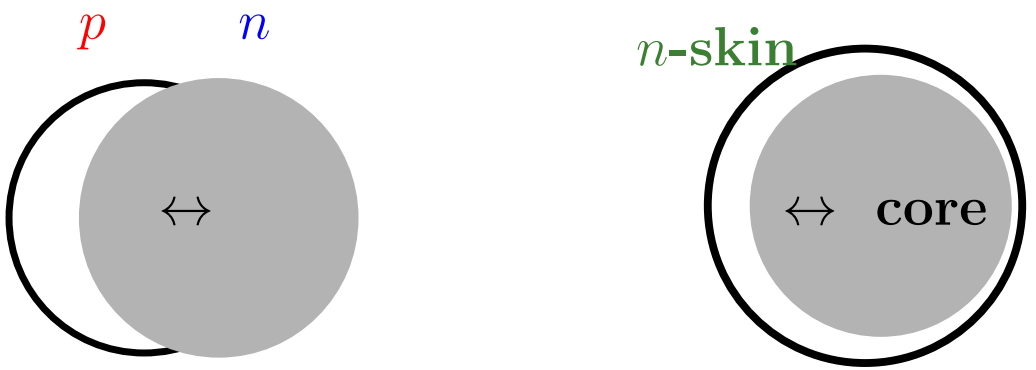
III. L parameter *vs.* PDR, revisited

Character of PDR ? $\Rightarrow$ **analysis using transition densities**

H.N., T. Inakura & H. Sawai, P.R.C 87, 034302 ('13)

(low-energy) $E1$ **excitation**

—
- "pn **mode**" : **oscillation between** p **&** n
- "**skin mode**" : **oscillation between core & skin**

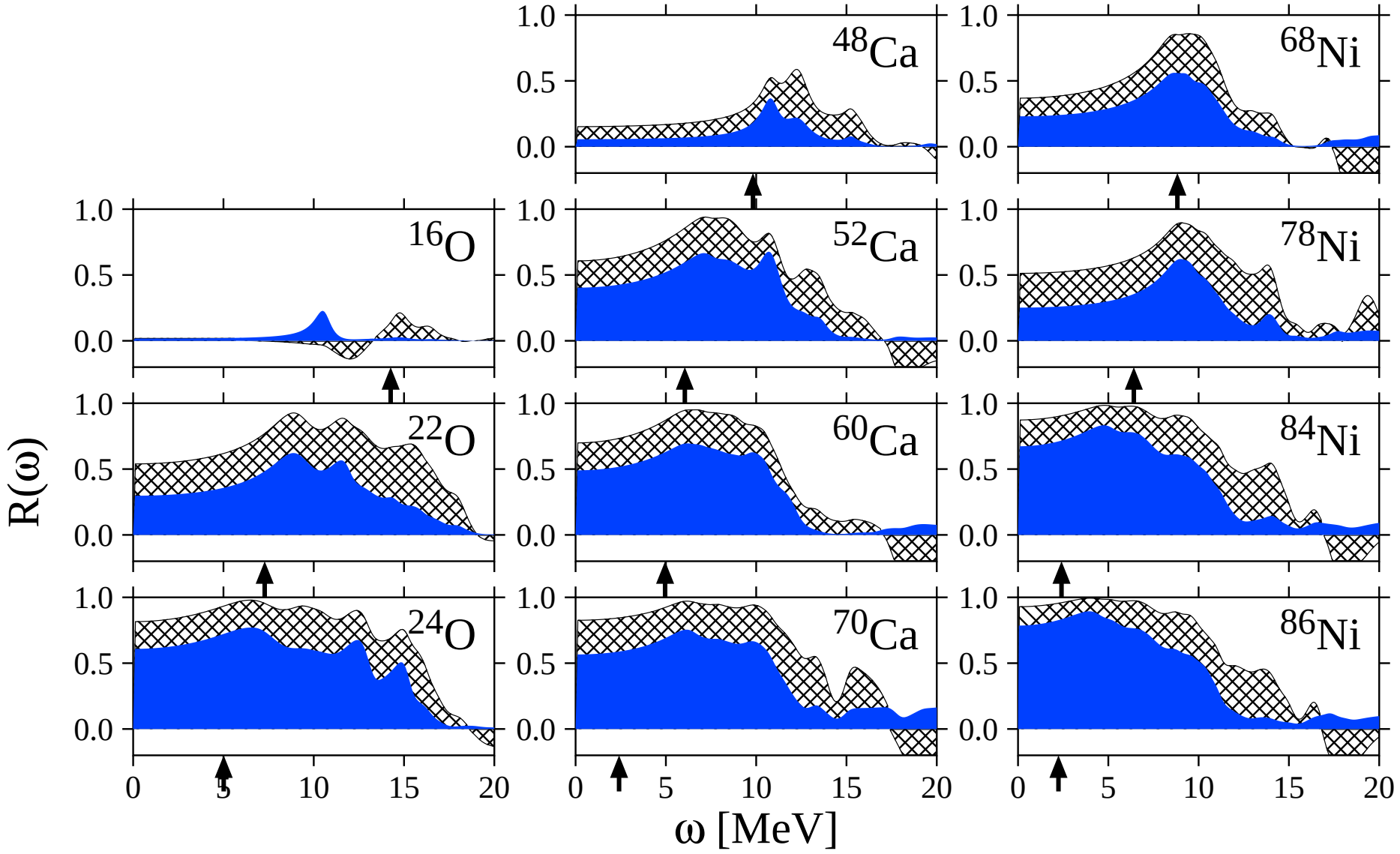


- **& their mixture**

phase of p/n **transition densities at each** r

$\rightarrow$ **decomposition into** pn **& skin modes**

$$\langle f|\mathcal{O}^{(E1)}|i\rangle = \langle f|\mathcal{O}^{(E1)}|i\rangle_{pn} + \langle f|\mathcal{O}^{(E1)}|i\rangle_{\rm skin} \quad \rightarrow \quad R_{\rm skin}(\omega) = \frac{S^{(E1)}_{\rm skin}(\omega)}{S^{(E1)}_{\rm tot}(\omega)}$$



$R_{\rm skin}(\omega)$ — **nucleus- & interaction-dep. very weak !**

$\Rightarrow$ correlation of "skin mode" & L parameter ?

(future work)

IV. Summary

To constrain the L parameter from nuclear structure information, interaction-dependence is checked within the EDF approach.

- **$S_0\alpha_D$ as well as Δr_{np} in heavy nuclei with well-developed PDR seem to be useful.**
- **Character of PDR deserves being examined further.**

  $\rightarrow$ possibility of alternative & more transparent connection ?