Nuclear Shell Structure, Nuclear Forces and Nuclear Weak Processes

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1. New shell-model Hamiltonians with proper tensor forces

- SFO: p-shell, p-sd shell
- GXPF1: pf-shell
- VMU (monopole-based universal interaction): sd-pf, p-sd

Spin modes - GT strengths - are well described.
Applications to nuclear weak processes - $\nu$-nucleus and e-capture reactions - at stellar environments, and nucleosynthesis in supernova explosions

2. Three-nucleon forces and repulsive corrections in $T=1$ monopoles

Structure of neutron-rich isotopes: C, O, Ca
Ca isotopes: $pf$ vs $pf_{9/2}$
New shell-model Hamiltonians and successful description of Gamow-Teller (GT) strengths and M1 transitions & moments

SFO (p-shell, p-sd shell): GT in $^{12}$C, $^{14}$C, M1 moments

GXPF1J (fp-shell): GT in Fe and Ni isotopes, M1 strengths
Honma, Otsuka, Mizusaki, Brown, PR C65 (2002); C69 (2004)
Suzuki, Honma et al., PR C79, (2009)

VMU (monopole-based universal interaction)
Otsuka, Suzuki, Honma, Utsuno et al., PRL 104 (2010) 012501

* important roles of tensor force

Monopole terms of $V_{NN}$

$$V_T^{M} (j_1 j_2) = \frac{\sum (2J+1) <j_1,j_2;JT | V | j_1,j_2;JT>}{\sum_j (2J+1)}$$

- $j_>- j_- :$ attractive
- $j_>- j_>, j_- - j_- :$ repulsive

G-matrix vs phenom. interactions

Tensor force $\rightarrow$ characteristic orbit dependence: kink

More repulsion than G in $T=1$
More attraction than G in $T=0$
Monopole terms: p-sd shell

$p_{1/2}$-$p_{3/2}$ (T=0) monopole and spe gap $\varepsilon(p_{1/2})$-$\varepsilon(p_{3/2})$ enhanced

Proper shell evolutions toward drip-lines: Change of magic numbers

$N=8$
Energy levels of p-shell nuclei

**Fig. 1.** Comparison of calculated and experimental energy levels for $^{10-13}\text{B}$ isotopes. Calculated energy levels are obtained for the PSDMK2, and the present and the PSDWBp Hamiltonians.

**Fig. 2.** Comparison of calculated and experimental energy levels for $^{12-15}\text{C}$ isotopes. Calculated energy levels are obtained for the PSDMK2, and present and the PSDWBp Hamiltonians.
**B(GT) values for $^{12}\text{C} \rightarrow ^{12}\text{N}$**

<table>
<thead>
<tr>
<th>PSZMK2</th>
<th>OFU*</th>
<th>PSDWBP</th>
</tr>
</thead>
</table>

**Magnetic moments of p-shell nuclei**

**B(GT) values for $^{14}\text{N} \rightarrow ^{14}\text{C}$**

**SFO**: $g_A^{\text{eff}}/g_A = 0.95$

**Space**: up to 2-3 hw

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Negret et al., PRL 97 (2006)

SFO*: $g_A^{\text{eff}}/g_A = 0.95$

**B(GT: $^{12}\text{C}$)_{cal} = experiment**

---

FIG. 3: Experimental B(GT) distributions, compared to the theoretical result of Aroua et al. [14], where the B(GT) to the $2^+$ state was scaled down by a factor of 3.
Systematic improvements in the magnetic moments and GT transitions in p-shell nuclei ($^{12}$C, $^{14}$C).

SFO*: $g_A^{\text{eff}}/g_A = 0.95 (0 - 2, 3\text{hw})$

$B(\text{GT: } 12\text{C})_{\text{cal}} = \text{experiment}$

$^{12}\text{C} (\nu_e, e^-) ^{12}\text{N} \text{ g.s.}$


Nucleosynthesis processes of light elements

Enhancement of $^{11}\text{B}$ and $^7\text{Li}$ abundances in supernova explosions
Normal hierarchy

\( \nu_\mu, \nu_\tau \to \nu_e \)

Increase in the rates of charged-current reactions

\( ^4\text{He}(\nu_e,e^-p)^3\text{He} \)

\( ^{12}\text{C}(\nu_e,e^-p)^{11}\text{C} \)

in the He layer
"Inverted Mass Hierarchy" is statistically more preferred!

First Detection of $^7\text{Li}/^{11}\text{B}$ in SN-grains


- T2K, MINOS (2011)
- Double CHOOZ, Daya Bay, RENO (2012)

$\sin^2 2\theta_{13} = 0.1$
- New $\nu^{-13}\text{C}$ cross sections with SFO

$^{13}\text{C}$ is a good target for low-energy $\nu$ detection; $E<10$ MeV
Suzuki, Balantekin and Kajino, PR C86, 015502 (2012)

$E_{th}(^{12}\text{C}) = 13$ MeV

$^{13}\text{C}$: 1% natural abundance in C isotopes

- New $\nu^{-16}\text{O}$ cross sections with SFO-tls

Full inclusion of tensor force in p-sd cross shells:

- tensor $\rightarrow \pi+\rho$
- LS $\rightarrow \sigma+\rho+\omega$

\[
\frac{\sigma(^{16}\text{O}(\nu, \nu'\alpha)p^{11}\text{B}))}{\sigma(^{12}\text{C}(\nu, \nu'p)^{11}\text{B})} \approx 20\%
\]

$^{11}\text{B}$ is produced from $^{16}\text{O}$ also
- $\nu$-$^{40}$Ar reactions

Liquid argon = powerful target for SN$\nu$ detection

VMU= Monopole-based universal interaction

tensor force: bare$\approx$renormalized

O $sd$-$pf$ shell: $^{40}$Ar ($\nu$, $e^{-}$) $^{40}$K
SDPF-VMU-LS
sd: SDPF-M (Utsuno et al.)
fp: GXPF1 (Honma et al.)
$sd$-$pf$: VMU + 2-body LS
$(sd)^{-2}$ $(fp)^{2}$ : 2hw

B(GT) & $\nu$-$^{40}$Ar cross sections
Solar $\nu$ cross sections folded over $^{8}$B $\nu$ spectrum

Important roles of tensor force

Otsuka, Suzuki, Honma, Utsuno, Tsunoda, Tsukiyama, Hjorth-Jensen
PRL 104 (2010) 012501

Suzuki and Honma, PR C87, 014607 (2013)
$^40\text{Ar} \rightarrow ^{40}\text{K}$

$p,n$ Bhattacharya et al., PR C80 (2009)

$^40\text{Ar} (\nu, e^-)^{40}\text{K}$
GT+IAS
$E_e > 5\text{ MeV} : \text{ICARUS}$

SDPF-VMU-LS
WBT

EXP.

$\Sigma B(\text{GT})$

$E_x (\text{MeV})$

$B(\text{GT})$

$E_x (\text{MeV})$

$\sigma (10^{-42}\text{cm}^2)$

GT+IAS
GT
SDPF-VMU-LS

$E_x (\text{MeV})$
Solar $\nu$ cross sections folded over $^8B\nu$ spectrum

$^40\text{Ar} (\nu, e^-)^{40}\text{K}$

\begin{align*}
\text{SDPF-VMU} & \quad \text{Ormand} \\
\begin{array}{c}
\sigma (10^{-43} \text{ cm}^2) \\
18 \quad 14 \quad 12 \quad 10 \quad 8 \quad 6 \quad 4 \quad 2 \quad 0
\end{array}
\end{align*}

IAS: $C_0 + L_0 \approx [(q^2 - \omega^2)/q^2]^2 \times C_0$; \hspace{1cm} + $C_0$ only

GT: $E_{1^5} + M_1 + C_{1^5} + L_{1^5}$; \hspace{1cm} + $E_{1^5}$ only


p: SFO, sd: SDPF-M (Utsuno)

p-sd: VMU tensor = $\pi + \rho$,
2-body LS = $\sigma + \rho + \omega$ (M3Y)
central = renormalized VMU
- \( \nu - ^{56}\text{Fe}, \nu - ^{56}\text{Ni} \) and \( ^{56}\text{Ni} \) (e\(^{-}\), \( \nu \)) \( ^{56}\text{Co} \) Reactions

New shell-model Hamiltonians in pf-shell

**GXP F1:** Honma, Otsuka, Mizusaki, Brown, PR C65 (2002); C69 (2004)

**KB3:** Caurier et al, Rev. Mod. Phys. 77, 427 (2005)

- KB3G \( A = 47-52 \) KB + monopole corrections
- GXP F1 \( A = 47-66 \)

- Spin properties of fp-shell nuclei are well described

\[
B(\text{GT}) \text{ for } ^{58}\text{Ni} \quad g_A^{\text{eff}}/g_A^{\text{free}} = 0.74 \quad ^{56}\text{Fe} \rightarrow ^{56}\text{Co}
\]

Fujita et al.

- \( B(\text{GT}) = 9.5 \)
- \( B(\text{GT})_{\text{exp}} = 9.9 \pm 2.4 \)
- \( B(\text{GT})_{\text{KB3G}} = 9.0 \)

SD + \ldots : RPA (SGII)

\[
\text{SM(GXP F1J)+RPA(SGII)} \quad 259 \times 10^{-42} \text{cm}^2
\]

RHB+RQRPA(DD-ME2) \( 263 \)

RPA(Landau-Migdal force) \( 240 \)

\[
\langle \sigma \rangle_{\text{exp}} = (256 \pm 108 \pm 43) \times 10^{-42} \text{ cm}^2
\]

\[
\langle \sigma \rangle_{\text{th}} = (258 \pm 57) \times 10^{-42} \text{ cm}^2
\]
e-capture rates on $^{56}$Ni in stellar environments: $\rho Y_e = 10^7 \rightarrow 10^{10}$ g/cm$^3$

Sasano et al., PRL 107, 202501 (2011)

**Type-Ia supernova explosion**

Accretion of matter to white-dwarf from binary star
→ supernova explosion when white-dwarf mass $>$ Chandrasekhar limit
→ $^{56}$Ni (N=Z)
→ $^{56}$Ni ($e^-$, $\nu$) $^{56}$Co $Y_e = 0.5 \rightarrow Y_e < 0.5$ (neutron-rich)
→ production of neutron-rich isotopes; more $^{58}$Ni
Decrease of $e^-$-capture rate on $^{56}$Ni
→ less production of $^{58}$Ni.

Problem of over-production of $^{58}$Ni may be solved.

Suzuki, Honma, Mao, Otsuka, Kajino, PR C83, 044619 (2011)
Problem of over-production of $^{58}\text{Ni}$

Nucleosynthesis in Chandrasekhar mass models for Type Ia supernovae and constraints on progenitor systems and burning-front propagation

Koichi Iwamoto,1,2,3 Franziska Brachwitz,4 Ken'ichi Nomoto,1,2,3 Noruhiro Kishimoto,1 Hideyuki Umeda,2,3 W. Raphael Hix,5,5 and Friedrich Karl Thielemann3,4,5

Received 1999 January 11; accepted 1999 July 29

The abundance of the Fe group, in particular of neutron-rich species like $^{48}\text{Ca}$, $^{50}\text{Ti}$, $^{54}\text{Cr}$, $^{54,58}\text{Fe}$, and $^{58}\text{Ni}$, is highly sensitive to the electron captures taking place in the central layers. The yields obtained from such a slow central and ignition densities to put new constraints on the above key quantities.

\[ Y_{e} \]

\[ \rho_{9} = 0.1, 0.3, 0.6 \]

\[ \text{KGB3, GXPF1} \]

\[ T_{9} = 4 \]

\[ \text{Ratio between } ^{58}\text{Ni} / ^{56}\text{Ni} \]

\[ \text{GXPF1} \rightarrow ^{58}\text{Ni} / ^{56}\text{Ni} \text{ decreases} \]
Evolution of $8-10M_\odot$ stars and nuclear URCA processes

- $M=0.5 \sim 8M_\odot$
  He burning $\rightarrow$ C-O core $\rightarrow$ C-O white dwarfs

- $M > 10M_\odot$
  $\rightarrow$ Fe core $\rightarrow$ core-collapse supernova explosion

- $M=8M_\odot \sim 10M_\odot$
  C burning $\rightarrow$ O-Ne-Mg core
  $\rightarrow$ (1) O-Ne-Mg white dwarf (WD)
  $\rightarrow$ (2) e-capture supernova explosion (collapse of O-Ne-Mg core induced by e-capture) with neutron star (NS) remnant
  $\rightarrow$ (3) core-collapse (iron-core collapse) supernova explosion with NS (neon burning shell propagates to the center)

Fate of the star is sensitive to its mass and nuclear e-capture and \(\beta\)-decay rates; Cooling of O-Ne-Mg core by nuclear URCA processes determines (2) or (3).

Detailed e-capture and beta-decay rates for URCA nuclear pairs in 8-10 solar-mass stars

Nuclear URCA process

\[ ^{23}Na + e^- \rightarrow ^{23}Ne + \nu \]
\[ ^{23}Ne \rightarrow ^{23}Na + e^- + \bar{\nu} \]
\[ ^{25}Mg + e^- \rightarrow ^{25}Na + \nu \]
\[ ^{25}Na \rightarrow ^{25}Mg + e^- + \bar{\nu} \]
\[ ^{27}Al + e^- \rightarrow ^{27}Mg + \nu \]
\[ ^{27}Mg \rightarrow ^{27}Al + e^- + \bar{\nu} \]

Cooling of O-Ne-Mg core of stars
→ ‘e-cap.SNe’ or ‘core-collapse SNe’

Richter, Mkhize, Brown, PR C78, 064302 (2008)
$^{23}\text{Ne}, \; ^{23}\text{Na}$

\begin{align*}
\Delta \log_{10}(\rho Y_e) &= 0.06 \\
\Delta \log_{10}(\rho Y_e) &= 0.2
\end{align*}

8.0 < $\log_{10}(\rho Y_e)$ < 9.2 in steps of 0.02

8.0 < $\log_{10} T$ < 9.2 in steps of 0.05

cf: Oda et al., At. Data and Nucl. Data Tables 56, 231 (1994): $\Delta \log_{10}(\rho Y_e) = 1.0$

URCA density at $\log_{10} \rho Y_e = 8.92$ for $A = 23$
$(^{25}\text{Na}, \ ^{25}\text{Mg})$

Cooling of O-Ne-Mg core by the nuclear URCA processes

URCA density at $\log_{10} \rho Y_e = 8.78$

$(^{27}\text{Mg}, \ ^{27}\text{Al})$

No clear URCA density for $A=27$

8.8$M_{\odot}$ star collapses triggered by subsequent e-capture on $^{24}\text{Mg}$ and $^{20}\text{Ne}$ (e-capture supernova explosion)

Toki, Suzuki, Nomoto, Jones and Hirschi, PR C 88, 015806 (2013)
### Table 1

**Summary of Model Properties**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>8.2 $M_\odot$</th>
<th>8.7 $M_\odot$</th>
<th>8.75 $M_\odot$</th>
<th>8.8 $M_\odot$</th>
<th>9.5 $M_\odot$</th>
<th>12.0 $M_\odot$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M^{C}<em>{\text{ign}}/M</em>\odot$</td>
<td>0.15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>$M^{\text{Ne}}<em>{\text{ign}}/M</em>\odot$</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.93</td>
<td>0.42</td>
<td>0.00</td>
</tr>
<tr>
<td>$T^{\text{Ne}}_{\text{ign}}/\text{GK}$</td>
<td>---</td>
<td>---</td>
<td>1.318</td>
<td>1.311</td>
<td>1.324</td>
<td>---</td>
</tr>
<tr>
<td>$\psi^{\text{Ne}}_{\text{Ne}}$</td>
<td>---</td>
<td>---</td>
<td>46.0</td>
<td>15.2</td>
<td>5.6</td>
<td>---</td>
</tr>
<tr>
<td>$\rho^{\text{Ne}}_{\odot}/g \text{ cm}^{-3}$</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>$3.343 \times 10^8$</td>
<td>$7.396 \times 10^7$</td>
<td>$1.730 \times 10^7$</td>
</tr>
<tr>
<td>$M_{\text{tot}}/M_\odot$</td>
<td>7.299</td>
<td>7.910</td>
<td>8.572</td>
<td>8.544</td>
<td>9.189</td>
<td>11.338</td>
</tr>
<tr>
<td>$M_{\text{en}}/M_\odot$</td>
<td>6.031</td>
<td>6.559</td>
<td>7.210</td>
<td>7.174</td>
<td>6.702</td>
<td>8.023</td>
</tr>
<tr>
<td>$M_{\text{He}}/M_\odot$</td>
<td>1.26721</td>
<td>1.35092</td>
<td>1.36230</td>
<td>1.36967</td>
<td>2.48733</td>
<td>3.31580</td>
</tr>
<tr>
<td>$M_{\text{CO}}/M_\odot$</td>
<td>1.26695</td>
<td>1.35086</td>
<td>1.36227</td>
<td>1.36964</td>
<td>1.49246</td>
<td>1.88602</td>
</tr>
<tr>
<td>Remnant</td>
<td>ONc WD</td>
<td>ONc WD/NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>SN type</td>
<td>---</td>
<td>---</td>
<td>EC-SN (IIP)</td>
<td>EC-SN (IIP)</td>
<td>CC-SN (IIP)</td>
<td>CC-SN (IIP)</td>
</tr>
</tbody>
</table>

*Note: Various elements and properties are listed in columns corresponding to different masses.*

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**Graphs**

- **Left Graph:**
  - $8.2 M_\odot$, $8.7 M_\odot$, $8.75 M_\odot$, $8.8 M_\odot$, $9.5 M_\odot$, and $12.0 M_\odot$ models are plotted on the graph.
  - The trend lines indicate variations in $T_\odot$ vs. $\rho_{\odot}/g \text{ cm}^{-3}$ for different core masses.

- **Right Graph:**
  - $X_c^{(24)}\text{Na}$, $X_c^{(25)}\text{Mg}$, and $X_c^{(27)}\text{Al}$ models are presented.
  - The graph shows $T_\odot$ vs. $\rho_{\odot}/g \text{ cm}^{-3}$ with distinct trends for each isotope concentration.
Coulomb corrections: screening effects

1. Screening effects of electrons

\[ V(r) = -\frac{Ze^2}{2\pi^2} \int \frac{e^{i\vec{k}\cdot\vec{r}}}{k^2\epsilon(k, 0)} d^3k \]

\[ = -\frac{Ze^22k_F}{2k_Fr} \frac{2}{\pi} \int \frac{\sin(2k_FR)}{q^2\epsilon(q, 0)} dq. \]

\[ V_s(r) = V(r) - \left( \frac{-Ze^2}{r} \right) = Ze^2(2k_F)J, \]

\[ V_s(0) > 0 \rightarrow \text{reduce both } e\text{-capture and } \beta\text{-decay rates} \]

2. Change of threshold energy

\[ \Delta Q_C = \mu_c(Z - 1) - \mu_c(Z), \]

\[ \mu_c(Z) = \text{the correction of the chemical potential of the ion with } Z \]

\[ \Delta Q_C \rightarrow \text{reduce } e\text{-capture rates & enhance } \beta\text{-decay rates} \]

\[ ^{25}\text{Na} \leftrightarrow ^{25}\text{Mg} \]

\[ \rho Y_e = 8.78 \rightarrow 8.81 \]

URCA density \( \rightarrow \) higher density region
2. Structure of Ca (and O) isotopes and three-body forces

Shell model

G-matrix vs. G-matrix + three-body force

G = BonnC, CD-Bonn for Ca; 3rd-order Q-box
G = Kuo, BonnC, CD-Bonn for O


FM (Fujita-Miyazawa) three-body force

Δ-excitation by two-pion exchange

• Effective neutron single-particle energies
• Ground state energies
• $E_x (2^+)$
• M1 transition in $^{48}$Ca
core-polarization effects

Kuo (HJ): 2\textsuperscript{nd}-order, up to 2hw
BonnC: 3\textsuperscript{rd}-order, up to 2-4 hw
CD-Bonn: 3\textsuperscript{rd}-order, up to 24hw


+3\textsuperscript{rd}-order
Tensor force + repulsive corrections in $T=1$ monopoles → SFO-tls

Structure of neutron-rich C isotopes; exotic M1 transitions in $^{17}$C is explained (Suzuki-Otsuka, PR C78 (2008))

3 body forces induced by $\Delta$ excitations (Fujita-Miyazawa) → repulsion in $T=1$ monopoles → drip-line at $^{24}$O in O isotopes (Otsuka, Suzuki, Holt, Schwenk, Akaishi, PRL 105, (2010))

More repulsion than G in $T=1$
More attraction than G in $T=0$
- Modification of SFO
- Full inclusion of tensor force
  - \( p\text{-sd}: \) tensor-\( \rightarrow \pi + \rho \)
  - \( LS \rightarrow \sigma + \rho + \omega \)

\[
V = V_C + V_T + V_{LS} \\
V_T = V_\pi + V_\rho \\
V_{LS} = V_\sigma + \omega + \rho
\]

- \( sd\): Kuo G-matrix
- T=1 monopole terms more repulsive
  \( \rightarrow \) SFO-tls
Anomalous suppression of B(M1) strength in $^{17}\text{C}$

$^{17}\text{C}$: B(M1: 3/2$^+$$\rightarrow$ 1/2$^+$) suppressed
Iwasaki et al., MSU

$|1/2^+|=|d_{5/2}^4(0^+)\times1s_{1/2}>$
$|3/2^+|=\alpha |d_{5/2}^3(3/2^+)\times1s_{1/2}>$
$+\beta |d_{5/2}^4(2^+)\times1s_{1/2}>$
$<3/2^+|| M1 ||1/2^+>=0$

Exp: D. Suzuki et al., PLB666 (2008)
Roles of three-body force on shell evolutions

three-body force = FM (Fujita-Miyazawa)

\[ \Delta \text{-excitation by two-pion exchange} \]

FM \rightarrow \text{repulsion between valence neutrons (T=1)}

\[ \frac{1}{\Delta E} |< pj' | V | hj >|^2 > 0 \]

\[ \frac{1}{\Delta E} |< pj | V | h'j' - j'h >|^2 > 0 \]

Oxygen isotopes: drip-line at \(^{24}\text{O}\)

**48Ca** B(M1) +3N \(\rightarrow\) concentration of the strength

EXP.: Steffen et al. NP A404, 413 (1983)

G-matrix; 3rd Q-box up to 24 hw excitations
Hjorth-Jensen

3-body force \(\rightarrow\) repulsion

shell-closure at \(A=48\)

**G**-matrix; 3rd Q-box up to 24 hw excitations
Hjorth-Jensen

**G**-matrix; 3rd Q-box up to 24 hw excitations
Hjorth-Jensen

**EXP.**
pf-$g_{9/2}$ shell

degenerate pf-$g_{9/2}$ orbits
Non-degenerate treatment of pf and $g_{9/2}$ shells by EKK (extended Kuo-Krenciglowa) method

Cf: monopoles with non-degenerate vs degenerate method

Kuo-Krenciglowa method

$$V_{\text{eff}}^{(n)} = \hat{Q}(\epsilon_0) + \sum_{k=1}^{\infty} \hat{Q}_k(\epsilon_0)\{V_{\text{eff}}^{(n-1)}\}^k,$$

$$P H_0 P = \epsilon_0 P.$$  

$$\hat{Q}(E) = PV P + PV Q \frac{1}{E - QHQ} QVP,$$

$$\hat{Q}_k(E) = \frac{1}{k!} \frac{d^k}{dE^k} \hat{Q}(E).$$

Extended Kuo-Krenciglowa method

$$\tilde{H} = H - E$$

$$\tilde{H}_{\text{eff}}^{(n)} = \tilde{H}_{BH}(E) + \sum_{k=1}^{\infty} \hat{Q}_k(E)\{\tilde{H}_{\text{eff}}^{(n-1)}\}^k,$$

$$\tilde{H}_{eff} = H_{\text{eff}} - E, \quad \tilde{H}_{RH}(E) = H_{RH}(E) - E,$$

$$H_{BH}(E) = PHP - PVQ \frac{1}{E - QHQ} QVP,$$

$$V_{\text{eff}} = H_{\text{eff}} - PH_0 P.$$  

energy independent

Ground state energies & $E(2_{1}^{+})$ for $^{48}$Ca

B(M1)

Mass number

Ex.

$\text{exp.}$

$pfg_{9/2}$

fp

Tsunoda, Shimizu
Summary

- New spin-dependent transition strengths based on new shell-model Hamiltonians with proper tensor forces (SFO for p-shell, GXPF1 for pf-shell, VMU)
- Good reproduction of experimental $B(GT)$ in $^{12}C$, $^{56}Fe$ and $^{56}Ni$ and cross section data for $\nu$-induced reactions on $^{12}C$ and $^{56}Fe$
- Light element synthesis in SN explosions and effects of $\nu$-oscillations (MSW effects) in nucleosynthesis
  Abundance ratio of $^7Li/^{11}B \rightarrow \nu$ mass hierarchy
- GXPF1J well describes the GT strengths in Ni isotopes: $^{56}Ni$ two-peak structure confirmed by recent exp.
  Accurate evaluation of e-capture rates at stellar environments
  Implications on synthesis of Ni isotopes; $^{58}Ni/^{56}Ni$
- VMU for $^{40}\text{Ar}$ (sd-pf-shell) and p-sd shell nuclei:
  GT strength consistent with observations
  New cross section for $^{40}\text{Ar} (\nu,e^-) ^{40}\text{K}$ induced by solar $\nu$

- Detailed e-capture and beta-decay rates for URCA nuclear pairs in 8-10 solar-mass stars
  → URCA density for $A=25$ and 23 with fine mesh of density and temperature
  → Cooling of O-Ne-Mg core by nuclear URCA processes determines the fate of the stars.

- Repulsive contributions from FM three-nucleon forces in $T=1$ monopoles
  → Shell evolutions in neutron-rich isotopes
    Ca: shell-closure at $^{48}\text{Ca}$ and M1 strength pf vs pf-$g_{9/2}$ by non-degenerate treatment of $g_{9/2}$
Collaborators

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