Symmetries in Nuclear and Particle Physics

- 1. Symmetries in Physics
- 2. Interacting Boson Model
- 3. Nuclear Supersymmetry
- 4. Quark Model
- 5. Unquenched Quark Model

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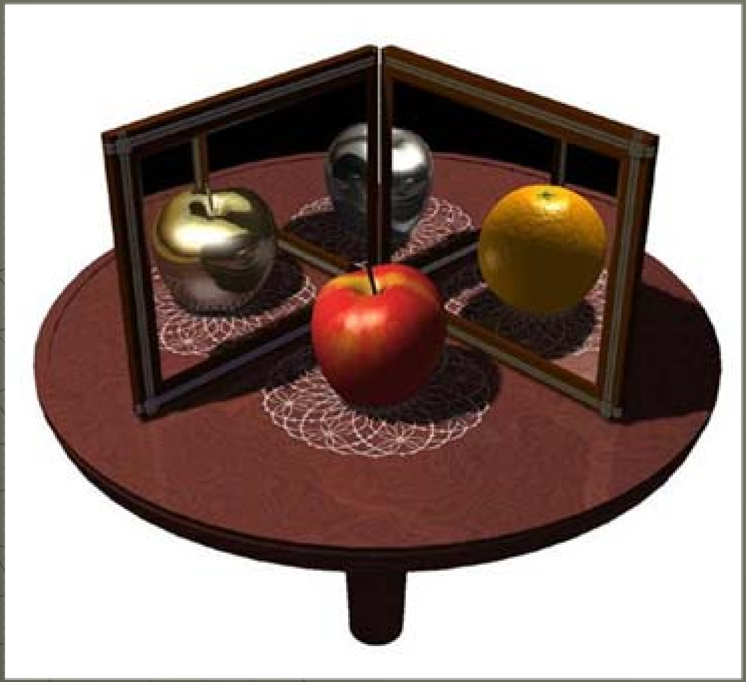
Resumen

- IBM: núcleos par-par
- IBFM: núcleos impar
- Simetrías dinámicas
- ¿Es posible describir los núcleos par-par e impares en el marco de un modelo unificado?

- La respuesta es sí: SUSY

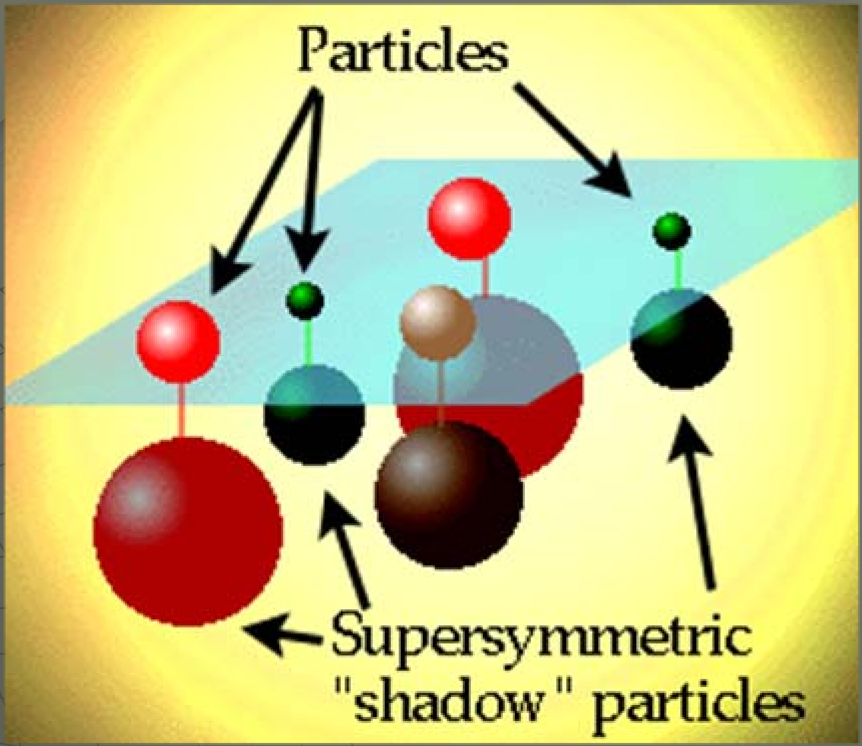
Outline

- First empirical evidence of SUSY was found in nuclear physics in 1980 (Iachello)
- Nuclear supersymmetry relates collective (bosonic) degrees of freedom with single-particle (fermionic) degrees of freedom
- New experiments in the A~190 mass region
- Pt-Au and Os-Ir nuclei
- Correlations between one- and two-nucleon transfer reactions



Supersimetría (SUSY)

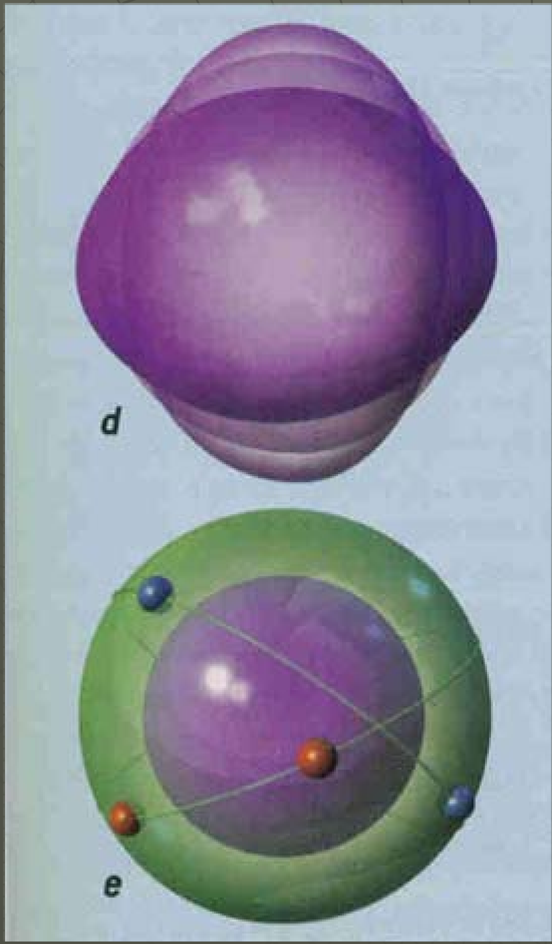
- Simetría fundamental
- Física más allá del Modelo Estándar
- Problema de jerarquía, unificación de las interacciones fuerte, débil y electromagnética
- Cada partícula tiene una pareja supersimétrica: foton-fotino, quark-squark, lepton-slepton, etc.
- Teoría bella y elegante
- ¿Solución en busca de un problema?
- LHC: búsqueda para partículas supersimétricas



¿Solución en busca de un problema?

- Álgebra de corriente (Miyazawa, 1966)
- Graded Lie groups (Berezin & Kac, 1970)
- Modelos duales (Neveu & Schwarz, 1971; Ramond, 1971)
- Teoría de campo (Volkov & Akulov, 1973; Wess & Zumino, 1974)
- Física nuclear (Iachello, 1980)
- Mecánica cuántica supersimétrica (Witten, 1981)
- ...

Interacting Boson Model



- The IBM describes even-even nuclei in terms of a system of correlated pairs of nucleons which are treated as bosons with angular momentum $L=0,2$ (Arima, Iachello, 1974)
- The IBM can be extended to odd-even nuclei by including, in addition to the collective degrees of freedom (bosons), the single-particle degrees of freedom of an extra unpaired proton or neutron (fermion with $J=j_1, j_2, \ldots$)
- Nuclear supersymmetry relates collective (bosonic) degrees of freedom with single-particle (fermionic) degrees of freedom

Building Blocks

bosons	$l = 0, 2$	$\sum_l (2l+1) = 6$
fermions	$j = j_1, j_2, \ldots$	$\sum_j (2j+1) = \Omega$

Model	Generators	Invariant	Algebra
IBM	$b_i^\dagger b_j$	N	$U(6)$
IBFM	$b_i^\dagger b_j,\ a_\mu^\dagger a_\nu$	$N,\ M$	$U(6) \otimes U(\Omega)$
SUSY	$b_i^\dagger b_j,\ a_\mu^\dagger a_\nu,\ b_i^\dagger a_\mu,\ a_\mu^\dagger b_i$	$\mathcal{N}$	$U(6/\Omega)$

$N = \sum_i b_i^\dagger b_i$	total number of bosons
$M = \sum_\mu a_\mu^\dagger a_\mu$	total number of fermions
$\mathcal{N} = N + M$	total number of bosons plus fermions

Estructura Algebraica

B_{ij}	$=$	$b_i^\dagger b_j$	boson	$\rightarrow$	boson
$A_{\mu\nu}$	$=$	$a_\mu^\dagger a_\nu$	fermion	$\rightarrow$	fermion
$F_{i\mu}$	$=$	$b_i^\dagger a_\mu$	fermion	$\rightarrow$	boson
$G_{\mu i}$	$=$	$a_\mu^\dagger b_i$	boson	$\rightarrow$	fermion

En la supersimetría se conserva
el número total de bosones y fermiones

$$\mathcal{N} = N + M$$

Graded Lie algebra U(6/Ω)

$$
\begin{aligned}
[B_{ij}, B_{kl}] &= B_{il}\delta_{jk} - B_{kj}\delta_{il} \\
[A_{\mu\nu}, A_{\rho\sigma}] &= A_{\mu\sigma}\delta_{\nu\rho} - A_{\rho\nu}\delta_{\mu\sigma} \\
[B_{ij}, A_{\mu\nu}] &= 0 \\
\left[B_{ij}, F_{k\mu}\right] &= F_{i\mu}\delta_{jk} \\
[G_{\mu i}, B_{kl}] &= G_{\mu l}\delta_{ik} \\
[F_{i\mu}, A_{\rho\sigma}] &= F_{i\sigma}\delta_{\mu\rho} \\
[A_{\mu\nu}, G_{\rho i}] &= G_{\mu i}\delta_{\nu\rho}
\end{aligned}
$$

$$
\begin{aligned}
\{F_{i\mu}, G_{\nu j}\} &= B_{ij}\delta_{\mu\nu} + A_{\nu\mu}\delta_{ij} \\
\{F_{i\mu}, F_{j\nu}\} &= 0 \\
\{G_{\mu i}, G_{\nu j}\} &= 0
\end{aligned}
$$

Supermultiplete

$$\begin{array}{ccccccc} U(6/\Omega) & \supset & U(6) & \otimes & U(\Omega) \\ \mid [\mathcal{N}\} & , & [N] & , & \{M\} \rangle \\ & & & & \\ b_i^\dagger b_j & & b_i^\dagger b_j & & \\ a_\mu^\dagger a_\nu & & & & a_\mu^\dagger a_\nu \\ b_i^\dagger a_\mu & & & & \\ a_\mu^\dagger b_i & & & & \end{array}$$

$$\mathcal{N} = N + M$$

N	M		
$\mathcal{N}$	0	par-par	IBM
$\mathcal{N}-1$	1	impar	IBFM

El supermultiplete $[\mathcal{N}\}$ contiene
tanto a núcleos par-par como a los impares

Supersimetría U(6/4)

$$
\begin{array}{ccccc}
 & & U(6/4) & & \\
 & & [\mathcal{N}\} & & \\
 & & \downarrow & & \\
U(6) & & \otimes & & U(4) \\
[N] & & & & \{M\} \\
\downarrow & & & & \downarrow \\
SO(6) & & \otimes & & SU(4) \\
(\Sigma,0,0) & & & & (\Sigma'_1,\Sigma'_2,\Sigma'_3) \\
 & \searrow & & \swarrow & \\
 & & Spin(6) & & \\
 & & (\sigma_1,\sigma_2,\sigma_3) & & \\
 & & \downarrow & & \\
 & & Spin(5) & & \\
 & & (\tau_1,\tau_2) & & \\
 & & \downarrow & & \\
 & & Spin(3) & & \\
 & & J & &
\end{array}
$$

Hamiltoniano

$$
\begin{aligned}
H &= -A\, C_{2Spin(6)} + B\, C_{2Spin(5)} + C\, C_{2Spin(3)} \\
&= -\kappa_2\, G^{(2)} \cdot G^{(2)} + \kappa_3\, G^{(3)} \cdot G^{(3)} + \kappa_1\, G^{(1)} \cdot G^{(1)}
\end{aligned}
$$

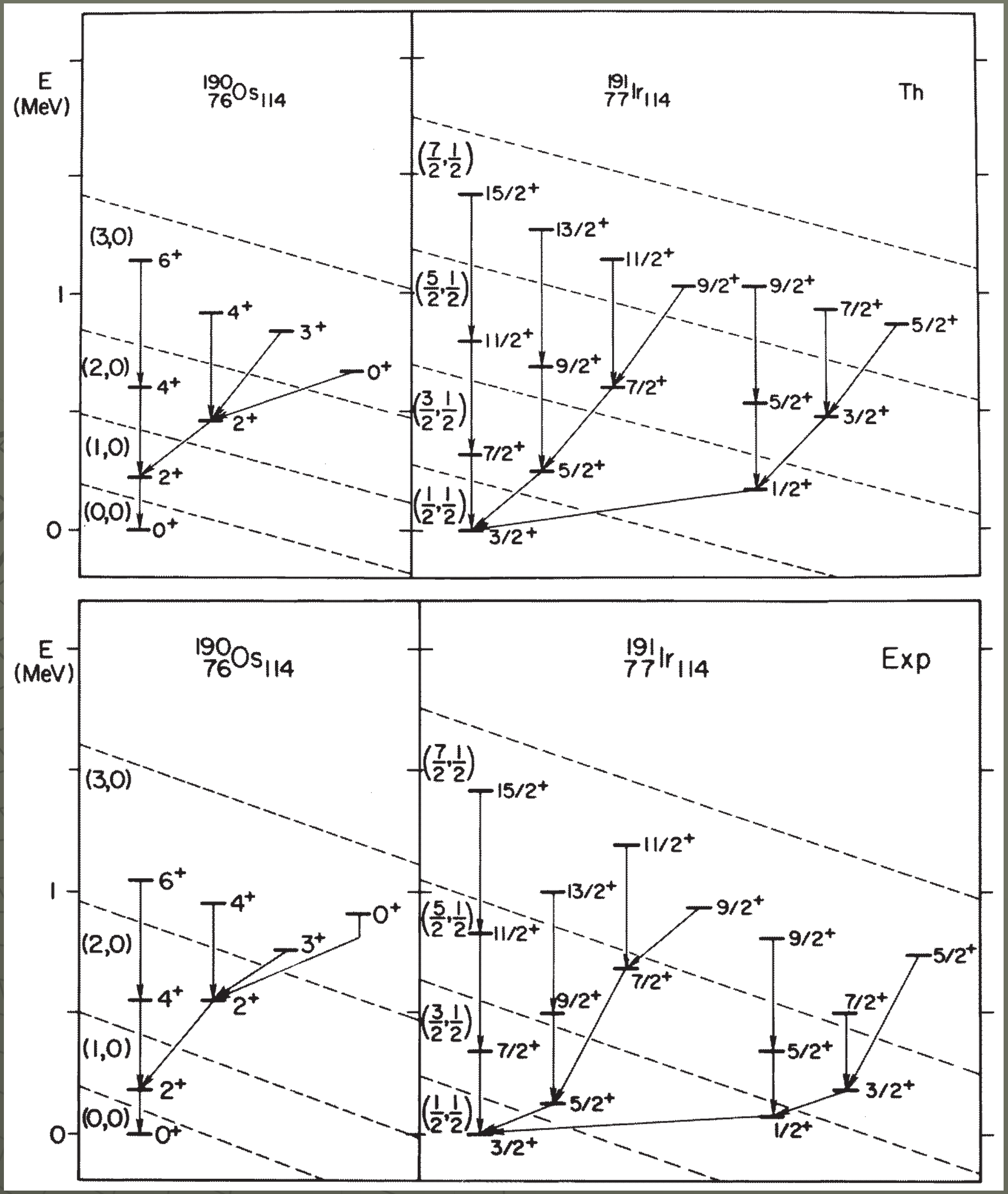
$$
\begin{aligned}
E &= -A\, \left[\sigma_1(\sigma_1+4)+\sigma_2(\sigma_2+4)+\sigma_3^2\right] \\
&\quad +B\, [\tau_1(\tau_1+3)+\tau_2(\tau_2+1)] + C\, J(J+1)
\end{aligned}
$$

$$
\begin{aligned}
\kappa_2 &= A \\
\kappa_3 &= -2A+2B \\
\kappa_1 &= -2A+2B+10C
\end{aligned}
$$

Ejemplo U(6/4)

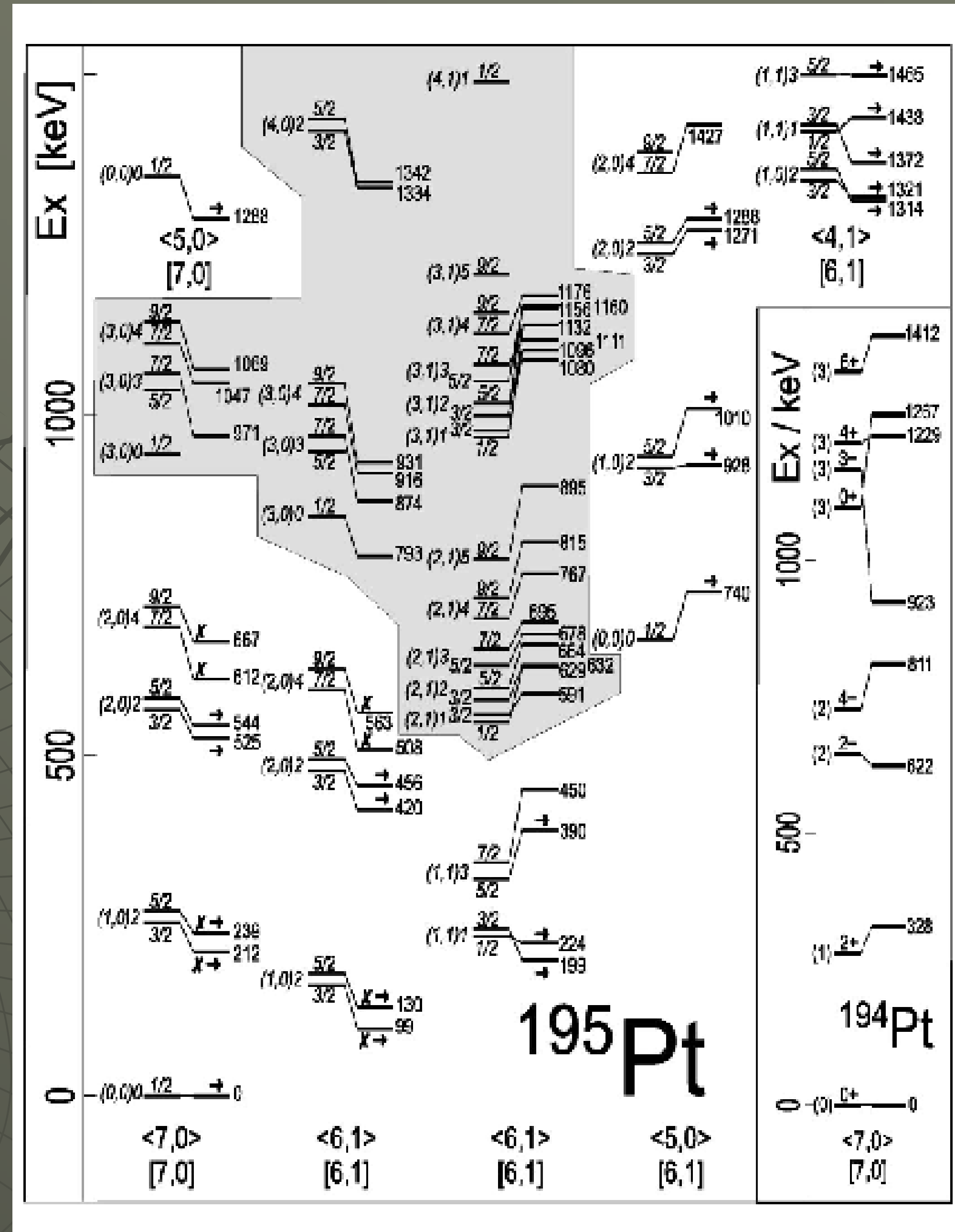
El Hamiltoniano describe simultáneamente los espectros del núcleo par-par ^{190}Os e impar ^{191}Ir con los mismos valores de los parámetros A, B y C

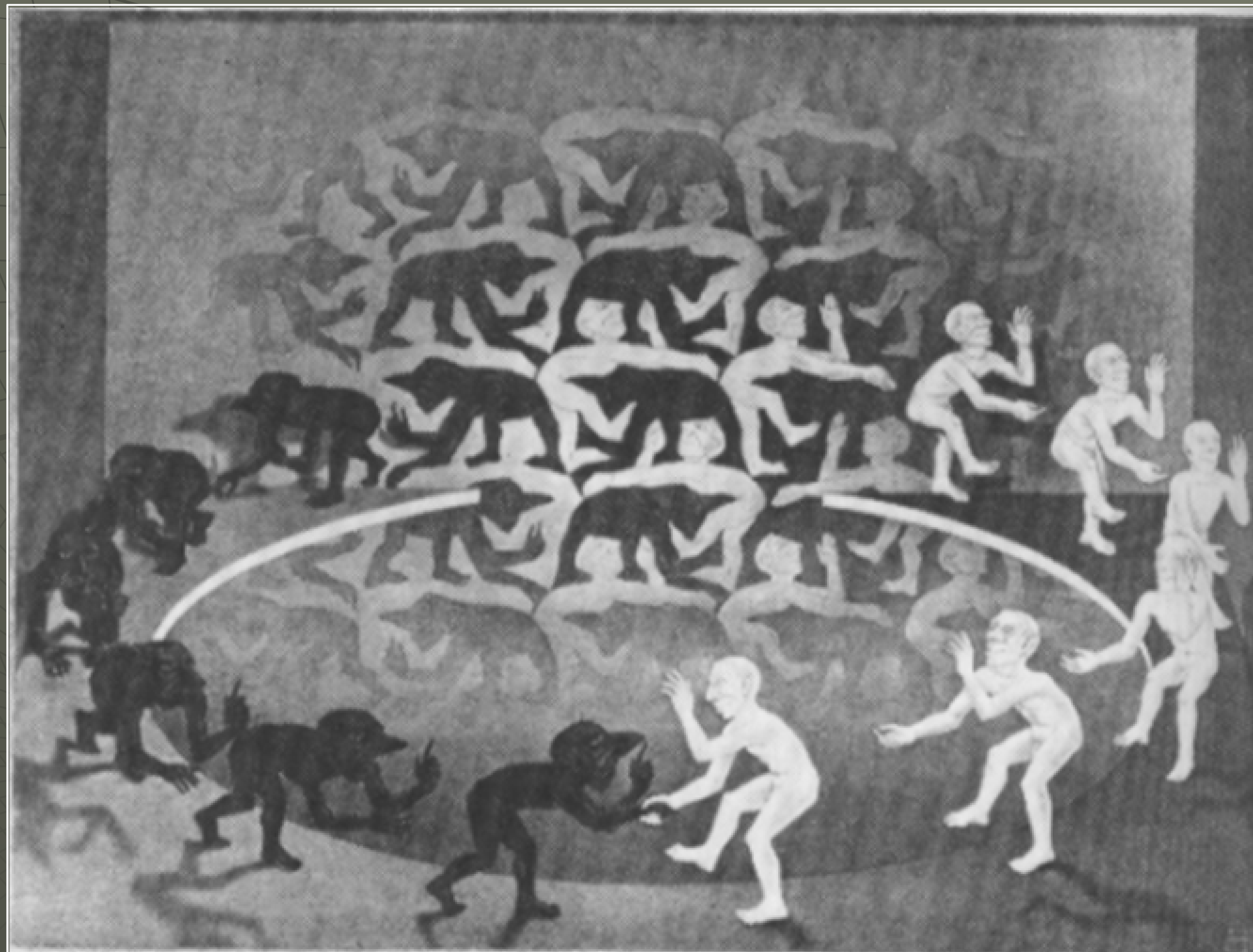
	N	M	$\mathcal{N}$
$^{190}_{76}Os_{114}$	9	0	9
$^{191}_{77}Ir_{114}$	8	1	9



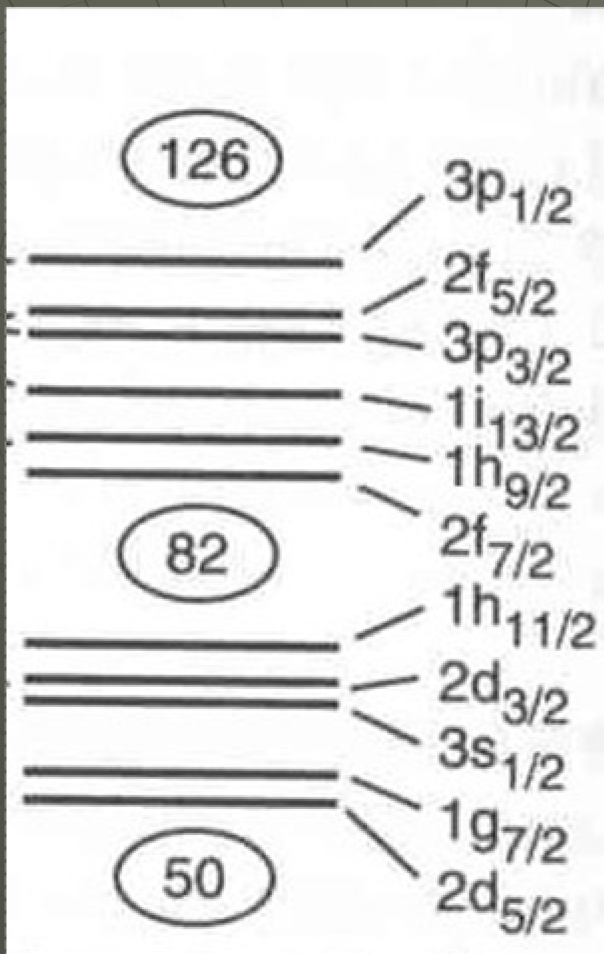
Ejemplo U(6/12)

	N	M	$\mathcal{N}$
$^{194}_{78}Pt_{116}$	7	0	7
$^{195}_{78}Pt_{117}$	6	1	7





Núcleos A~190



Niveles de neutrón, capa 82-126

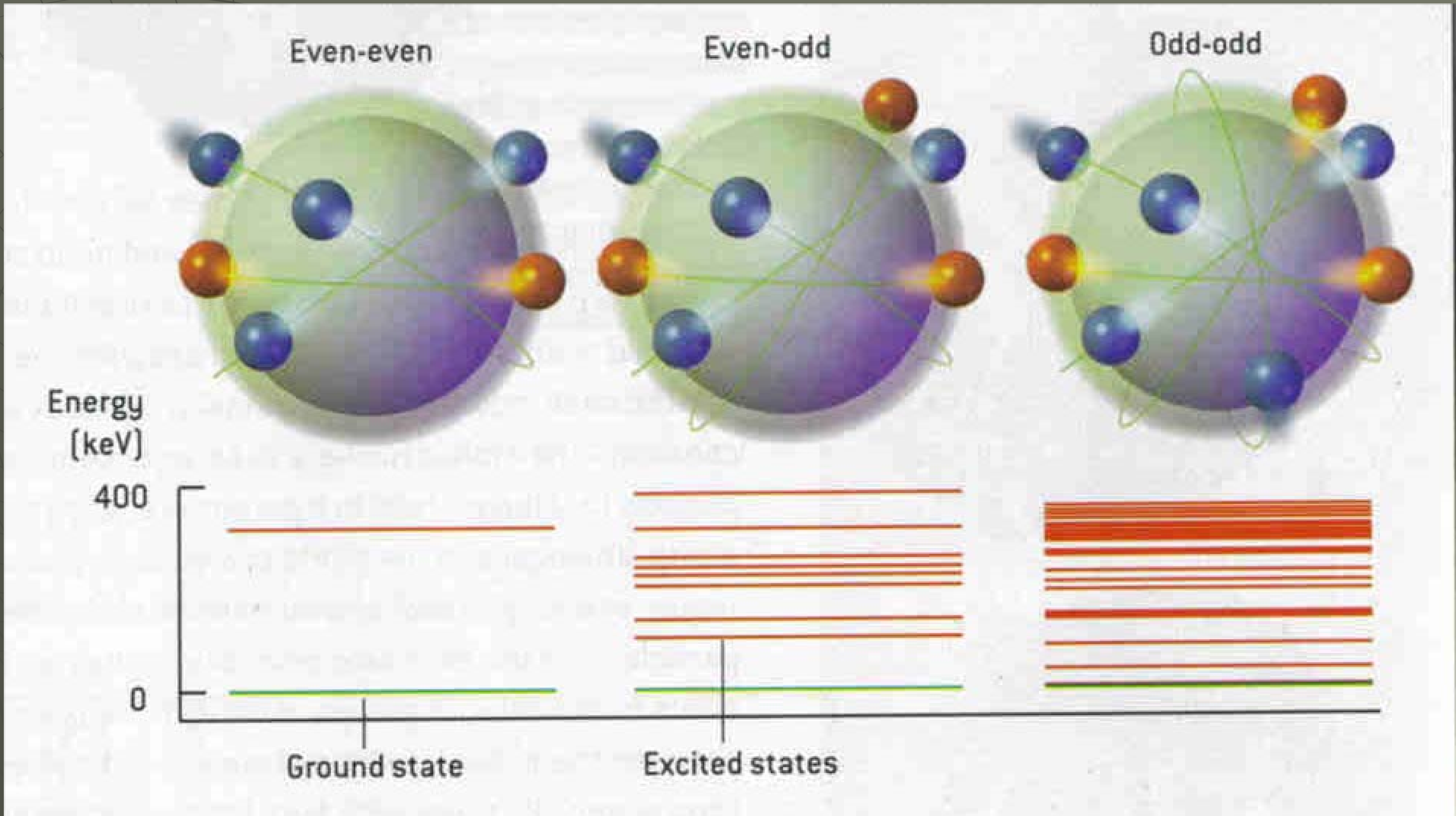
Niveles de protón, capa 50-82

Núcleos Os, Ir, Pt, Au
con 76, 77, 78, 79 protones

Nuclear Supersymmetry

even-even	s, d	$U(6) \supset SO(6)$
odd-proton	$j_\pi = 2d_{3/2}$	$U(6/4)$
odd-neutron	$j_\nu = 3p_{1/2}, 3p_{3/2}, 2f_{5/2}$	$U(6/12)$
odd-odd	$j_\pi = 2d_{3/2}$ $j_\nu = 3p_{1/2}, 3p_{3/2}, 2f_{5/2}$	$U(6/4)_\pi \otimes U(6/12)_\nu$

Arima & Iachello, PRL 40, 385 (1978)
Iachello, PRL 44, 772 (1980)
Balantekin, Bars, Bijker & Iachello, PRC 27, 1761 (1983)
Van Isacker, Jolie, Heyde & Frank, PRL 54, 653 (1985)


Even-even
Even-odd
Odd-odd
Energy (keV)
400
0
Ground state
Excited states

Supersimetría Neutrón-Protón

Neutron-proton SUSY : $U(6/12)_\nu \otimes U(6/4)_\pi$

odd-proton		odd-odd
${}^{195}_{79}\mathrm{Au}_{116}$	$\leftrightarrow$	${}^{196}_{79}\mathrm{Au}_{117}$
$\updownarrow$		$\updownarrow$
${}^{194}_{78}\mathrm{Pt}_{116}$	$\leftrightarrow$	${}^{195}_{78}\mathrm{Pt}_{117}$
even-even		odd-neutron

Van Isacker, Jolie, Heyde, Frank, PRL 54, 653 (1985)

$^{194}_{78}\mathrm{Pt}_{116}$ $\quad N_\pi = \frac{1}{2}(82-78) = 2$

$$N_\nu = \frac{1}{2}(126-116) = 5$$

	N_π	M_π	N_ν	M_ν
$^{194}_{78}\mathrm{Pt}_{116}$	2	0	5	0
$^{195}_{78}\mathrm{Pt}_{117}$	2	0	4	1
$^{195}_{79}\mathrm{Au}_{116}$	1	1	5	0
$^{196}_{79}\mathrm{Au}_{117}$	1	1	4	1

$$\mathcal{N}_\pi = 2 \qquad \mathcal{N}_\nu = 5$$

$$\mathcal{N} = 7$$

Tezcatlipoca

Quetzalcóatl

$^{194}_{78}Pt_{116}$

$^{195}_{78}Pt_{117}$

Diseño:
ELAF 2004
Renato Lemus

$^{195}_{79}Au_{116}$

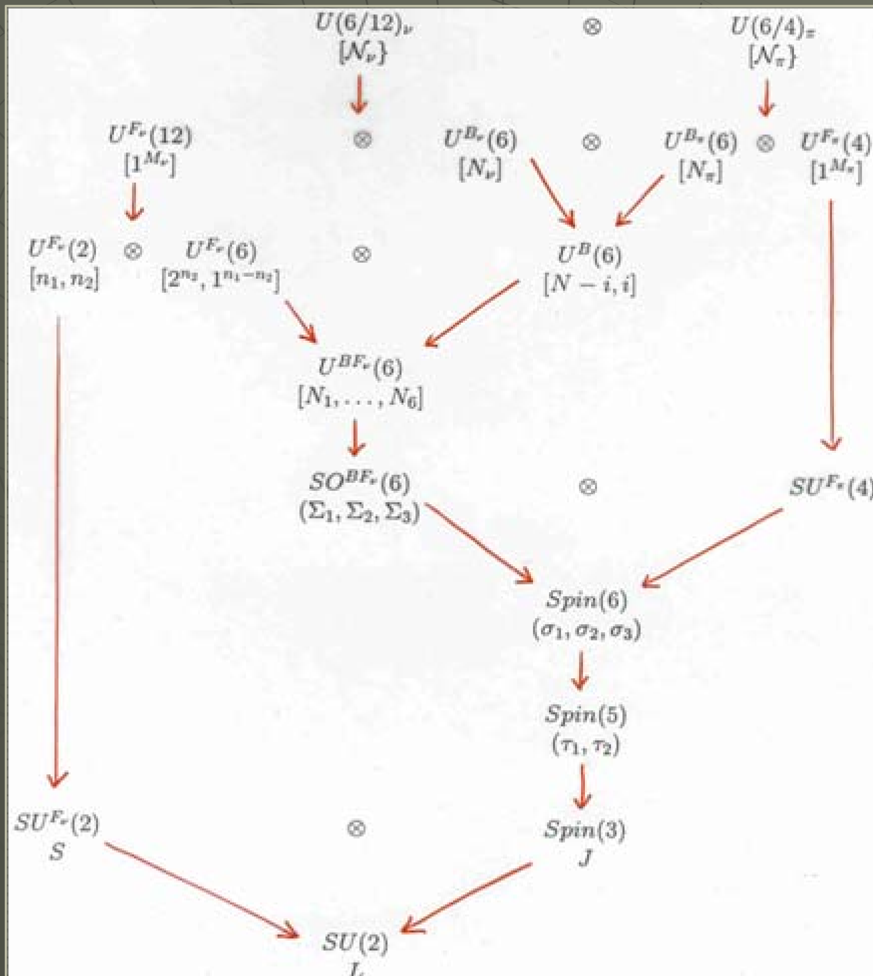
$^{196}_{79}Au_{117}$

Camaxtle

Diseño: Renato Lemus

Huitzilopochtli

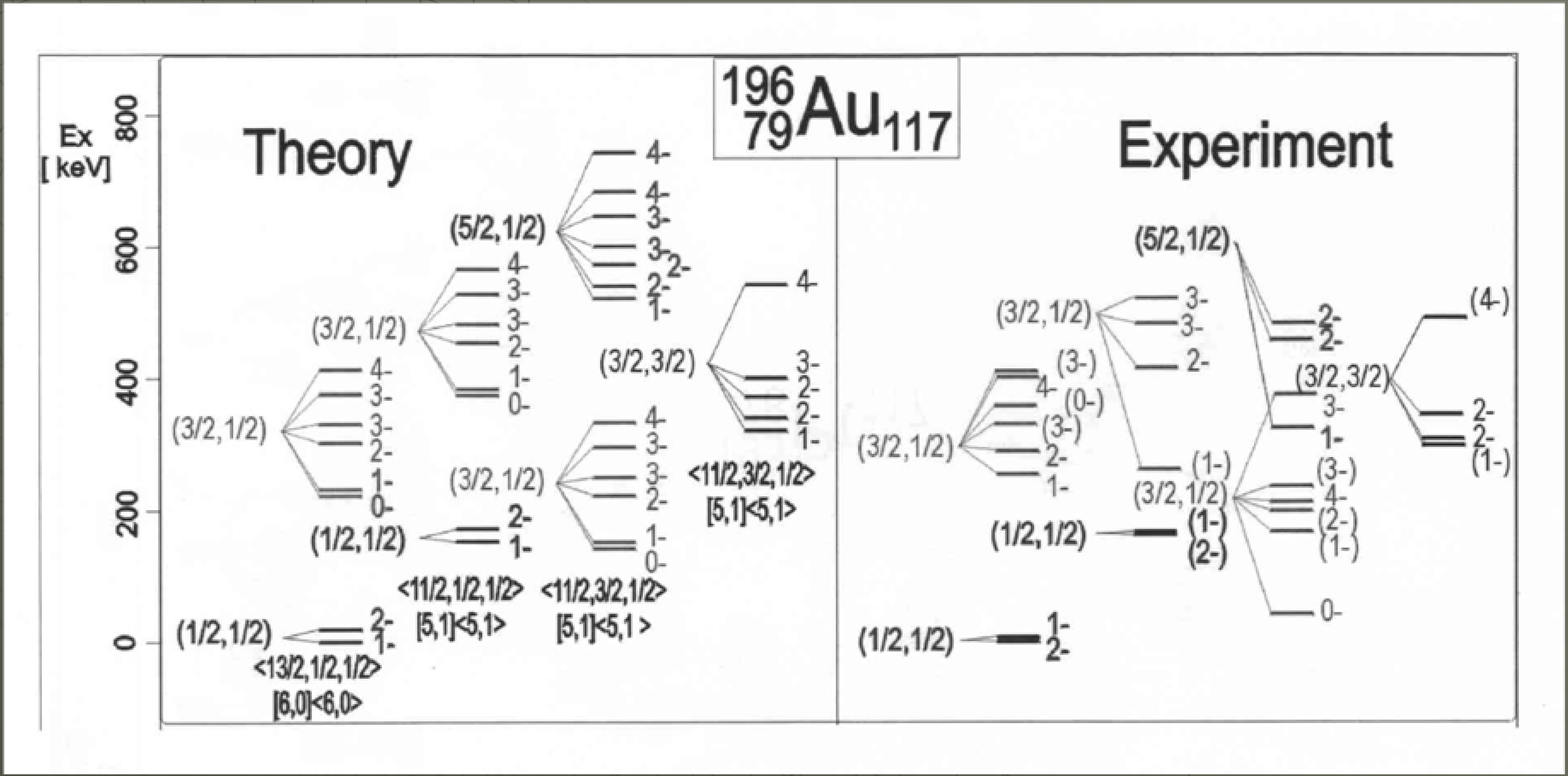
Supersimetría Dinámica



$$
\begin{aligned}
H &= a\, C_{2U^{BF_\nu}(6)} + b\, C_{2SO^{BF_\nu}(6)} + c\, C_{2Spin(6)} \\
&\quad + d\, C_{2Spin(5)} + e\, C_{2Spin(3)} + f\, C_{2SU(2)}
\end{aligned}
$$

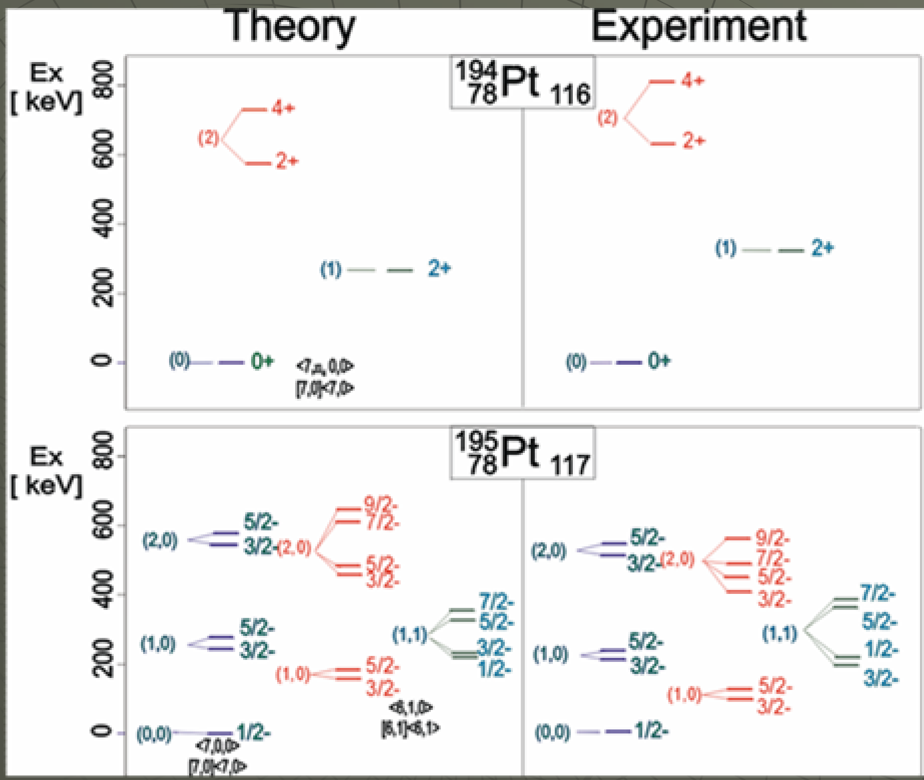
$$
\begin{aligned}
E &= a\,[N_1(N_1+5) + N_2(N_2+3) + N_3(N_3+1)] \\
&\quad + b\left[\Sigma_1(\Sigma_1+4) + \Sigma_2(\Sigma_2+2) + \Sigma_3^2\right] \\
&\quad + c\left[\sigma_1(\sigma_1+4) + \sigma_2(\sigma_2+2) + \sigma_3^2\right] \\
&\quad + d\,[\tau_1(\tau_1+3) + \tau_2(\tau_2+1)] \\
&\quad + e\, J(J+1) + f\, L(L+1)
\end{aligned}
$$

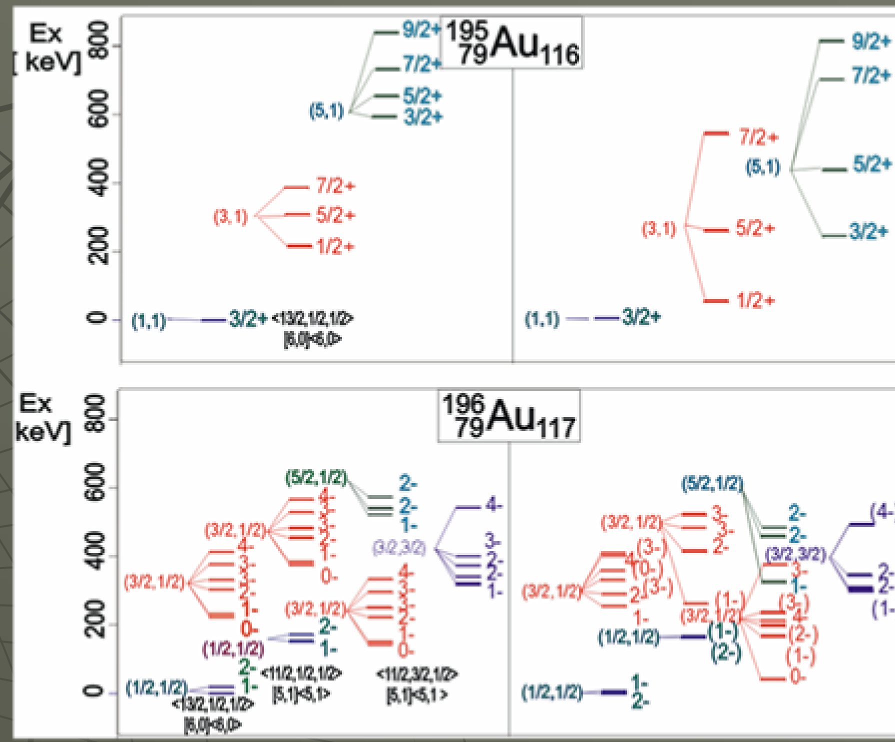
Núcleo Impar-Impar ^{196}Au



Metz et al, PRL 83, 1542 (1999)

Cuadruplete Supersimétrico





Two-Nucleon Transfer

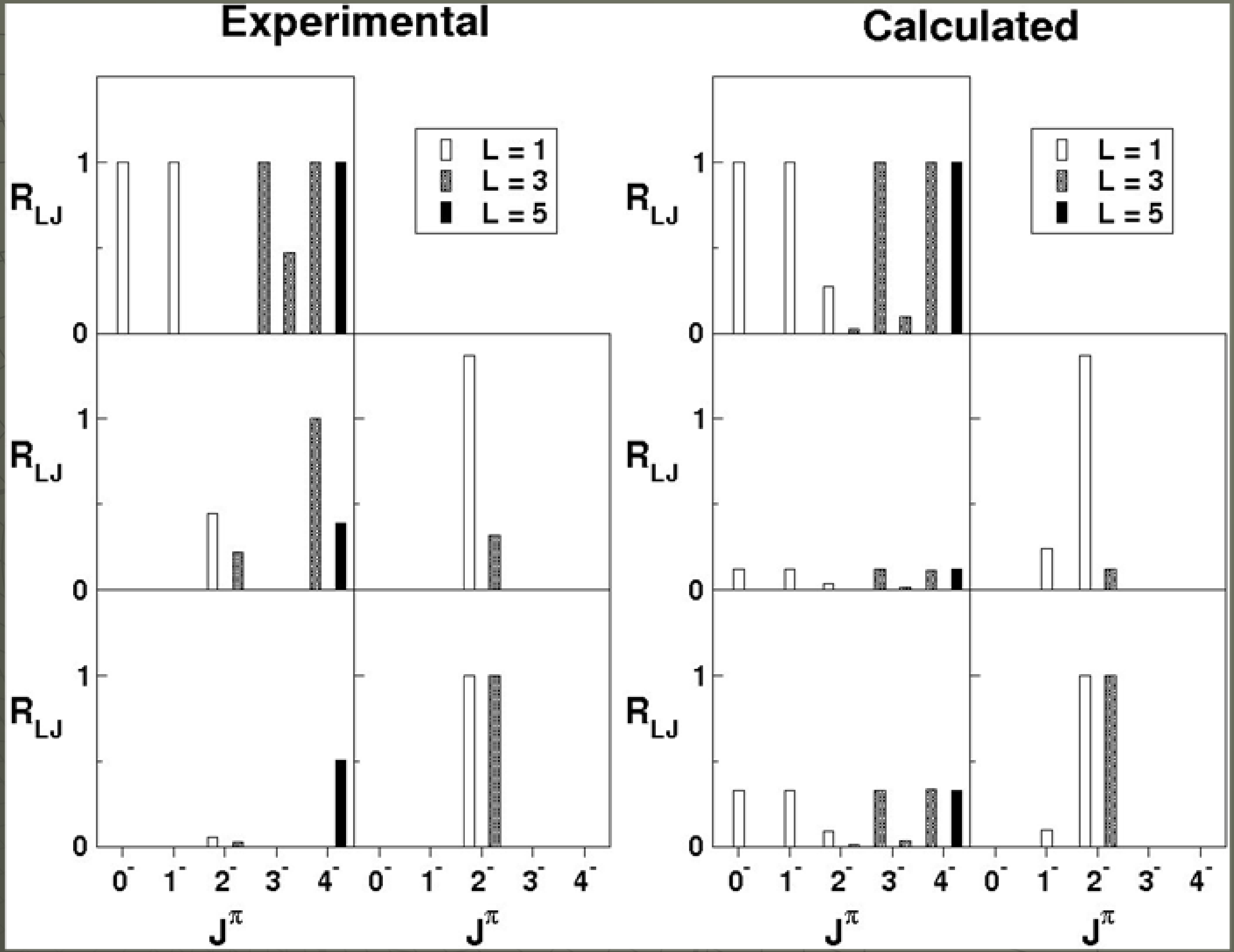
Reaction $^{198}\text{Hg}\,(\vec{d},\alpha)\,^{196}\text{Au}$

Spectroscopic factors

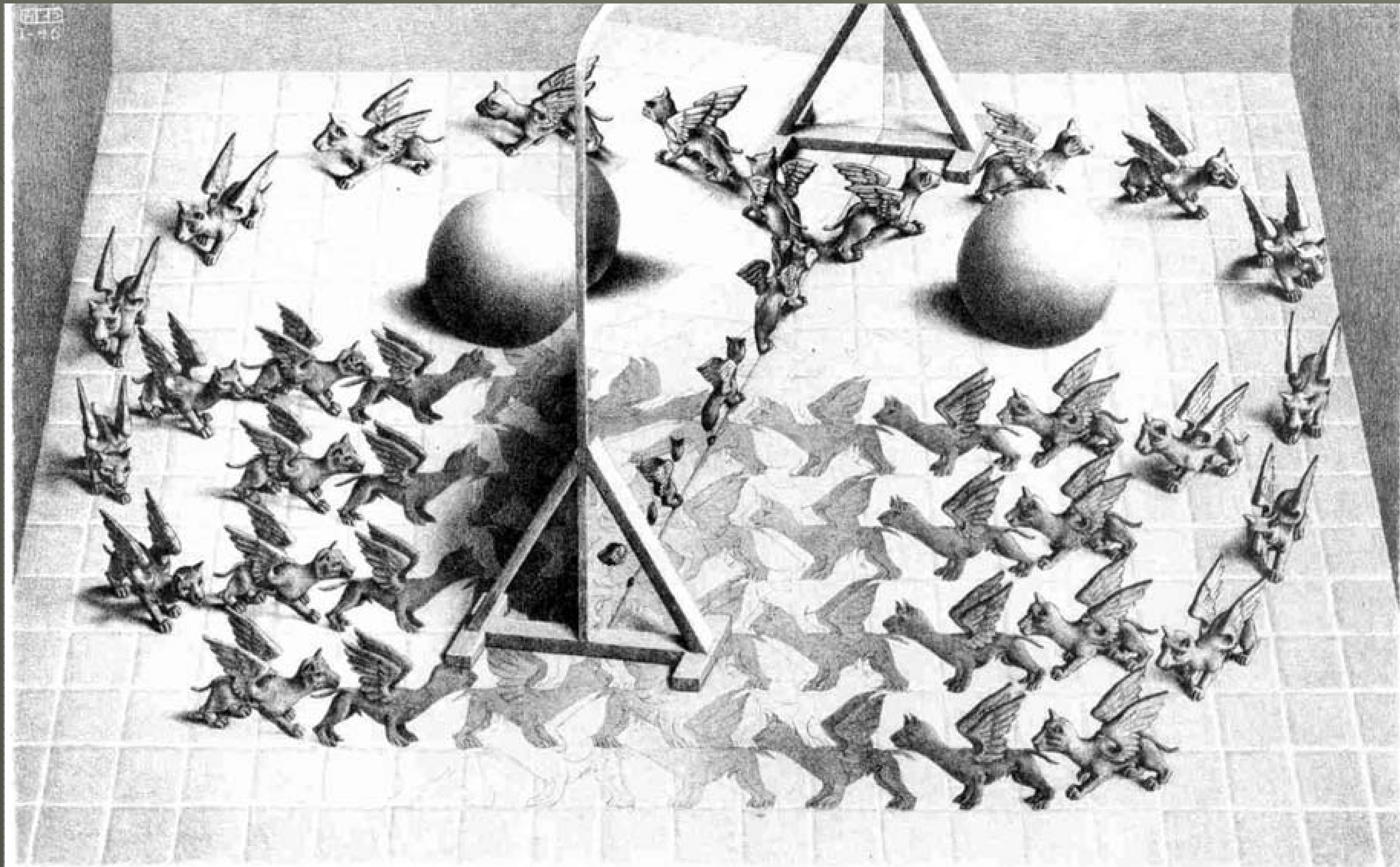
$$G_{LJ} = \left| \sum_{j_\nu j_\pi} g^{LJ}_{j_\nu j_\pi} \left\langle {}^{196}\text{Au} \right\| (a^\dagger_{j_\nu} a^\dagger_{j_\pi})^{(\lambda)} \left\| {}^{198}\text{Hg} \right\rangle \right|^2$$

Relative strength

$$R_{LJ} = \frac{G_{LJ}}{G_{LJ}(\text{ref})} = \begin{cases} \dfrac{N+4}{15N} & = \quad 0.12 \\[2ex] \dfrac{2(N+4)(N+6)}{15N(N+3)} & = \quad 0.33 \end{cases}$$



Barea, Bijker, Frank, PRL 94, 152501 (2005)



Magic mirror - M.C. Escher

New Supersymmetric Quartet

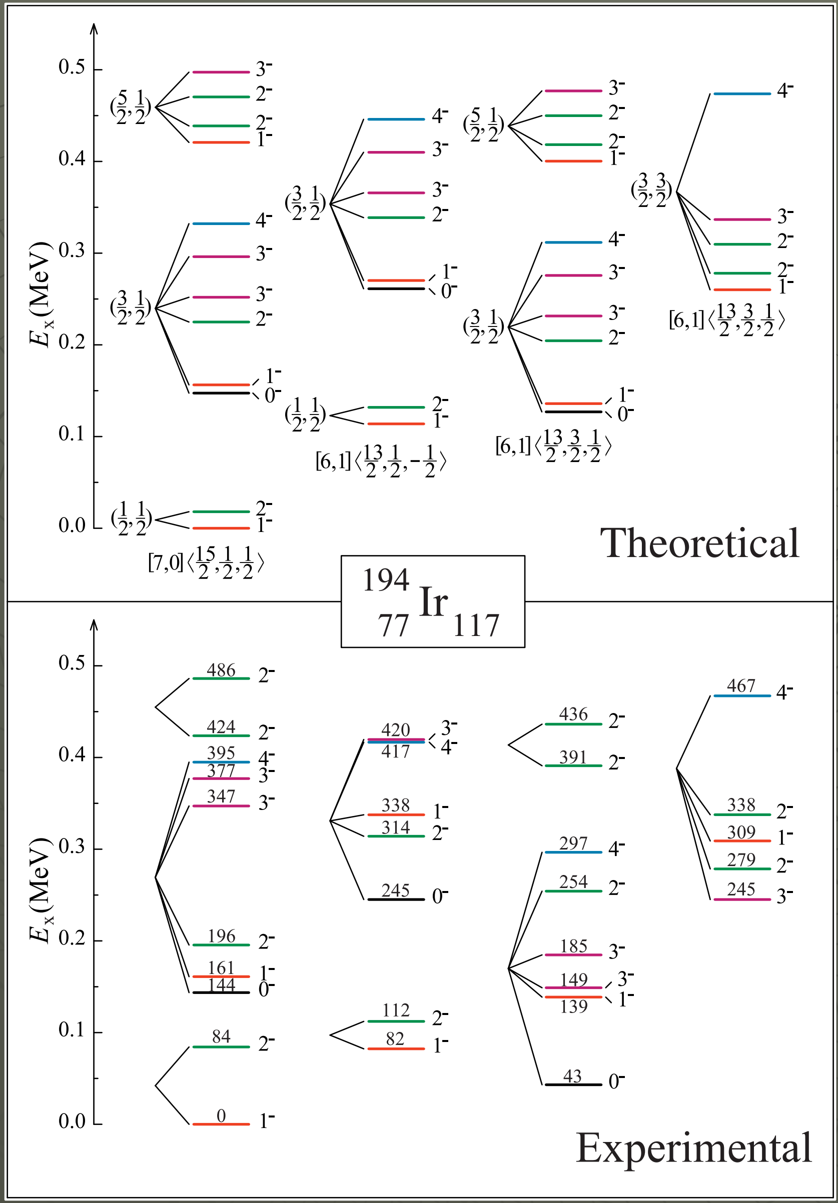
Neutron-proton SUSY : $U(6/4)_\pi \otimes U(6/12)_\nu$

${}^{193}_{77}\mathrm{Ir}_{116}$	$\leftrightarrow$	${}^{194}_{77}\mathrm{Ir}_{117}$
$\updownarrow$		$\updownarrow$
${}^{192}_{76}\mathrm{Os}_{116}$	$\leftrightarrow$	${}^{193}_{76}\mathrm{Os}_{117}$

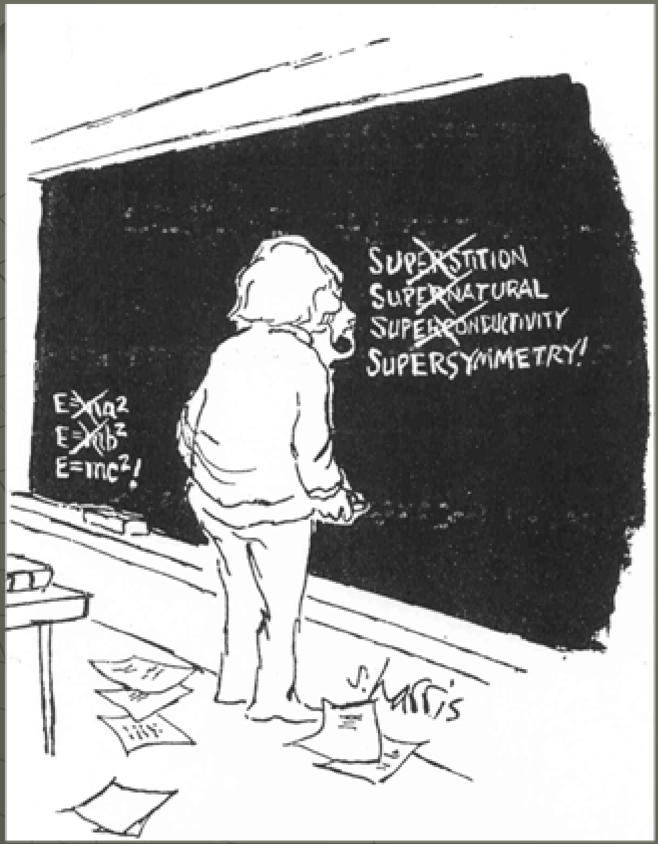
even-even ^{192}Os
odd-proton ^{193}Ir
odd-odd ^{194}Ir
Use supersymmetry to predict odd-neutron ^{193}Os

Balodis et al, PRC 77, 064602 (2008)
Barea et al, PRC 79, 031304 (2009)

Núcleo ^{194}Ir

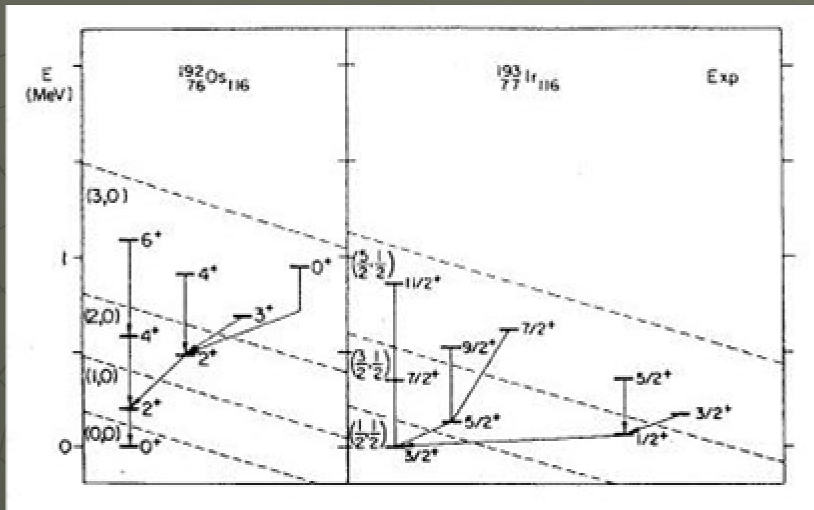


Balodis et al, PRC 77, 064602 (2008)
Barea et al, PRC 79, 031304 (2009)

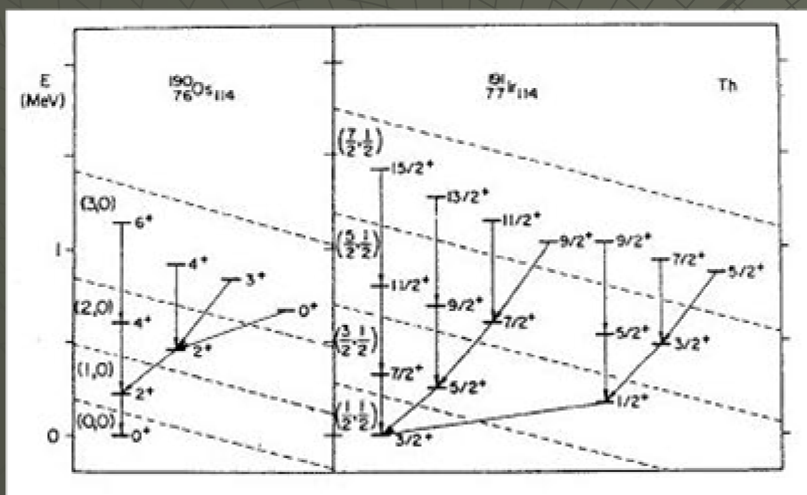


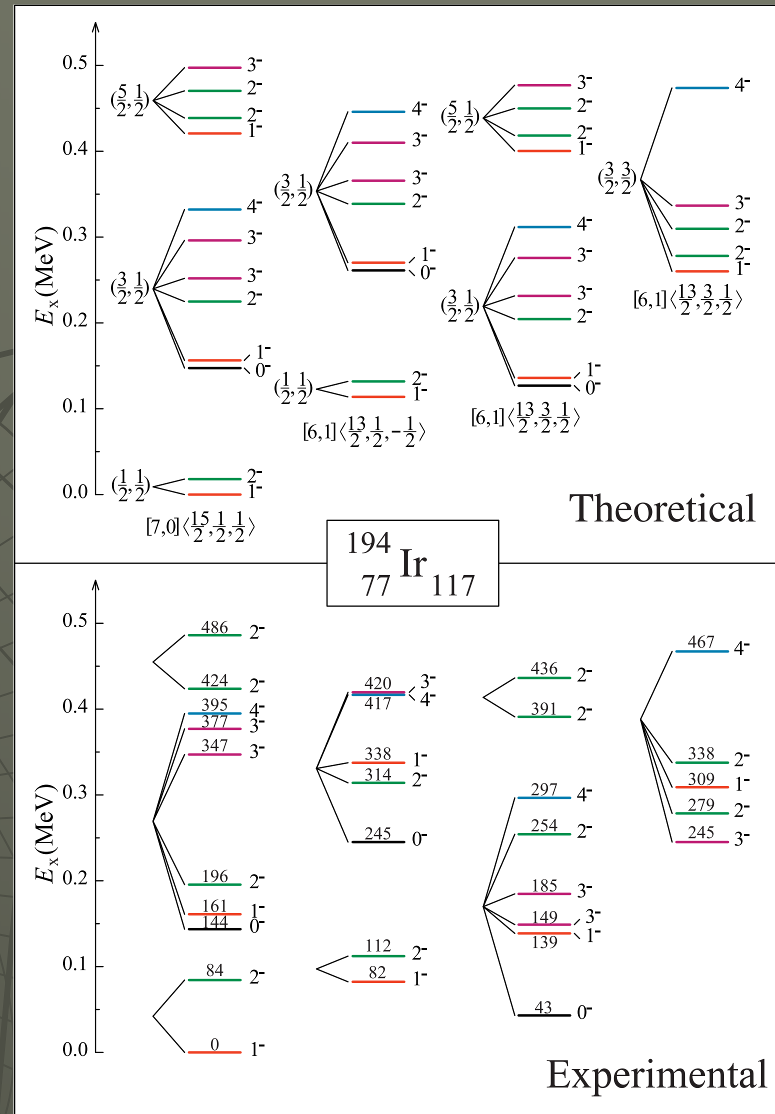
Supersymmetric Quartet Os-Ir

^{192}Os-^{193}Ir Balantekin 1981	^{194}Ir Balodis 2008	^{192,193}Os-^{193,194}Ir Barea 2009
		$a = 41$
$b + c = -33.5$	$a + b = 35$	$b = -6$
$c = -25.5$	$c = -33.6$	$c = -29$
$d = 40$	$d = 35.1$	$d = 38$
$e + f = 10$	$e = 6.3$	$e = 6.3$
	$f = 4.5$	$f = 4.5$



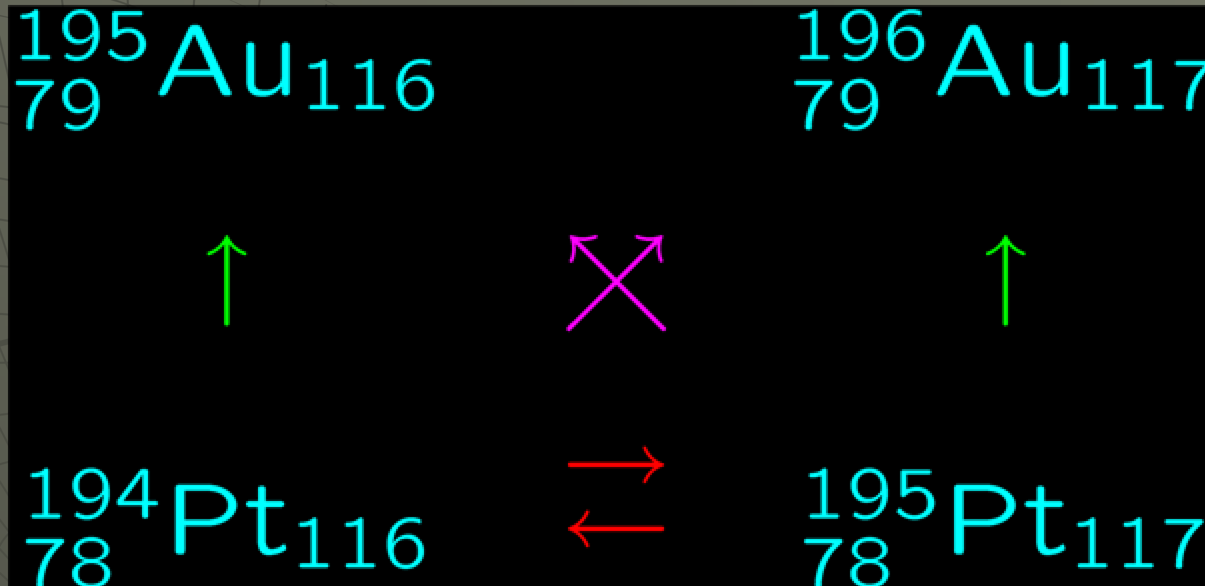
Balantekin et al. NPA 370, 284 (1981)






Susy
RESTAURANTE

Correlaciones



Wave functions related by supersymmetry: matrix elements of transfer operators correlated by SUSY

Quantum Numbers

- Correspondence of quantum numbers between even-even and odd-neutron nucleus

$$|\text{ee}\rangle = |[\mathcal{N}_\nu],[\mathcal{N}_\pi];[\mathcal{N}_\nu+\mathcal{N}_\pi-j,j],\alpha,L\rangle$$

$$|\text{on}\rangle = |[\mathcal{N}_\nu-1],[\mathcal{N}_\pi];[\mathcal{N}_\nu+\mathcal{N}_\pi-1-i,i],[1]_\nu; [\mathcal{N}_\nu+\mathcal{N}_\pi-j,j-k,k],\alpha,L,\frac{1}{2};J\rangle$$

- and odd-proton and odd-odd nucleus (k=0)

$$|\text{op}\rangle = |[\mathcal{N}_\nu],[\mathcal{N}_\pi-1];[\mathcal{N}_\nu+\mathcal{N}_\pi-1-j,j],\alpha,J\rangle$$

$$|\text{oo}\rangle = |[\mathcal{N}_\nu-1],[\mathcal{N}_\pi-1];[\mathcal{N}_\nu+\mathcal{N}_\pi-2-i,i],[1]_\nu; [\mathcal{N}_\nu+\mathcal{N}_\pi-1-j,j-k,k],\alpha,J,\frac{1}{2};L\rangle$$

Wave Functions

Wave functions result of coupling of three different U(6) representations: proton and neutron bosons, (π) and (ν), and orbital part of neutron orbitals (ρ)

$$\begin{array}{ccccccccccc} U^{B_\pi}(6) & \otimes & U^{B_\nu}(6) & \otimes & U^{F_\nu}(6) & \supset & U^{B}(6) & \otimes & U^{F_\nu}(6) & \supset & U^{BF_\nu}(6) \\ \downarrow & & \downarrow & & & & \downarrow & & \downarrow & & \downarrow \\ [N_\pi] & & [N_\nu] & & & & [N_\pi + N_\nu - i, i] & & [N_\rho] & & [N_1, N_2, N_3] \end{array}$$

Analogy to three-flavor quark model (u, d, s) with SU(3) $\supset$ SU(2) $\otimes$ U(1) symmetry

(λ,μ)	F	F_z	Y	
(1,0)	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{3}$	$b_\pi^\dagger$
	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{3}$	$b_\nu^\dagger$
	0	0	$-\frac{2}{3}$	$a_\nu^\dagger$

(λ,μ)	F	F_z	Y	
(0,1)	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{3}$	b_π
	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{3}$	b_ν
	0	0	$\frac{2}{3}$	a_ν

Generalized F-spin

$$\begin{array}{ccccc} U(18) & \supset & U(6) & \otimes & U(3) \\ \downarrow & & \downarrow & & \downarrow \\ [N] & & [N_1, N_2, N_3] & & [N_1, N_2, N_3] \end{array}$$

$$\begin{array}{ccccccccc} U(3) & \supset & SU(3) & \supset & [SU(2) & \supset & SO(2)] & \otimes & U(1) \\ \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ [N_1, N_2, N_3] & & (\lambda, \mu) & & F & & F_z & & Y \end{array}$$

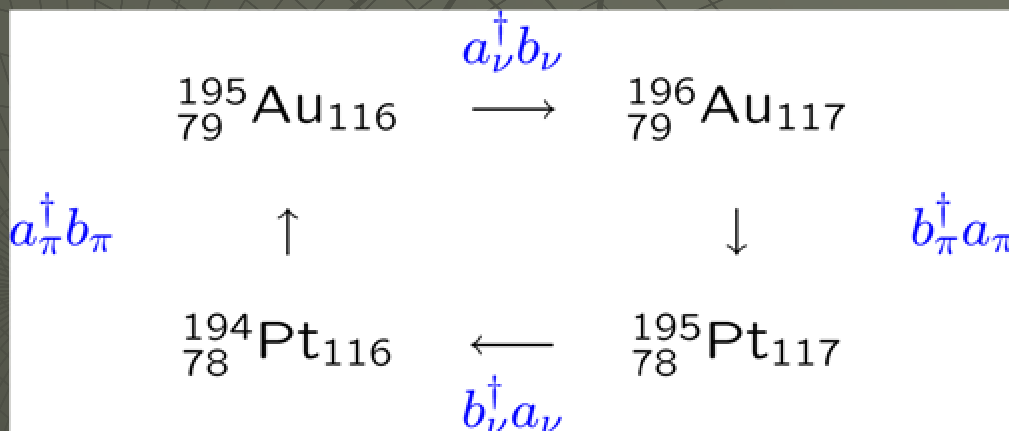
$$\begin{aligned} (\lambda, \mu) &= (N_1 - N_2, N_2 - N_3) \\ F &= \frac{1}{2}(N_\pi + N_\nu - 2i) \\ F_z &= \frac{1}{2}(N_\pi - N_\nu) \\ Y &= \frac{1}{3}(N_\pi + N_\nu - 2N_\rho) \end{aligned}$$

Matrix elements between states with the same quantum numbers but different U(6) couplings are related by SU(3) isoscalar factors and F-spin CG coefficients

Transfer Operators

- Tensorial character of one-proton and one-neutron transfer operators

$$T^{(\lambda,\mu)}_{F,F_z,Y} = T^{(1,1)}_{\frac{1}{2},\frac{1}{2},-1}$$



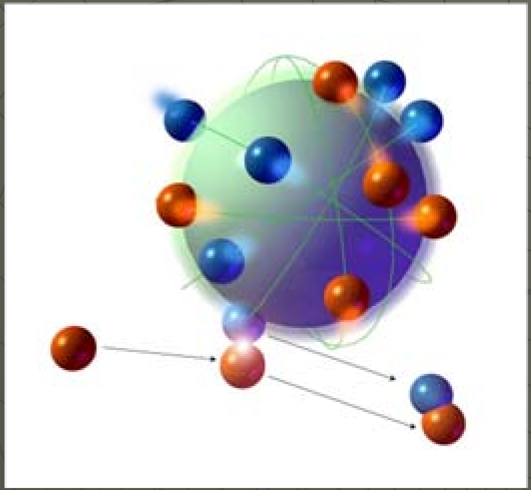
$$T^{(0,1)}_{\frac{1}{2},-\frac{1}{2},-\frac{1}{3}}$$

$$T^{(1,0)}_{\frac{1}{2},\frac{1}{2},\frac{1}{3}}$$

$$T^{(1,1)}_{\frac{1}{2},-\frac{1}{2},1}$$

Smaller and Smaller
M.C. Escher

One-proton transfer



Test of the fermionic generators of the superalgebra

$$T^{(0,1)}_{\frac{1}{2},-\frac{1}{2},-\frac{1}{3}}$$

$$P^{(\frac{3}{2})\dagger}_{\pi,1} = -\sqrt{\frac{1}{6}}\left(\tilde{s}_\pi \times a^\dagger_{\pi,\frac{3}{2}}\right)^{(\frac{3}{2})} + \sqrt{\frac{5}{6}}\left(\tilde{d}_\pi \times a^\dagger_{\pi,\frac{3}{2}}\right)^{(\frac{3}{2})}$$

$$P^{(\frac{3}{2})\dagger}_{\pi,2} = +\sqrt{\frac{5}{6}}\left(\tilde{s}_\pi \times a^\dagger_{\pi,\frac{3}{2}}\right)^{(\frac{3}{2})} + \sqrt{\frac{1}{6}}\left(\tilde{d}_\pi \times a^\dagger_{\pi,\frac{3}{2}}\right)^{(\frac{3}{2})}$$

Barea, Bijker, Frank, JPA 37, 10251 (2004)
Ruslan Magaña, B.Sc. Thesis 2010

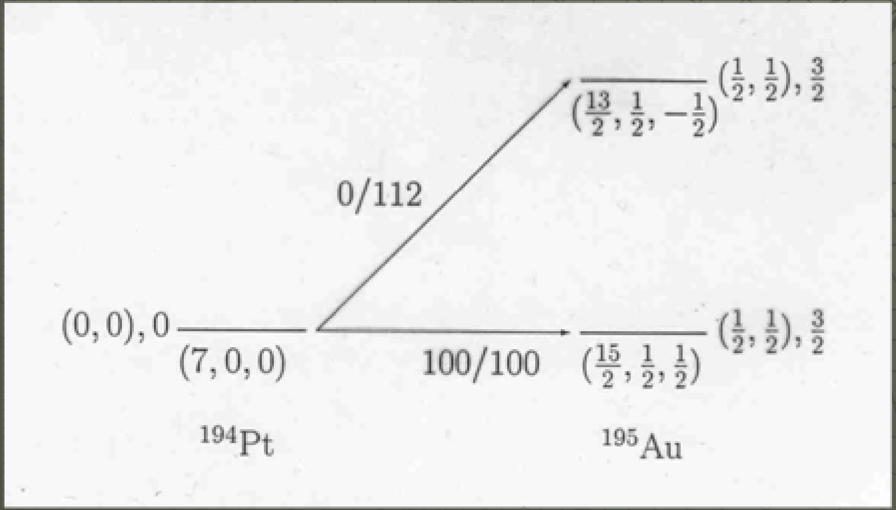
$^{194}\mathrm{Pt} \rightarrow {}^{195}\mathrm{Au}$	$\mid \langle f \| P^{(\frac{3}{2})\dagger}_{\pi,1} \| i \rangle \mid^2$	$\mid \langle f \| P^{(\frac{3}{2})\dagger}_{\pi,2} \| i \rangle \mid^2$
$\langle (N+\frac{3}{2},\frac{1}{2},\frac{1}{2}),(\frac{1}{2},\frac{1}{2}),\frac{3}{2} \mid$	$\frac{2(N_\pi+1)}{3}$	$\frac{8(N+6)^2(N_\pi+1)}{15(N+3)^2}$
$\langle (N+\frac{1}{2},\frac{1}{2},-\frac{1}{2}),(\frac{1}{2},\frac{1}{2}),\frac{3}{2} \mid$	0	$\frac{6(N+1)(N+5)(N_\pi+1)}{5(N+3)^2}$

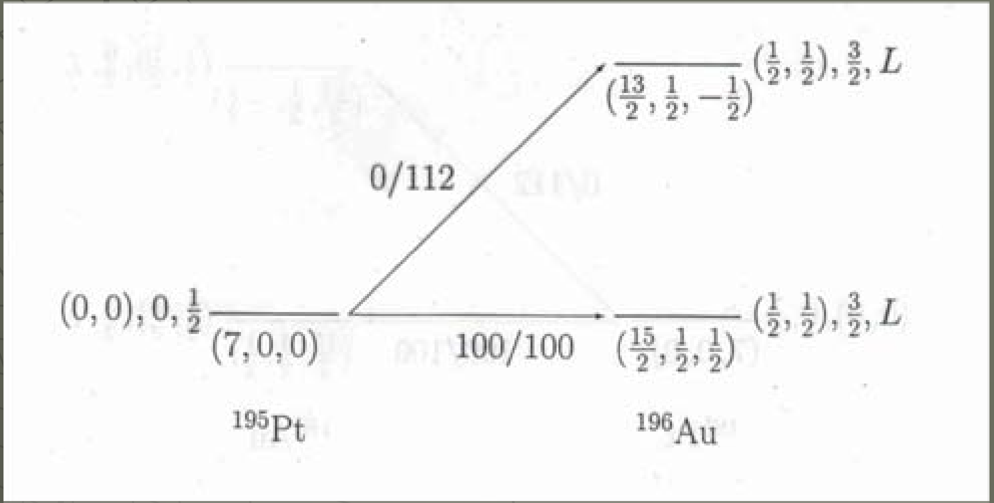
$^{195}\mathrm{Pt} \rightarrow {}^{196}\mathrm{Au}$	$\mid \langle f \| P^{(\frac{3}{2})\dagger}_{\pi,1} \| i \rangle \mid^2$	$\mid \langle f \| P^{(\frac{3}{2})\dagger}_{\pi,2} \| i \rangle \mid^2$
$\langle (N+\frac{3}{2},\frac{1}{2},\frac{1}{2}),(\frac{1}{2},\frac{1}{2}),\frac{3}{2},L \mid$	$\frac{2(N_\pi+1)}{3}\frac{2L+1}{4}$	$\frac{8(N+6)^2(N_\pi+1)}{15(N+3)^2}\frac{2L+1}{4}$
$\langle (N+\frac{1}{2},\frac{1}{2},-\frac{1}{2}),(\frac{1}{2},\frac{1}{2}),\frac{3}{2},L \mid$	0	$\frac{6(N+1)(N+5)(N_\pi+1)}{5(N+3)^2}\frac{2L+1}{4}$

Correlaciones

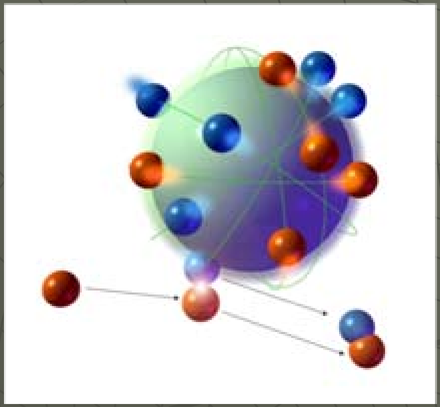
$$R_1 = \frac{I_{\mathrm{gs}\to\mathrm{exc}}}{I_{\mathrm{gs}\to\mathrm{gs}}} = 0$$

$$R_2 = \frac{I_{\mathrm{gs}\to\mathrm{exc}}}{I_{\mathrm{gs}\to\mathrm{gs}}} = \frac{9(N+1)(N+5)}{4(N+6)^2} = 1.12 \quad (N=5)$$





One-Neutron Transfer



One-neutron transfer reactions between Pt isotopes

Bijker & Iachello, Ann. Phys. 161, 360 (1985)

$$P_{\nu}^{(j)\dagger} = \sqrt{\frac{1}{2}}\left[\left(\tilde{s}_{\nu} \times a_{\nu,j}^{\dagger}\right)^{(j)} - \left(\tilde{d}_{\nu} \times a_{\nu,1/2}^{\dagger}\right)^{(j)}\right] \qquad j = \frac{3}{2}, \frac{5}{2}$$

$$T_{\frac{1}{2},\frac{1}{2},-1}^{(1,1)}$$

Matrix elements between states with the same quantum numbers but different U(6) couplings are related by SU(3) Isoscalar Factors and F-spin CG coefficients

$^{194}\mathrm{Pt} \rightarrow {}^{195}\mathrm{Pt}$	$\mid \langle f \| P_{\nu}^{(j)\,\dagger} \| i \rangle \mid^2$	S_{th} $j=\frac{3}{2}$	S_{th} $j=\frac{5}{2}$	S_{exp} $j=\frac{3}{2}$	S_{exp} $j=\frac{5}{2}$
$\langle [N+2],(N+2,0,0),(1,0),2,J \mid$	$\frac{2(2j+1)(N+6)(N_{\nu}+1)}{5(N+2)(N+3)^2}\delta_{J,j}$	2.3	3.4	11.8	5.2
$\langle [N+2],(N,0,0),(1,0),2,J \mid$	$\frac{(2j+1)N(N+1)(N+5)(N_{\nu}+1)}{10(N+2)^2(N+3)^2}\delta_{J,j}$	2.2	3.3		
$\langle [N+1,1],(N+1,1,0),(1,0),2,J \mid$	$\frac{(2j+1)(N+1)(N+6)^2(N_{\nu}+1)}{5(N+2)(N+3)(N+4)}\delta_{J,j}$	66.7	100.0	44.7	100.0
$\langle [N+1,1],(N,0,0),(1,0),2,J \mid$	$\frac{(2j+1)N^2(N+1)(N+5)(N_{\nu}+1)}{10(N+2)^2(N+3)(N+4)}\delta_{J,j}$	9.9	14.8	3.9	

$^{195}\mathrm{Pt} \rightarrow {}^{194}\mathrm{Pt}$	$\mid \langle f \| \tilde{P}_{\nu}^{(j)} \| i \rangle \mid^2$	S_{th} $j=\frac{3}{2}$	S_{th} $j=\frac{5}{2}$	S_{exp} $j=\frac{3}{2}$	S_{exp} $j=\frac{5}{2}$
$\langle [N+2],(N+2,0,0),(1,0),2 \mid$	$\frac{2(2j+1)(N+6)(N_{\nu}+1)}{5(N+2)(N+3)^2}$	1.1	1.7	2.0	
$\langle [N+2],(N,0,0),(1,0),2 \mid$	$\frac{(2j+1)N(N+1)(N+5)(N_{\nu}+1)}{10(N+2)^2(N+3)^2}$	1.1	1.6		
$\langle [N+1,1],(N+1,1,0),(1,0),2 \mid$	$\frac{(2j+1)(N+1)(N+6)^2(N_{\nu}+1)}{5(N+2)(N+3)(N+4)}\frac{N_{\pi}+1}{(N+1)(N_{\nu}+1)}$	2.1	3.1		
$\langle [N+1,1],(N,0,0),(1,0),2 \mid$	$\frac{(2j+1)N^2(N+1)(N+5)(N_{\nu}+1)}{10(N+2)^2(N+3)(N+4)}\frac{N_{\pi}+1}{(N+1)(N_{\nu}+1)}$	0.3	0.5		

Correlaciones

$$R\left({}^{194}\text{Pt} \rightarrow {}^{195}\text{Pt}\right) = \frac{(N+1)(N+3)(N+6)}{2(N+4)}$$
$$= \frac{88}{3} = 29.3$$
$$R\left({}^{195}\text{Pt} \rightarrow {}^{194}\text{Pt}\right) = \frac{(N+1)(N+3)(N+6)}{2(N+4)} \frac{N_\pi + 1}{(N+1)(N_\nu+1)}$$
$$= \frac{88}{3} \times \frac{1}{15} = 1.96$$
$$N_\pi = 1, \qquad N_\nu = 4, \qquad N = N_\pi + N_\nu$$

		^{195}Pt	^{194}Pt
gs band	E_1	300 keV	300 keV
exc band	E_3	150 keV	2500 keV

Mixed symmetry state!

Correlations

- One-proton transfer reactions

$$\frac{S_i(^{195}\text{Pt} \rightarrow ^{196}\text{Au})}{S_i(^{194}\text{Pt} \rightarrow ^{195}\text{Au})} = \frac{2L+1}{8}$$

- One-neutron transfer reactions

$$\frac{S_i(^{195}\text{Pt} \rightarrow ^{194}\text{Pt})}{S_i(^{194}\text{Pt} \rightarrow ^{195}\text{Pt})} = \begin{cases} \frac{1}{2} \\ \\ \frac{N_\pi+1}{2(N+1)(N_\nu+1)} \end{cases}$$

Summary and Conclusions

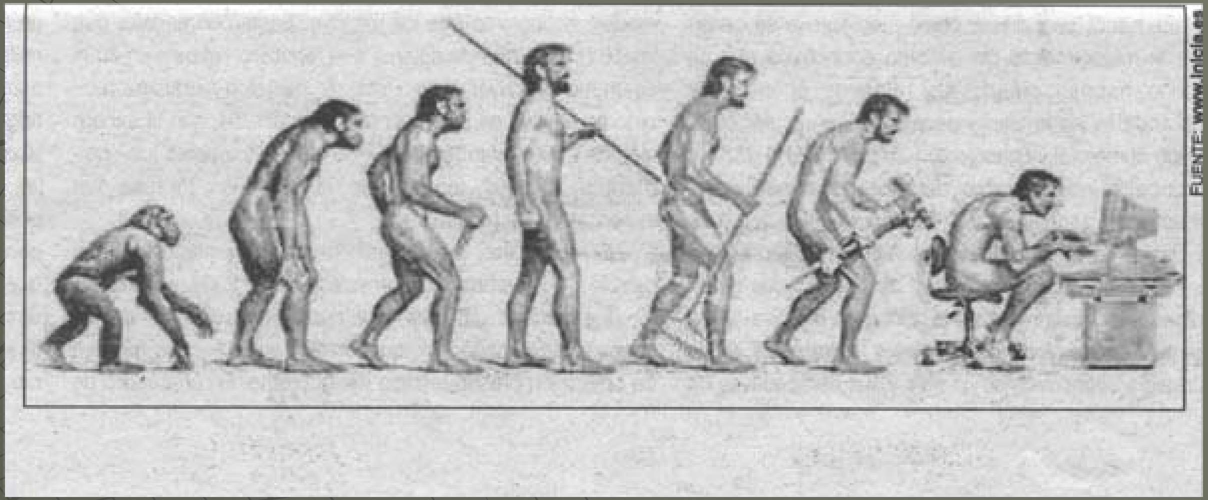
- Nuclear supersymmetry
- Energy formula, selection rules, transition rates and spectroscopic factors for transfer reactions
- Supersymmetric quartets of nuclei: Pt-Au and Os-Ir

- Correlations between different transfer reactions
- Generalized F-spin and SU(3) isoscalar factors
- Predictions that can be tested experimentally

Ruslan Magaña, B.Sc. 2010 & M.Sc. 2013

- Light nuclei: isospin invariant extensions of IBM, IBFM and SUSY?
- Supersymmetry without dynamical symmetry


E=mc²
s.harris


FUENTE: www.inicia.es

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