Importance of Approximate Symmetries in Nuclear Physics



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Overarching Historical Perspectives

Nuclear (LE-QED) Discoveries!







Eugene Wigner

Simplicity

within

Complexity

Maria Goeppert Mayer & Hans Jansen Won Nobel Prize (1963) "...for their discoveries (late 1940s) concerning nuclear shell structure"

Particle (HE-QCD) Challenges?



Standard Model? The Periodic Table of Elementary Particles and Forces Three Generations of Matter (Fermions) mass→ 2.4 MeV 1.27 Gev 171.2 GeV charαe→ 2/ ⁷³ **C** spin→ ½ U charm 104 MeV 4.2 GeV -¼₃ **S** -^{1/3} b d g Quarks down strange gluon trong force 91.2 GeV <2.2 eV <0.17 MeV V_{e} Higgs $V_{4_2} V_{\mu}$ Ζ electron tau neutrino weak force muon **Show me Something Mister!** 0.511 MeV 80.4 GeV Where's the Mass, Man? e $\frac{1}{1}W$ $\frac{1}{1/2} \mu$.eptons τ electron weak force muon tau Numerous Follow-on Developments: Confinement – Long & Short Range What is Mass, or a Quantum? higgs Group Theory & 1990s - HPC - 2000s Therapy **Dynamic Mass Generation** Lattice or Continuum (Strong) QCD

"The Next Few Generations may Cross the Standard Model's Final Frontier!" ... Sir Craig D Roberts (2021)

Strong QCD 2021 Teleworkshop on Strong QCD 06/07-10/21 INP, Nanjing University, Jiangsu 210093, China



Numerous Follow-on Developments:

Single-particle Models SP plus Pairing Modes Many-body Approaches Collective Models (BH) Geometrical Theories Quasi-particle Models Algebraic Approaches **Effective Interactions**

1990s - HPC - 2000s

No-Core Shell Model (NCSM) Non-compact Symplectic Model Symplectic Symmetry & EFT Roots*

*Sp(3,R) -> SU(3) is the Dynamical Symmetry Group of the 3D Oscillator!

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60 -

Years



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No-Core (Regular & Symplectic) Shell Model



Symplectic Symmetry / Spectrum Generating Algebra



Symplectic Symmetry is the Dynamical Symmetry Group of the Harmonic Oscillator ... !



Every configuration is labeled by the SU(3) (lambda, mu) quantum numbers of the Elliott Model (1958), which in turn defines the shape of the so-called "band head" configuration.)

David Kekejian – Graduate Student (JPD#20 PhD Expected 12/2021) from Armenia

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Symmetry Adapted NCSM (SA-NCSM) Campaign (Going on 20 years ... 2001 – 2021)

Timeline: 5(2002-06) + 5(2007-2011) + 5(2012-16)

Goal -

Reproduce and predict properties of heavy as well as light nuclei, starting with and building upon QCD/EFT informed and inspired interactions ...

Plan -

- ✓ Exploit existing capabilities to evaluate probability of success and level of effort required to develop a full-blown symmetry adapted NCSM
- ✓ Develop a symmetry adapted no-core shell model code that capitalizes on exact and approximate (partial) symmetries of nuclei (SA-NCSM)
 - Exploit existing NCSM technology to prove efficacy of method, revealing (or not) any inherent limitations
 - Explore need (or not) for renormalization, winnowing space to physically relevant and tractable subspaces
 - Evaluate extensibility of theory and its characteristics vis-à-vis current/emerging computational resources

✓ Study the emergence of collective phenomena, tracking their evolution to and from fundamental (ab initio) features of the interaction

- Apply the theory to study of extreme processes known to be important to understanding nuclei and nuclear systems
- Develop a user-friendly desktop vérsion of code for simple applications as well as educational and training purposes
- Extend theory to include coupling to the continuum, and apply to the result to the study of nuclear reactions



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Results for ⁶Li with N_{max} = 10 (Proof of Principle)



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Creation of ¹²C in Hot Stars / Nucleosyntheses



... The Elusive Hoyle State ...



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Three Primary "Slices" in NCSpM Description



 ^{12}C Systematics as a Function of N_{max} (N_{max} = Total Number of $2\hbar\Omega$ Excitations above Ground State)



¹²C – Cluster Formations

(Now with mixing at the band-head level turned on ... !)



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Medium Mass Nuclei (Gegory Tobin / REU Student)







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Further sd-shell Results (Robert Baker - GS)



Plus fp-shell Results (Grigor Sargsyan - GS)







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0

2

4

-2

-4

0

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-4

Ζ



300

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 $r_{\rm XV}$

Constructing an Effective Field Theory (David Kekejian - GS)



Symplectic symmetry emerges naturally from quantum effective field theory!



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... Here's the Deal ...

Nuclear (LE-QED) Discoveries!

Particle (HE-QCD) Challenges?

20th Century Subatomic Physics





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