A Vision for Nuclear Theory

*** PRELIMINARY ***

Initiatives
And
Recommendations
Overview

- Committee and Charge
- Update on the 1988 “Koonin” Report
- Recent Achievements
- Scientific Opportunities
- Community Surveys
- Recommendations & Initiatives
- Budget Scenarios
Membership

Joseph Carlson (LANL)
Barry Holstein (U. Massachusetts)
Xiangdong Ji (U. Maryland)
Gail McLaughlin (NCSU)
Berndt Mueller (Duke) - Chair
Witold Nazarewicz (UT/ORNL)
Krishna Rajagopal (MIT)
Winston Roberts (ODU/Jlab)
Xin-Nian Wang (LBNL)
Richard Casten (Ex-Officio)
Charge to NSAC

• Part of recommendation I of NSAC Long Range Plan:

  “Significantly increase funding for nuclear theory, which is essential for developing the full potential of the scientific program.”

• Specific charge for NSAC Theory Subcommittee:

  “NSAC is asked to review and evaluate current NSF and DOE supported efforts in nuclear theory and identify strategic plans to ensure a strong U.S. nuclear theory program under various funding scenarios….”
1988 Recommendations

- 5-year plan to strengthen nuclear theory:
  - 60-65 additional PhD level personnel
  - 70% budget increase ($13M = 6% → $22M = 10%).

✓ Encourage creation and support theory groups at universities with strong experimental programs.
✓ Create one or more nuclear theory centers of truly national and interdisciplinary character.

- Include theoretical funding as integral part of new large experimental projects.
- Adequate access to supercomputers and workstations.
- Foster interactions between nuclear theorists.
✓ Add nuclear theorists as permanent program officers.
Nuclear Theory Funding

Nuclear Theory

Funding Categories:
- DOE 2003 $
- DOE Actual $
- NSF 2003 $

Years:
- FY81
- FY83
- FY85
- FY87
- FY89
- FY91
- FY93
- FY95
- FY97
- FY99
- FY01
- FY03

Values:
- 0.0
- 5.0
- 10.0
- 15.0
- 20.0
- 25.0

Legend:
- DO 2003 $
- DOE Actual $
- NSF 2003 $

Graph showing the funding trend from FY81 to FY03.
Theory Manpower

Manpower 2002 vs. 1986

- National Labs
- DOE Univ.
- NSF Univ.

<table>
<thead>
<tr>
<th>Year</th>
<th>Faculty/Staff</th>
<th>Postdocs</th>
<th>Total PhD</th>
<th>Graduate students</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- FY86: 1986
- FY02: 2002
Effort by Subfield

DOE effort by subfield

- Hadron structure
- Nuclear structure
- Hot nuclear matter
- Nuclear astrophysics
- Beyond SM

FY03

FY86

0% 20% 40% 60% 80% 100%
### TABLE 4

Professorial nuclear scientists at top-rated physics departments

<table>
<thead>
<tr>
<th>University</th>
<th>Theorists</th>
<th></th>
<th>Experimentalists</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UC Berkeley</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Caltech</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Chicago</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Columbia</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Cornell</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Harvard</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Illinois</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>9</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>MIT</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Princeton</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Stanford</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13</strong></td>
<td><strong>12</strong></td>
<td><strong>44</strong></td>
<td><strong>30</strong></td>
<td><strong>57</strong></td>
<td><strong>42</strong></td>
</tr>
</tbody>
</table>
# Funding for Nuclear Theory

## TABLE 6

Annual funding for nuclear theory (M$)

<table>
<thead>
<tr>
<th></th>
<th>FY87 (in 2003 $)</th>
<th>FY03 (in 2003 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSF</td>
<td>DOE</td>
</tr>
<tr>
<td>Universities</td>
<td>4.2</td>
<td>8.9</td>
</tr>
<tr>
<td>National Labs</td>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>INT (Prog.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.2</td>
<td>16.1</td>
</tr>
</tbody>
</table>
### Support per Senior Ph.D.

**TABLE 8** Support per senior Ph.D. (k$)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF</td>
<td>42</td>
<td>70</td>
<td>73</td>
</tr>
<tr>
<td>DOE Univ.</td>
<td>71</td>
<td>118</td>
<td>114</td>
</tr>
</tbody>
</table>

Serious discrepancy between NSF and DOE remains.
Recent Achievements I

- General: Theory has provided, and is providing, guidance, justification, and planning of new facilities and highly complex experimental programs (JLab & upgrade, RHIC, RIA, NUSL, EIC, …).

- QCD based EFT of nuclear forces.
- Ab-initio “exact” calculations of light nuclei.
- Microscopic theory of complex nuclei.
- Lattice QCD: QCD equation of state ($T_c$ etc.), origin of chiral symmetry breaking, methodology for quantitative computation of hadron properties.
Recent Achievements II

- Generalized parton distributions.
- Diagnostics of hot and dense matter (jets, flow, etc.).
- Theoretical framework for gluon saturation and universal hadron structure at small $x$ (CGC).
- Color superconducting phases of cold, dense matter.
- Theoretical studies of type-II supernovae.
- Confirmation of the standard solar model and matter induced neutrino oscillations.
- Interdisciplinary many-body physics (condensed Bose gases, atomic clusters, random matrix theory, etc.)
INT is a huge success (community consensus!):
- Excellent leadership and operation
- Programs have great intellectual impact
- INT has raised recognition of nuclear theory in the broader physics community

DOE-NP deserves praise for creating and adequately supporting the INT

DOE has significantly increased support for nuclear theory in real terms since 1988
- but the field has grown even faster!
• **Lattice QCD:**
  – Methodology (improved actions, domain wall fermions, chiral extrapolations) is in place to calculate important observables with 5% precision or better;
  – $1\text{M/Tflops}$ hardware makes 10+ Tflops facility affordable now;
  – Wide range of program relevant questions are accessible:
    - Structure of the QCD vacuum and $T_c$
    - Structure of ground state hadrons, including exotics
    - Form factors, generalized parton distributions, etc.
    - QCD equation of state at $\mu>0$
    - Frontier I: spectral functions
    - Frontier II: solutions of the fermion sign problem
Opportunities II

- **Quantitative analysis of JLab and RHIC experiments:**
  - Reaction theory for hadron spectroscopy
  - Phenomenology of polarization observables for RHIC-SPIN
  - Quantitative phenomenology of soft and hard probes of hot QCD matter

- **Nuclear structure theory:**
  - Microscopic ab initio calculations of complex nuclei
  - EFT phenomenology of nuclear interactions
  - Universal energy density functional
  - Unification of nuclear structure and reaction theory
  - Microscopic understanding of symmetries and collective motion
• **Nuclear astrophysics:**
  – Quantitative simulations of type-II supernovae (2D + 3D)
  – Dynamics and nuclear physics of gamma-ray bursts
  – Neutrino astrophysics
  – Neutron star physics

• **Tests of fundamental symmetries and search for Beyond Standard Model physics:**
  – EDM and cosmic baryon asymmetry
  – Neutrinoless double beta decay
  – Hadronic radiative corrections to symmetry violations
  – Weak hadronic interactions
• Soft collinear effective theory
• Thermalization and transport in QCD matter
• Interdisciplinary Many-Body Physics
  – Strong coupling systems with pairing and disorder
  – Solutions of the fermion sign problem (meron cluster alg’s, etc.)
  – Condensed trapped Fermi and Bose gases

• *Unifying theme*: Controlled precision calculations of quantities of experimental relevance in microscopic theoretical frameworks.
Community Input

- **Detailed survey of nuclear theory PIs and co-PIs:**
  - 74 responses from all subfields and age groups
  - Responses confirm our analysis of scientific achievements and opportunities and support our recommendations
  - Most urgent needs: Increased manpower, postdocs, bridged positions

- **Questionnaire to experimental PIs**
  - 22 responses from different subfields
  - Broad support for increased support for theory addressing critical needs of the national nuclear physics program
Guiding Principles and Aims

• Ensure future excellence of nuclear theory in the U.S.
• Maximize effectiveness of nuclear theory research
• Develop increased manpower required to address scientific opportunities and programmatic needs
• Attract, train, and retain best possible talent
• Reverse decline of nuclear theory in top-rated physics departments
• Build program accountability into major new initiatives
Priorities: Overview

- Postdoctoral prize fellowships
- Topical centers
- Centers of excellence
- Large scale computing initiatives
- Revitalization mechanisms
- Enhance NSF core grants
- Protect DOE core program
Priorities: Manpower

• **Postdoctoral prize fellowships:**
  – 5 awards annually for 3-year terms
  – National selection committee
  – Postdocs select host institution
  – Raise visibility of best young nuclear theorists
  – Enhance early career attractiveness and opportunities

• **Targeted manpower enhancements:**
  – Topical ("seeding") centers
  – Interdisciplinary centers of excellence
  – 5-year terms; competitive renewal possible
Priorities: Topical Centers I

• 2-3 centers per year to be awarded competitively on the basis of scientific quality and relevance to the national program, at $300-500k each.
• Proposals should contain “deliverable” results.
• Centers to function as hubs of wider networks.
• Centers could involve staff/faculty bridge funding.
• Review and possible competitive renewal after 5 years.
• Steady state: 10-12 topical centers in maximal scenario, creating 30-50 new staff/faculty and postdoc positions.
• Some examples of program relevant topics:
  – systematic development of EFT description of nuclear forces
  – properties of nuclei far from stability
  – microscopic study of nuclear input parameters for astrophysics
  – calculation of electroweak corrections to precision data
  – microscopic nuclear reaction theory
  – analysis of the spectrum of excited baryons (and mesons)
  – phenomenology of hard probes of hot, dense matter
  – phenomenology of thermal probes of hot matter
  – simulations of core collapse supernovae
  – lattice simulations of hadron properties
  – lattice simulations of thermal QCD
  – *ab initio* many-body calculations
  – phenomenology of neutrino oscillations
  – etc ...
Priorities: Centers of Excellence

• Interdisciplinary centers at universities or national labs targeting areas benefiting from intense interactions with scholars from other communities (astrophysics, CM physics, HE physics, etc.).
• Broad and curiosity driven research agenda.
• Flexible specific structure to accommodate special circumstances (from NSF PFC model to …).
• Funding $0.5-1M/year; faculty bridge support could be an important component.
• 3-5 centers nationally.
• Review and competitive renewal after 5 years.
Priorities: Computing

• Aggressive investment in computational nuclear science with the goal of solving problems of core importance to the physics program:
  – Urgently needed investments include >10 teraflops scale national facilities to capitalize on immediate scientific opportunities: precise lattice QCD calculations of the structure of hadrons and dense matter, realistic simulations of supernova dynamics, and \textit{ab initio} solutions of quantum many-body problems.
  – The opportunities are so compelling that even when new external resources, such as SciDAC, are unavailable or inadequate, a minimal sum of $3M/year from the nuclear science budget should be allocated to computational nuclear physics with an appropriate share being borne by the nuclear theory program.
  – Start longer term planning for >100 teraflops facility.
  – Utilize synergies with HEP initiatives.
Priorities: Revitalization

- **Bridge positions:**
  - Funding agencies should expand existing practice of bridging new faculty and staff positions
  - Peer review of proposals

- **OJI / CAREER programs:**
  - Continue very successful OJI program, but
  - Increase OJI grants to ≥100k/year budget
  - Allow national lab staff to compete

- **Graduate students:**
  - Develop attractive fellowship program
  - Start new REU programs led by nuclear theorists

- **Sabbatical leaves**
  - home inst. 50%, host inst. 25%, agency 25%
Priorities: Base Program

• NSF base program:
  – Raise $70k/PI funding to DOE level (>$110k/PI) even in a constant level of effort scenario
    ➢ Make best theory groups and single PIs more effective
    ➢ Make NSF program more attractive to best young theorists
    ➢ Raise competitiveness of NSF nuclear theory program with respect to other theory areas.
  – Aim at 50% growth of nuclear theory funding

• DOE base program:
  – Modest decrease in constant level of effort scenario
  – Protect core program in growth scenarios
## Budget Scenarios I

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Constant Effort</th>
<th>Option I</th>
<th>Option II</th>
<th>Option III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postdoc Fellows</td>
<td>0.6</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Topical Centers</td>
<td>1.0</td>
<td>2.5</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Centers of Excellence</td>
<td>0.5</td>
<td>1.5</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Computing</td>
<td>0.2</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Graduate students</td>
<td>-0.6</td>
<td>-0.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Enhanced OJIs</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>NSF base budget</td>
<td>0.0</td>
<td>0.6</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>DOE base budget</td>
<td>-0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.0</td>
<td>5.6</td>
<td>9.7</td>
<td>13.7</td>
</tr>
<tr>
<td>Current NP Theory</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Future NP Theory</td>
<td>25.0</td>
<td>30.6</td>
<td>34.7</td>
<td>38.7</td>
</tr>
<tr>
<td>Increase (%)</td>
<td>0</td>
<td>22</td>
<td>39</td>
<td>55</td>
</tr>
</tbody>
</table>
Budget Scenarios II

- NSF Base Budget
- DOE Base Budget
- Computing
- Centers of Exc
- Top. Centers
- Enh. OJI
- Grad students
- PhD Fellows
Budget Scenarios III

- Const Effort
- Option I
- Option II
- Option III

$M

- Postdoc Fellows
- Grad students
- Enhanced OUs
- Topical Centers
- Centers of Excellence
- Computing
- DOE base budget
- NSF base budget