Report to NSAC – 13 September 2003

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)
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Gail McLaughlin (NCSU)
Berndt Mueller (Duke) - Chair
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Krishna Rajagopal (MIT)
Winston Roberts (ODU/Jlab)
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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."

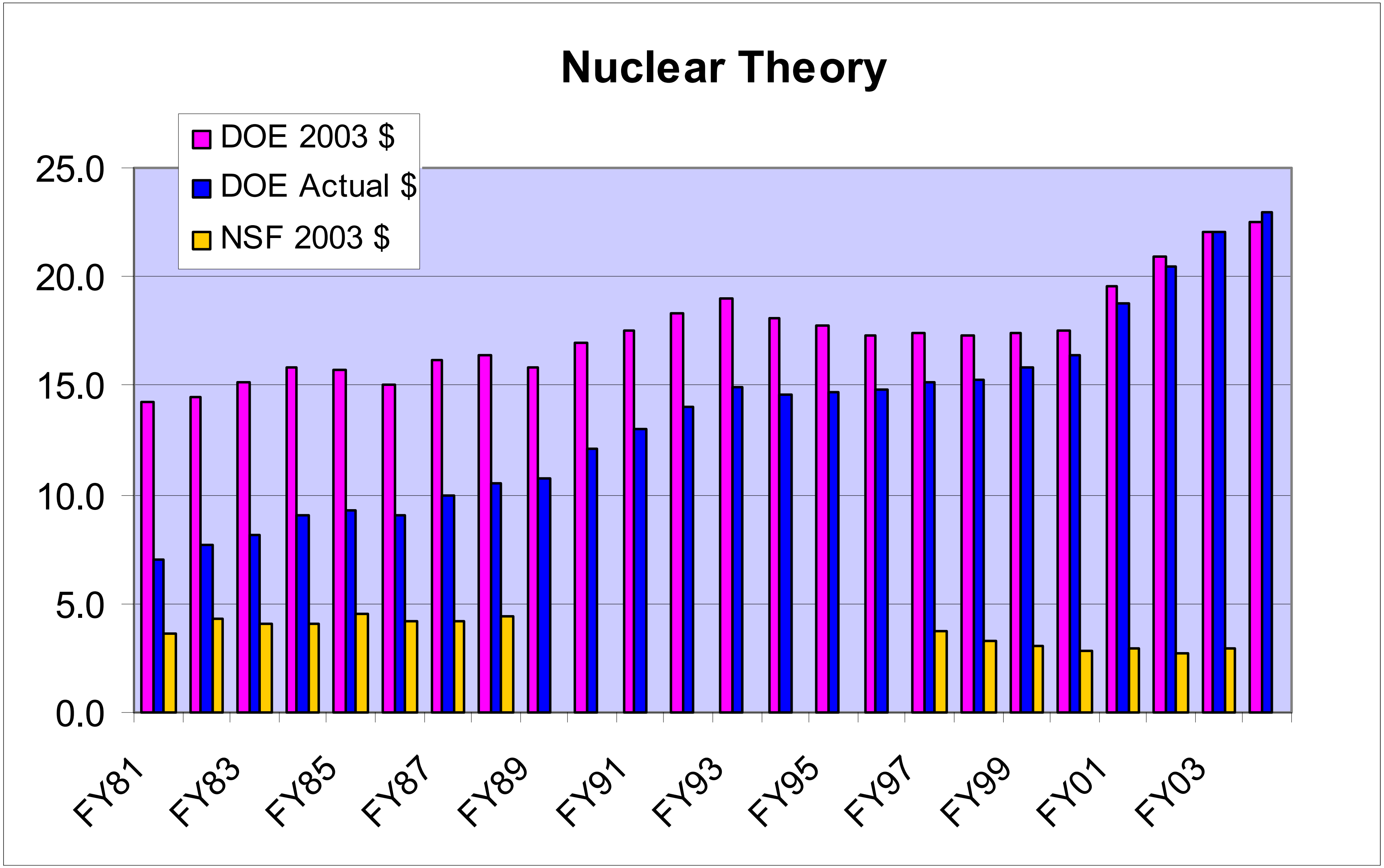
- Specific charge for NSAC Theory Subcommittee:

  "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…."

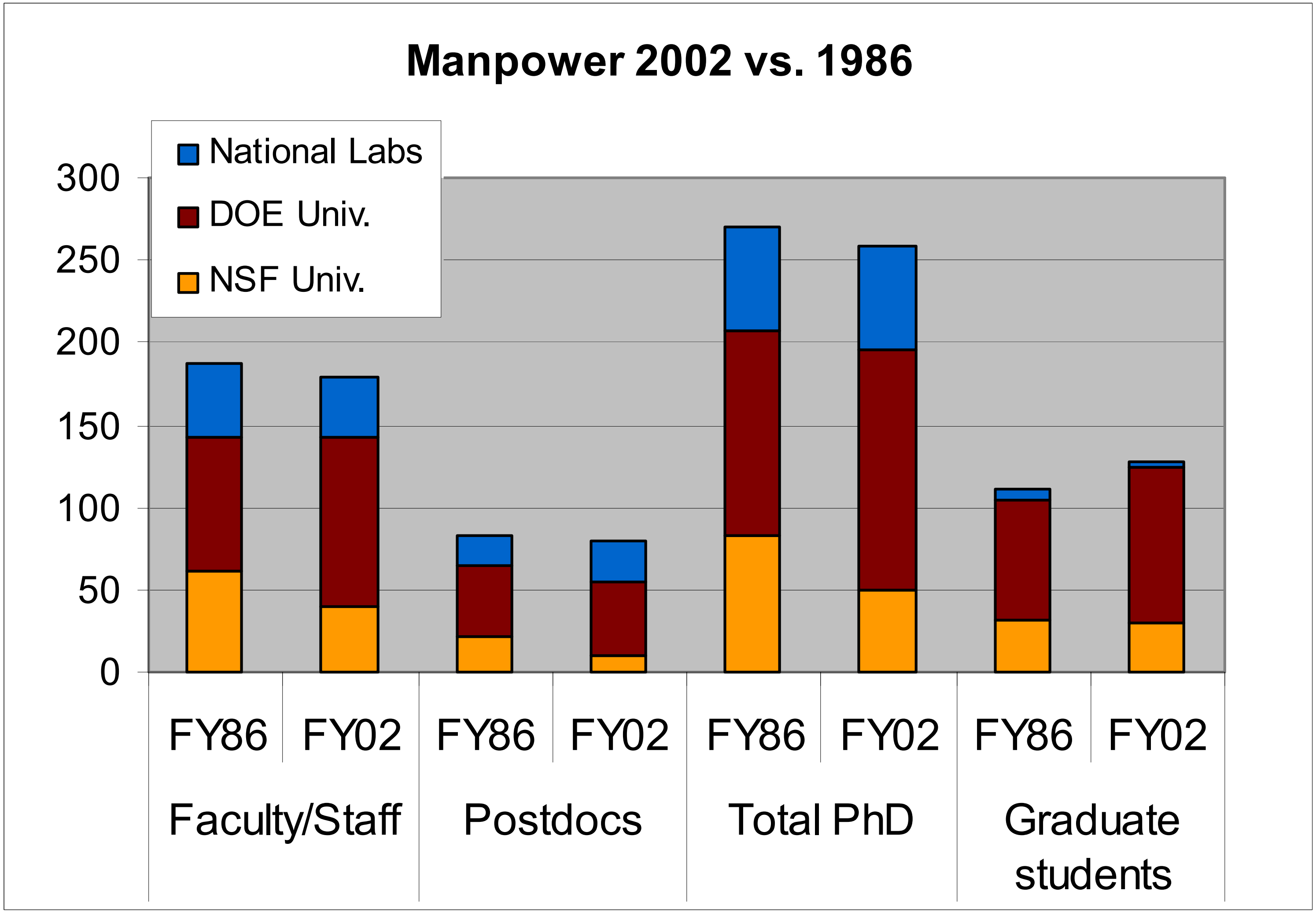
1988 Recommendations

- 5-year plan to strengthen nuclear theory:
  - 60-65 additional PhD level personnel
  - 70% budget increase (\$13M = 6% $\rightarrow$ \$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



Theory Manpower



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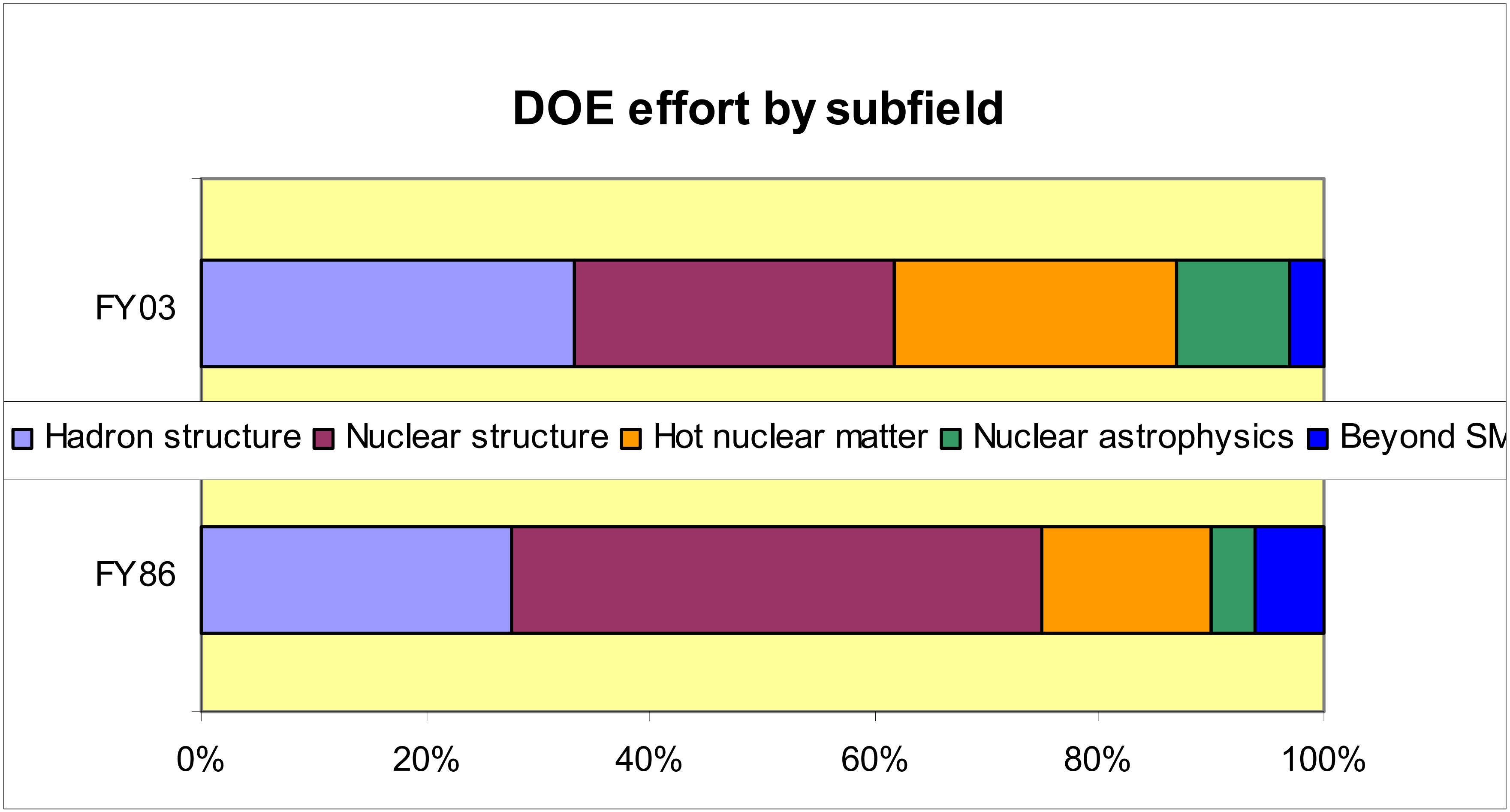
Effort by Subfield



Top-Rated Universities

TABLE 4 Professorial nuclear scientists at top-rated physics departments

University	Theorists		Experimentalists		Total	
	1987	2003	1987	2003	1987	2003
UC Berkeley	0	0	3	1	3	1
Caltech	1	2	5	3	6	5
Chicago	0	2	2	1	2	3
Columbia	0	1	3	3	3	4
Cornell	0	0	0	0	0	0
Harvard	0	0	2	1	2	1
Illinois	5	2	10	9	15	11
MIT	7	5	8	9	15	14
Princeton	0	0	8	2	8	2
Stanford	0	0	3	1	3	1
Total	13	12	44	30	57	42

Funding for Nuclear Theory

TABLE 6 Annual funding for nuclear theory (M$)

	FY87 (in 2003 $)			FY03 (in 2003 $)		
	NSF	DOE	Total	NSF	DOE	Total
Universities	4.2	8.9	13.1	2.9	11.7	14.6
National Labs		7.3	7.3		9.5	9.5
INT (Prog.)					0.9	0.9
Total	4.2	16.1	20.3	2.9	22.1	25

Support per Senior PhD

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

	FY86 (1986 $)	FY86 (2003 $)	FY03 (2003 $)
NSF	42	70	73
DOE Univ.	71	118	114

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.)

Institute for Nuclear Theory

- 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!

Opportunities I

- Lattice QCD:
  - Methodology (improved actions, domain wall fermions, chiral extrapolations) is in place to calculate important observables with 5% precision or better;
  - $1M/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

Opportunities III

- 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

Opportunities IV

- 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

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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 attractivity 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.

Priorities: Topical Centers II

- 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.

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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 *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

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Budget Scenarios I

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

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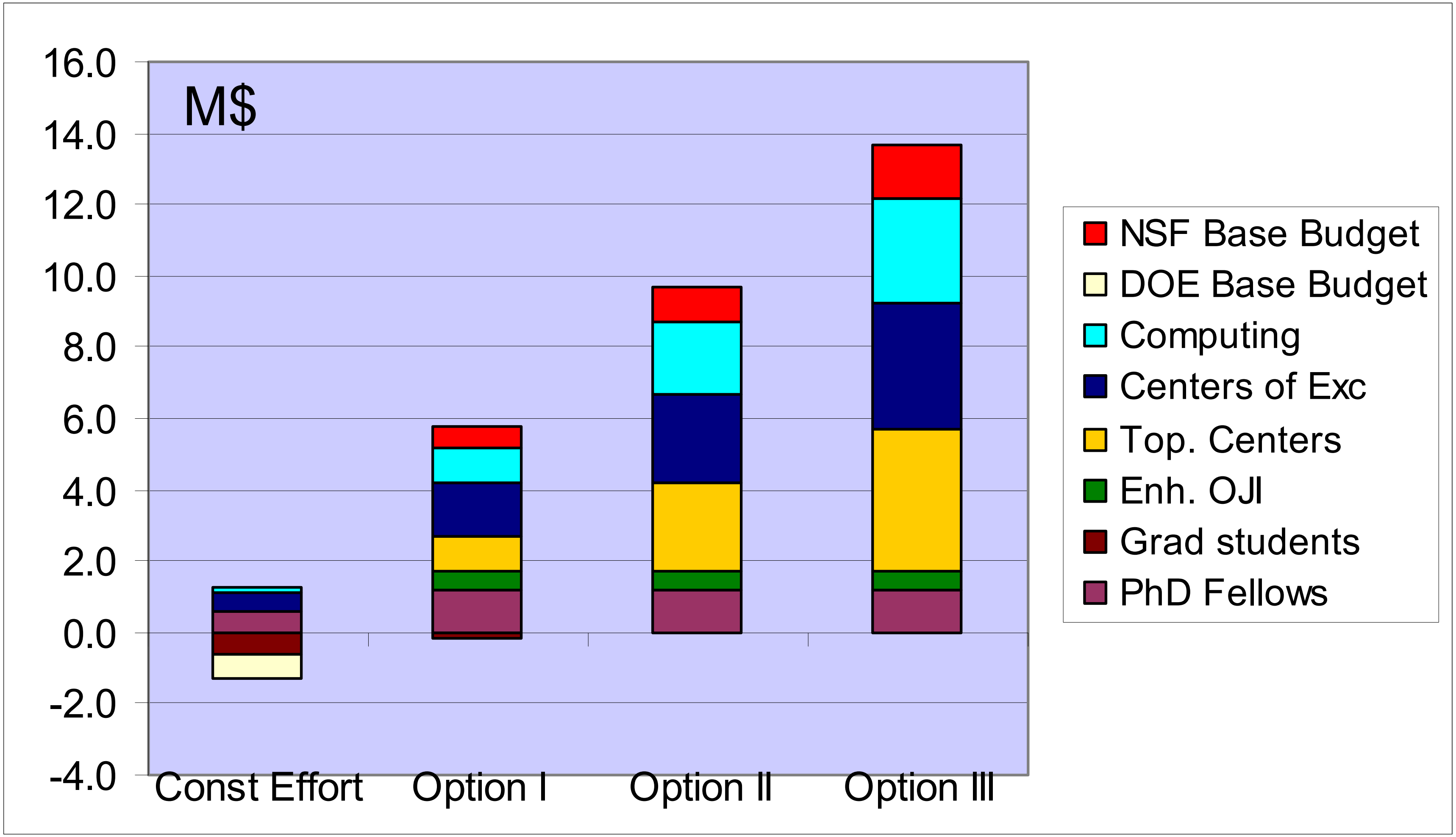
Budget Scenarios II



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Budget Scenarios III