# *Town Meeting on Nuclear Astrophysics & Study of Nuclei*

***Chicago, January 19 – 21***

***Hendrik Schatz   and   Robert Janssens***

## Organizing Committee:

Ani Aprahamian
Larry Cardman
Art Champagne
David Dean
George Fuller
Robert Grzywacz
Anna Hayes
I. Yang Lee
Erich Ormand
Jorge Piekarewicz
Michael Thoennessen
Robert Wiringa
Sherry Yennello

Hendrik Schatz & Robert Janssens (co-chairs)

Attendance: ~ 260 participants – 375 registered for the two town meetings & workshop

# General outline of the Meeting:

***Day 1:*** - ***Morning:*** Joint session with the town meeting on
Neutrinos, Neutrons, Fundamental Symmetries

Intro by R. Tribble & Report from workshop on Education (P. McMahan)
Talks by R. Casten, S. Freeman, J. Truran, M. Ramsey-Musolf

- ***Afternoon:*** Plenary Sessions with invited talks by:
Nuclear Astrophysics: J. Blackmon, J. Lattimer, M. Wiescher
Structure of Nuclei: Th. Glasmacher, K. de Jager, A. Macchiavelli,
W. Nazarewicz

- ***Evening:***
Working supper: Discussion of recommendations from workshop on
Nuclear Science Education and Outreach

Joint session with the town meeting on Neutrinos, Neutrons,
Fundamental Symmetries
Talks by B. Mueller (NSAC Theory Report), B. Keister (DUSL),
J. Symons (NSAC RIB Task Force), D. Kaplan (INT)

# General outline of the Meeting:

***Day 2:*** **-** ***Morning:*** Parallel Working Group Session:

1. ***Nuclear Theory*** *(T. Duguet, E. Ormand, R. Wiringa)*
2. ***Experiments with hot nuclei, dense matter*** *(W. Lynch, S. Yennello, L. Sobotka)*
3. ***Nuclear Structure & Reactions*** *(L. Cardman, R. Grywacz, M. Carpenter, A. Gade, F. Liang)*
4. ***Nuclear Astrophysics*** *(A. Champagne, G. Fuller, M. Wiescher)*

***- Afternoon (1):*** Parallel Working Group Session:

4. ***Nuclear Astrophysics continued*** *(A. Champagne, G. Fuller, M. Wiescher)*
5. ***Joint session:*** *Bringing together working groups 1, 2 & 3 (L. Cardman, R. Grzywacz, E. Ormand, R. Wiringa, S. Yennello)*

***- Afternoon (2):*** Parallel Working Group Session:

6. ***Joint session:*** *Bringing together working groups 4 & 5 (A. Aprahamian, D. Dean)*
7. ***Joint session:*** *Bringing together working groups 2 & 4 (J. Piekarewicz, S. Reddy, B. Tsang)*
8. ***Facilities & Instrumentation*** *(J. Beene, J. Nolen, I.-Y. Lee, M. Thoennessen)*

*Note: Applications & Nuclear Data held joint with the American Competitiveness workshop (A. Hayes, E. Norman, M. Chadwick)*

# General outline of the Meeting:

***Day 3:*** **- *Morning*:** Session 1:

*Reports of Working Groups*

Session 2:

*Reports of Working Groups*

*General Discussion of content of White Paper & Resolutions*

Note: - A number of meetings took place in preparation of this town meeting:
RIA Users Organization, RIA Theory working group, JINA,
GRETINA/GRETA, MONA, etc.

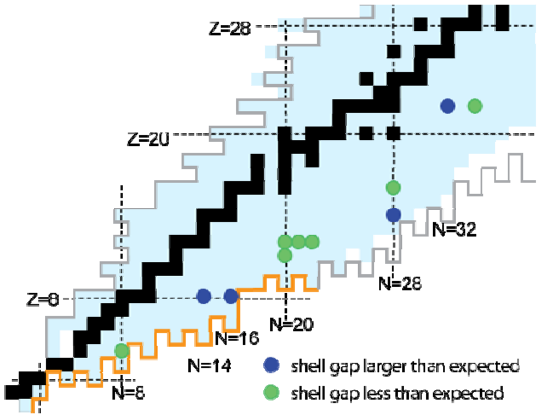
- A number of documents & white papers were available:
  → see Town Meeting web site:
  http://www-mep.phy.anl.gov/atta/dnp/papers_nasn.htm

# Charge to the Working Groups:

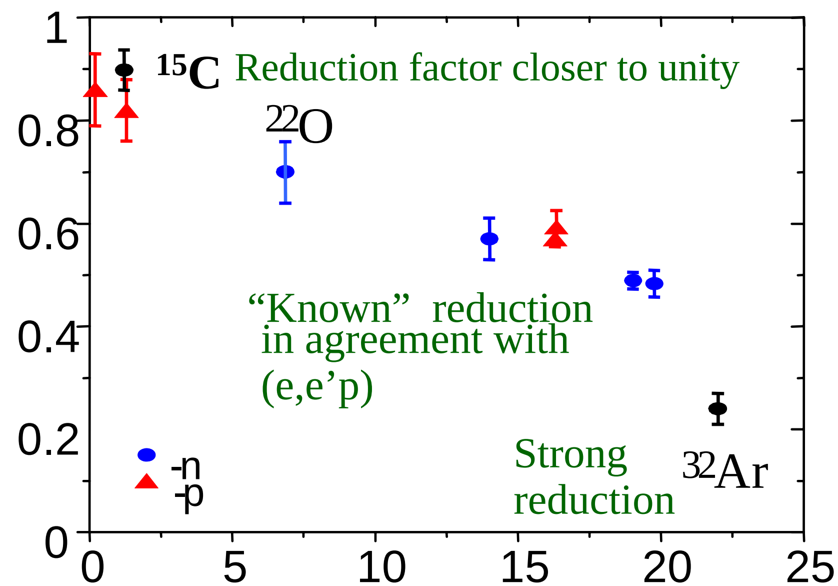
- Identify the most compelling scientific questions and opportunities for the next decade (within US) and their scientific impact.
- What facilities and other resources are needed for realizing these opportunities?
- A "lower cost" version of an advanced Rare Isotope facility is explicitly mentioned in the charge as the main major new facility for our area compatible with projected funding levels. What role does this facility play in realizing the major future opportunities in the area you are covering?
- What other needs does your field have until this new facility is operational?
- What will be the scientific impact on other fields, are there interdisciplinary aspects?
- Identify the major accomplishments in your area since the last long range plan.
- What has been the impact of this progress within and outside of the field?

# The five main themes of our field:

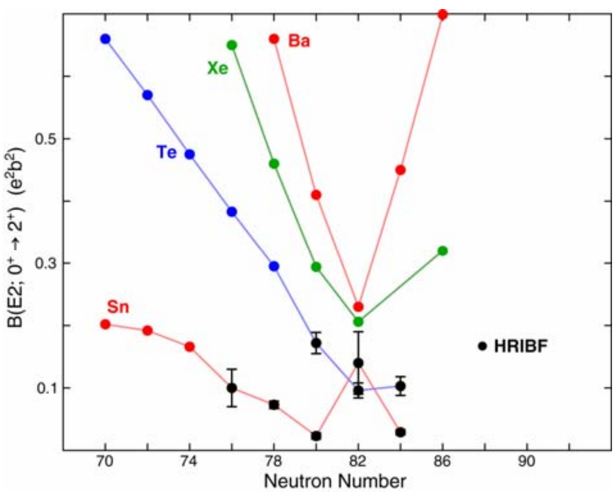
## 1. What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?




**N-rich systems amplify components of the interactions hidden near stability & new magic numbers appear.**




**Correlation effects beyond effective-interaction theory: Reduction is not "universal" (~0.6) and has strong dependence on binding energy**

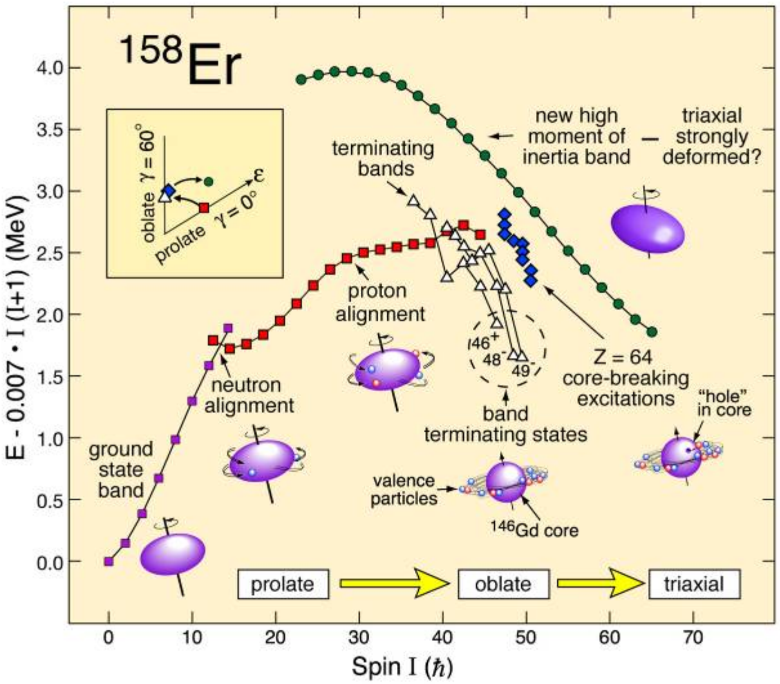



**Doubly-magic $^{132}$Sn is a new benchmark for studies of systems with large neutron excess:**

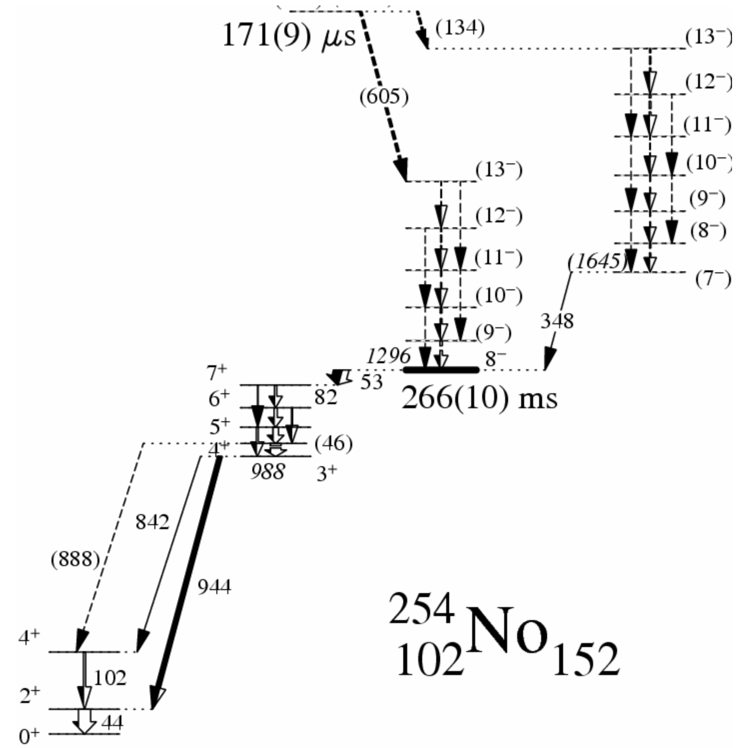
- **Unexpected evolution of collective states**
- **Strongly enhanced cross section for sub-barrier fusion**

# The five main themes of our field:

## 2. What is the origin of simple patterns in complex nuclei?



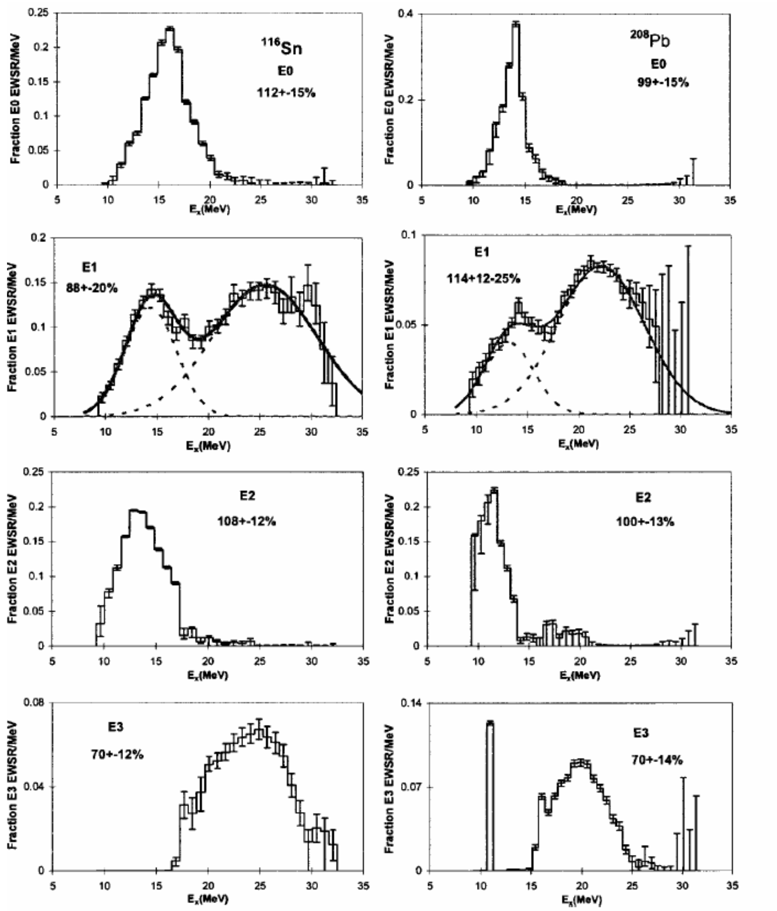

Return of collectivity at the highest spins, in a regime where it had been thought to be destroyed

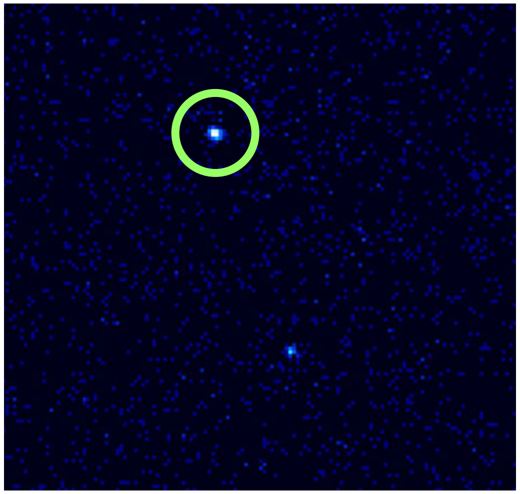



K-isomers is very heavy nuclei:
→Direct proof of axial symmetry
→Information on $E_{sp}$ → gaps and spacings
→ shell stabilization → SHN

# The five main themes of our field:

## 3. What is the nature of neutron stars and dense nuclear matter?



Neutron stars:

- what are their mass and radius?
- how do they cool?
- what is the core made of?
- what is the nature of transient phenomena?

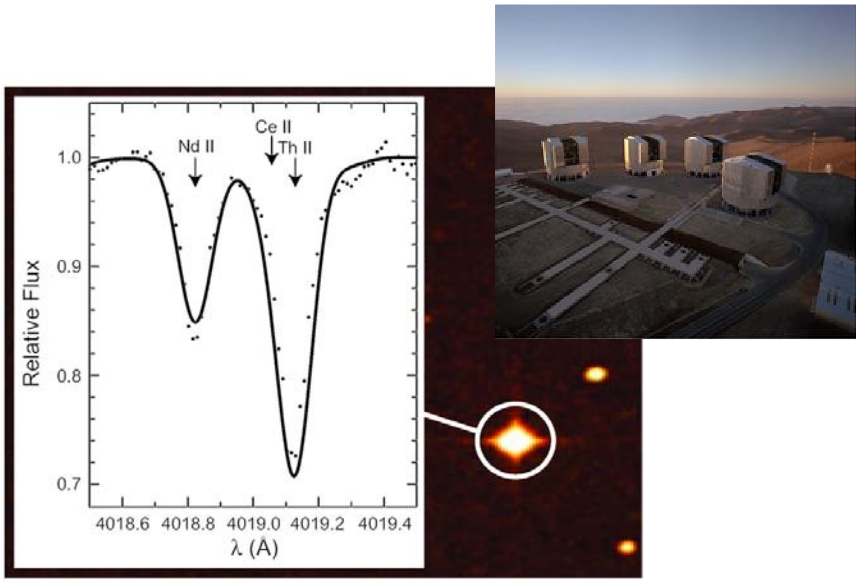
**•Nuclear reactions in the lab. constrain the nuclear matter equation of state**
**•A consistent value for the compressibility is emerging from two distinct approaches:**

***K = 230 +/- 10 MeV (Giant Resonance Studies)***
***K = 233 +/- 39 MeV (Multi-Fragm. HI collisions)***

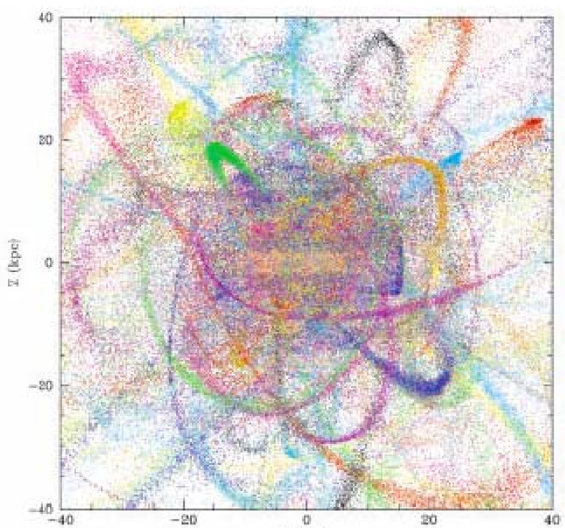
# The five main themes of our field:

## 4. What is the origin of the elements in the cosmos?

How were the elements from iron to uranium made?
(And how can we interpret the new precision observations made in stars?)

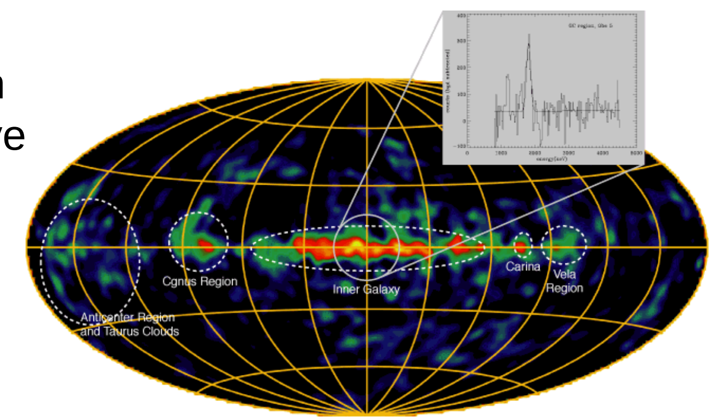



What is the chemical history
of the Galaxy and its components?



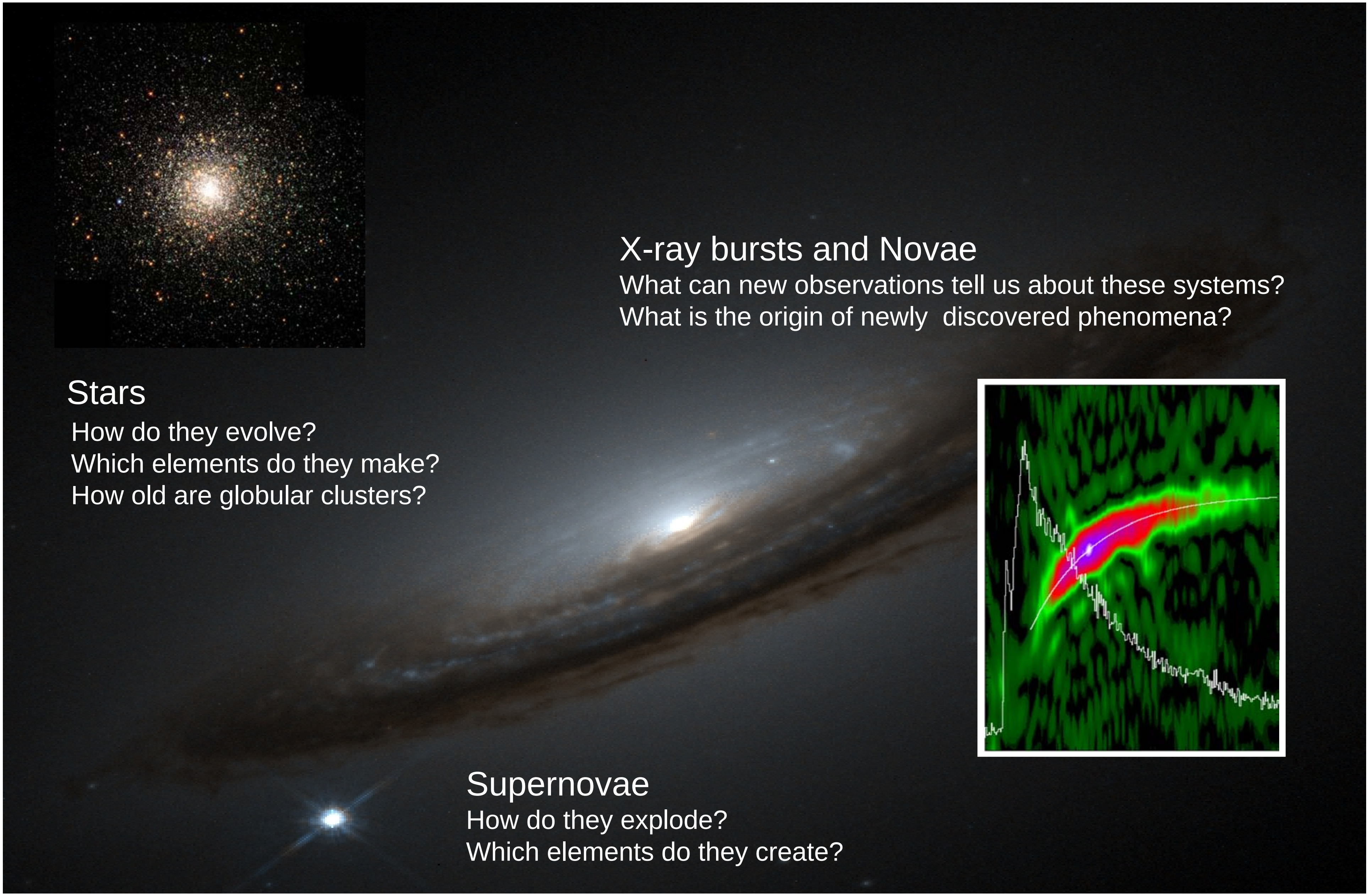

(Bland-Hawthorn & Freeman,
Science 287, 2000)

What is the distribution
and origin of radioactive
nuclei in the Galaxy?



# The five main themes of our field:

## 5. What are the nuclear reactions that drive stars and stellar explosions?



## **Results of Town Meeting: (1) Lessons Learned**

1. There is tremendous excitement and interest because of bright prospects:

   in theory & experiment

2. The nuclear astrophysics & nuclear structure communities are increasingly one:

   The interconnections between the various subfields continue to grow & develop:

   Global "strategies" in theory

   Ever increasing links between structure and reactions,

   structure & reactions and astrophysics

   Direct connections with studies done at JLab

This makes for an increasingly "connected community"!

# <u>Results of Town Meeting:</u> (1) Lessons Learned

3. There are a number of serious worries about the future:

The delay in RIA and the reduction in scope are issues

→ what should FRIB look like??

The present funding situation is a concern at all levels

This translates in:

grave concerns about: manpower

the situation with education

4. The community has a solid vision of its future:

There is agreement about the required science reach for FRIB

There is a solid vision for the “pre-FRIB” era:

There is a “theory game plan”

There are upgrades proposed for the facilities

There are excellent ideas for new detector developments

# Results of Town Meeting: (1) Resolutions – Global View

1. The physics of the nucleus is a fundamental component of modern science, and understanding exotic nuclei is essential to address this physics. The study of rare isotopes is therefore compelling not only for the breakthroughs it will allow in understanding nuclei and their role in the cosmos, but also for the many cross-discipline contributions it will enable, in basic sciences, national security, and many societal applications. To pursue this science, to educate the next generations of nuclear scientists and to maintain its cutting edge in this field, it is imperative that the U.S. initiate a major investment into a more powerful rare isotope production facility as early as possible. We therefore recommend that:

    - The highest priority in low-energy nuclear physics be the construction of a heavy-ion linac based rare isotope facility, including the capabilities for stopped, re-accelerated and in-flight beams to realize the scientific potential defined by the community and endorsed by the National Academies of Sciences in their recent RISAC report.

2. In support of this science goal, we must continue forefront research at existing facilities to make new discoveries, train new people and develop new detector and accelerator technologies. Hence, we also recommend that:

    - Appropriate funds for operations and near-term upgrades of existing rare isotope and stable beam research capabilities at ANL, NSCL, ORNL, and other national and university facilities be supported together with a strong theory program and interdisciplinary initiatives. In particular, it is critical that funding be increased immediately to allow the effective utilization of the US national user facilities;
    - Construction of the GRETA array begin immediately upon the successful completion of the GRETINA array;
    - Support for nuclear theory to address key questions in nuclear structure, nuclear reactions, and nuclear astrophysics be strongly increased to nurture young scientists in this critical area of research in concert with an overall increase in nuclear theory as recommended in the 2003 NSAC Theory subcommittee report.

## <u>Results of Town Meeting: </u>(2) Resolutions – Step by Step

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## The Case FRIB

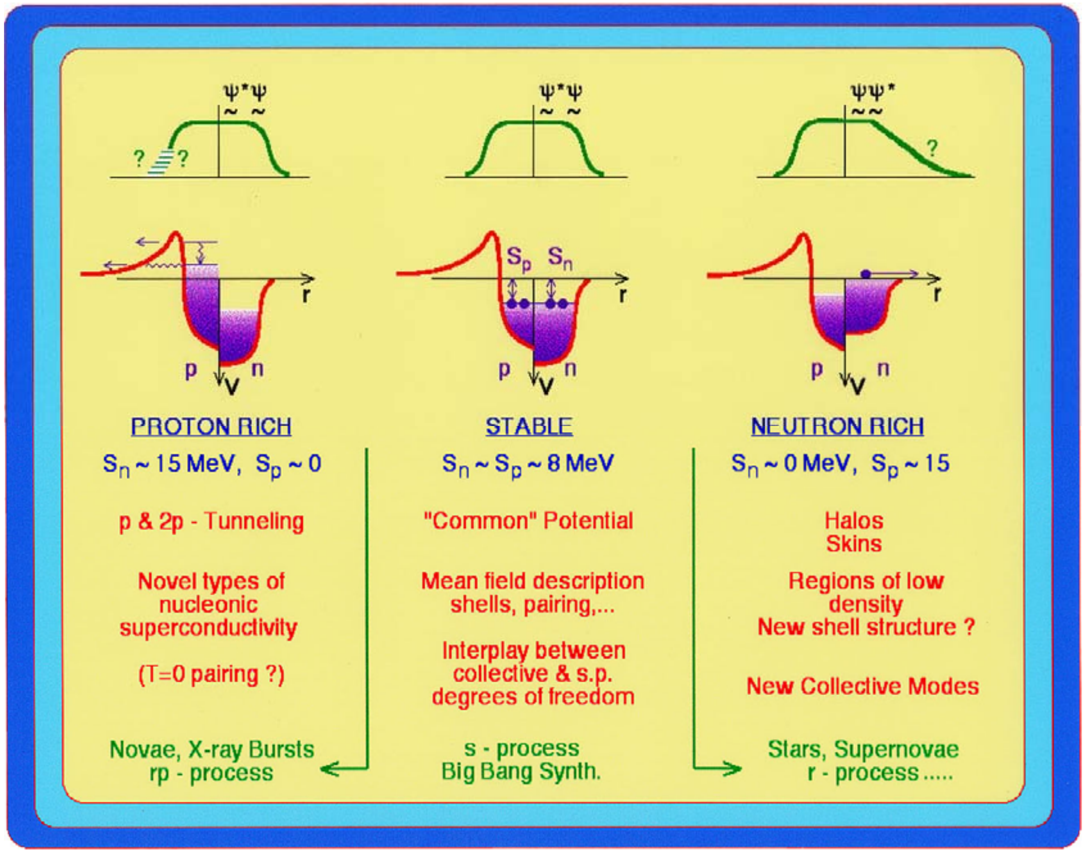
### Basic “facts” of nuclear physics that may be wrong in far-from-stability nuclei

- The charge-independence of the strong interaction makes isospin a good quantum number.
- The radius and diffuseness of the neutron and proton distributions are similar.

$$\rho(r) = \frac{1}{1 + \exp[(r - R)/a]}$$

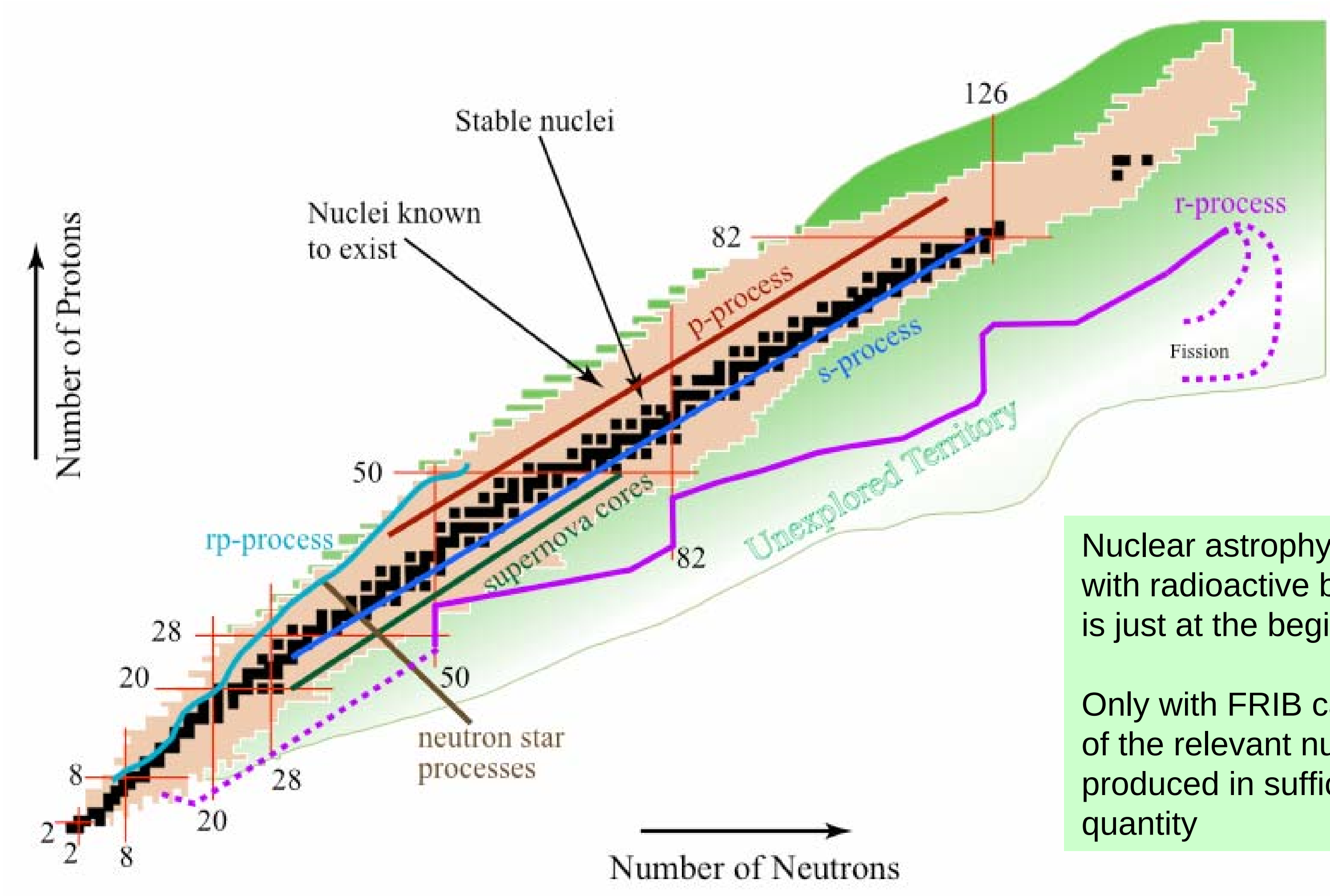
R=1.2 $A^{1/3}$, a~ 0.55 fm

- The magic numbers of the shell model are fixed.
- The deformations of the neutrons and protons are similar.
- Valence single-particle states are only occupied at the 60% level due to short-range correlations.



# The Case FRIB

need to produce and study the unstable nuclei
- that govern stellar explosions,
- that exist in the interiors of neutron stars,
- and that are the progenitors of the stable nuclei found in the solar system today




Nuclear astrophysics with radioactive beams is just at the beginning

Only with FRIB can most of the relevant nuclei be produced in sufficient quantity

# Milestones in RIA/FRIB Development

NSAC has already endorsed RIA/FRIB six times

- **1996: Advanced ISOL facility and MSU upgrade are given the highest priority for new construction within the field of nuclear physics in the United States in the DOE/NSF 1996 *Long Range Plan* . "**We strongly recommend development of a plan for a next generation ISOL-type facility and its construction when RHIC construction is substantially complete"**.**
- **1999: ISOL Task Force concludes "**building a world-leading accelerator facility is a scientific imperative for the United States." **Task Force sets performance standards, recommends technical approach to facility and estimates cost. Task Force recommends commissioning Conceptual Design Report in the immediate future.**
- **2001: NSAC Subcommittee reviews RIA preliminary cost estimate: "reasonable" and "appropriate".**
- **April 2002 DOE/NSF Long Range Plan:** "RIA is the highest priority for major new construction for nuclear physics in the United States."
- **March 2003 NSAC Facilities Subcommittee:** "absolutely central to nuclear physics" **and** "ready to initiate construction"
- **2003 DOE RIA R&D Workshop -- 112 participants- DOE RIA R&D Panel – "credible reference designs exist" and "most of the potential risks … have now been removed"**
- **January 04 NSAC Comparison of RIA and GSI:** "very strong science case", "upgrade of GSI will not duplicate the capability of RIA".

# Office of Science Facilities Plan

## Facilities for the Future of Science:

*A Twenty-Year Outlook*

### Contents


**A Message from the Secretary**

**Steward of the World's Finest Suite of Scientific Facilities and Instruments**

**Introduction**

- Prioritization Process
- A Benchmark for the Future
- The Twenty-Year Facilities Outlook—A Prioritized List

**Facility Summaries**

Near-Term Priorities

| | |
|---|---|
| Priority: 1 | ITER |
| Priority: 2 | UltraScale Scientific Computing Capability (USSCC) |
| Priority: Tie for 3 | Joint Dark Energy Mission (JDEM) |
| | Linac Coherent Light Source (LCLS) |
| | Protein Production and Tags |
| | Rare Isotope Accelerator (RIA) |
| Priority: Tie for 7 | Characterization and Imaging of Molecular Machines |
| | Continuous Electron Beam Accelerator Facility (CEBAF) 12 GeV Upgrade |
| | Energy Sciences Network (ESnet) Upgrade |
| | National Energy Research Scientific Computing Center (NERSC) Upgrade |
| | Transmission Electron Achromatic Microscope (TEAM) |
| Priority: 12 | BTeV |

# Conclusions of RISAC report:

- Nuclear structure and nuclear astrophysics constitute **a vital component of the nuclear science portfolio** in the United States.
- **Failure to pursue** a U.S.-FRIB would likely lead to a **forfeiture of U.S. leadership** in nuclear-structure-related physics and would **curtail the training of future U.S. nuclear scientists.**
- A U.S. facility for rare-isotope beams of the kind described to the committee would be **complementary to existing and planned international efforts**, particularly if based on a heavy-ion linear accelerator.
  With such a facility, the United States would be a **partner among equals** in the exploration of the world-leading scientific thrusts listed above.
- The science addressed by a rare-isotope facility, most likely based on a heavy-ion driver using a linear accelerator, should be a **high priority** for the United States. The facility for rare-isotope beams envisaged for the United States would provide capabilities **unmatched elsewhere** that would help to provide answers to the key science topics outlined above

## Results of Town Meeting: (2) Resolutions – Step by Step

2. In support of this science goal, we must continue forefront research at existing facilities to make new discoveries, train new people and develop new detector and accelerator technologies. Hence, we also recommend that:

   - Appropriate funds for operations and near-term upgrades of existing rare isotope and stable beam research capabilities at ANL, NSCL, ORNL, and other national and university facilities be supported together with a strong theory program and interdisciplinary initiatives. In particular, it is critical that funding be increased immediately to allow the effective utilization of the US national user facilities;

On-going & Planned upgrades:

CARIBU (&super-Caribu) (ATLAS), HPTL & $e^-$ driver (HRIBF), re-accelerator (NSCL)
CLAIRE (LBNL), RESOLUT (FSU), TAMU RIB upgrade, HI$\gamma$S (TUNL)
& preserving stable beam capabilities – especially for the nuclear astrophysics program

Interdisciplinary Initiatives:

JINA, SciDAC-2, JUSTIPEN,..

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   - Construction of the GRETA array begin immediately upon the successful completion of the GRETINA array;

Adequate funding for the continued development of state-of-the-art detectors at existing facilities for subsequent use at FRIB is viewed as an essential step towards ensuring that this new facility achieves its full potential at its start of operations.

A number of developments are on-going at the Users facilities & University laboratories

GRETA is a special case:
- LRP 2002 let to GRETINA (~ ¼ of GRETA)
- Timely & cost-effective completion depends critically on steady production of Ge detectors & availability of highly specialized workforce → interruption of effort would be very damaging

## <u>Results of Town Meeting:</u> (2) Resolutions – Step by Step

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    - Support for nuclear theory to address key questions in nuclear structure, nuclear reactions, and nuclear astrophysics be strongly increased to nurture young scientists in this critical area of research in concert with an overall increase in nuclear theory as recommended in the 2003 NSAC Theory subcommittee report.

The low-energy theory community has organized itself to take a coherent approach to resolving the scientific challenges it faces (roadmap):

→ there is a high level of enthusiasm and optimism in the nuclear theory community
“ there are unprecedented opportunities for substantial progress towards the goal of arriving at a comprehensive and unified microscopic description of the structure of all nuclei and their low-energy reactions from the basic interactions between the constituent protons and neutrons”

→ “ While the number of creative young scientists, who are fast becoming leaders in the revitalization of nuclear theory, has increased, the present level of manpower is insufficient to carry out the current program, let alone to take advantage of the new opportunities.”

## Results of Town Meeting: (3) Comment on Education

Concerns about education were present throughout the Town Meeting:

→ Education in Low-energy nuclear science (physics & chemistry) is important for societal applications
→ To attract the best and the brightest, new facilities are essential
→ Without adequate support today, the highly skilled manpower base required in the next decade will not be available

The NSAC subcommittee on education recently estimated that the **national need** is between **100 and 120 nuclear science PhDs** per year to meet the demand. The current rate of production is approximately 70 percent of this amount. Hence, there is a **critical need to maintain, if not expand, the number of talented experts in nuclear science and, in particular, in rare isotope science.**

This can only be done by having **forefront research opportunities for undergraduate and graduate students**, as they are offered by the cutting edge low energy nuclear physics accelerator facilities currently operating and, in the near future, by the FRIB facility that will attract the most talented students into the field.

Education and outreach are key components of any vision of the future of the field of nuclear science.
We therefore fully endorse the recommendations of the education white paper.

## White Paper:

- A White paper is being written
- Contents:
  - resolutions
  - roadmap for the next decade
  - response of the low-energy community to the questions in the NSAC charge
  - summaries of the working groups
  - links to other documents & white papers
- Time Table:
  - the draft is with the organizing committee for comments
  - final version ready by end of March