
# The Facility for Rare Isotope Beams

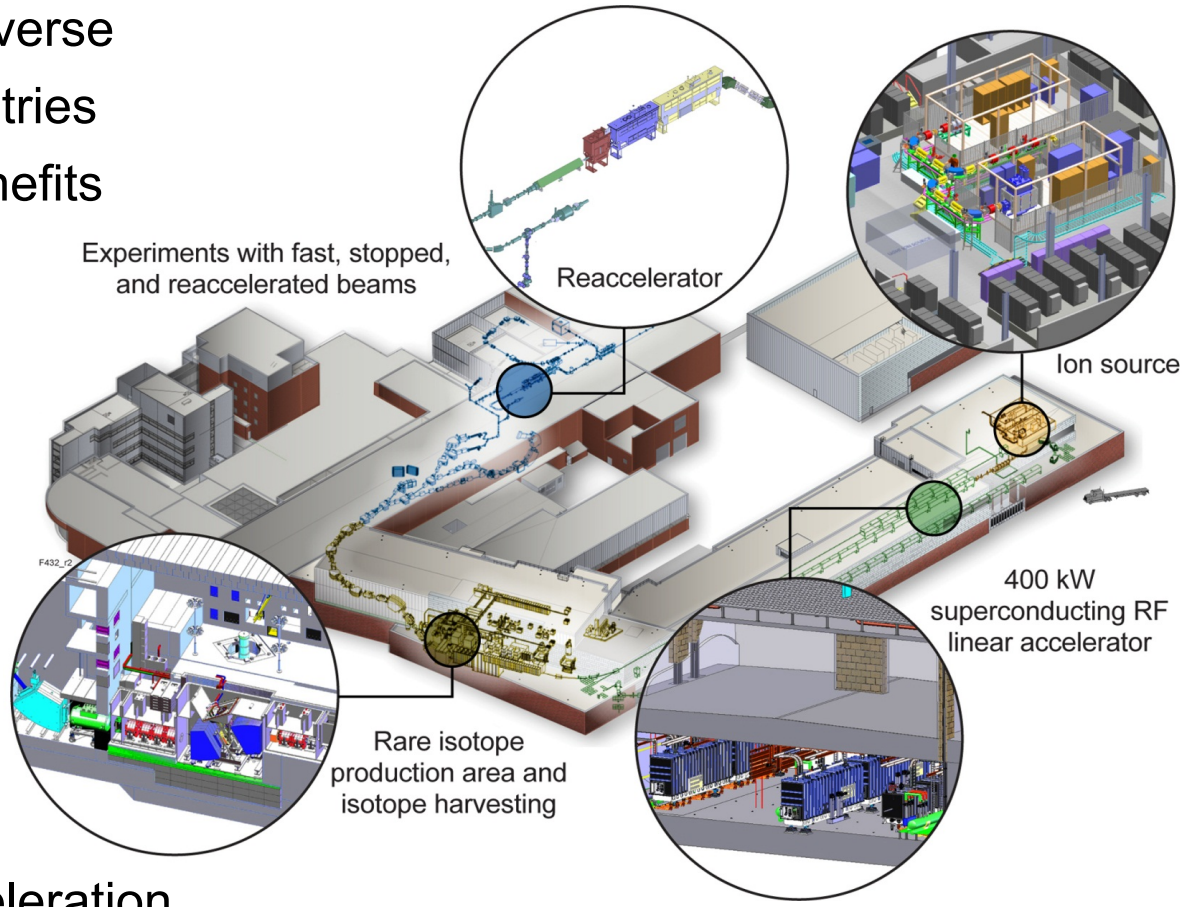
MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

# FRIB: Facility for Rare Isotope Beams

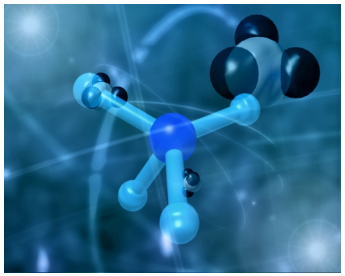
- Properties of nucleonic matter
- Nuclear processes in the universe
- Tests of fundamental symmetries
- Societal applications and benefits



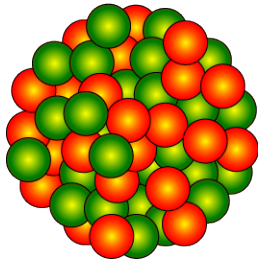

- 200 MeV/u, 400 kW superconducting heavy-ion driver linac
- Initial capabilities include fragmentation of fast heavy-ion beams combined with gas stopping and reacceleration

# Fundamental physics

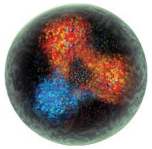
Rocks



Molecules

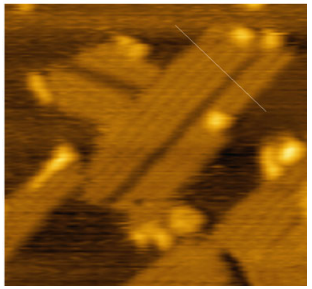


Nuclei

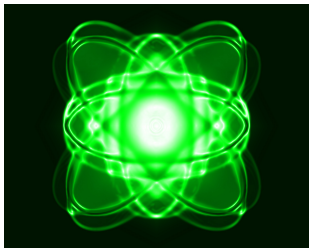


Quarks

Crystals



Atoms



Nucleons

# There is more than Fundamental Physics

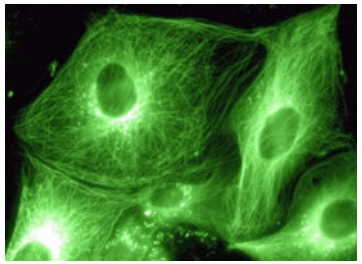
I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, "What are the strange particles?") but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations.

Richard Feynman

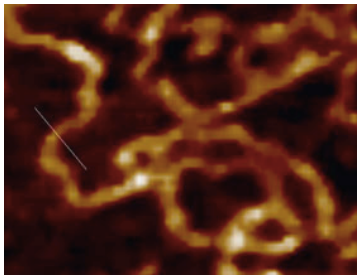
APS Meeting 1959, *Engineering and Science*, February 1960

# From Simplicity to Complexity

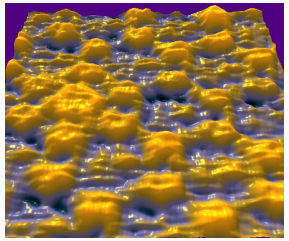
Human life



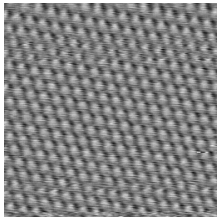
Cells



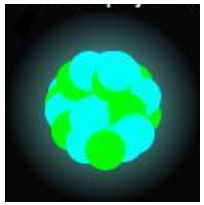
DNA



Molecules

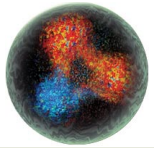


Atoms



Nuclei

Nucleons



Quarks

# History of FRIB

FRIB Users Organization

FACILITY FOR RARE ISOTOPE BEAMS

Breaking News | FRIB Science | FRIB Info | Working Groups | Theory Users | Gather-ings | JOIN ! | Organi-zation | Home | FRIB Site

## FRIB History

**1951:** First radioactive beam experiment performed at the Niels Bohr Institute in Copenhagen

**1967:** ISOL method introduced at CERN/ISOLDE

**1978:** First use of radioactive beams from projectile fragmentation at Berkeley

**1984:** Workshop on Prospects for Research with Radioactive Beams from Heavy Ion Accelerators in Washington, DC

**1985:** A proposal for an intense radioactive beams facility at TRIUMF

**1989:** First International Conference on Radioactive Nuclear Beams in Berkeley (Earthquake Meeting)

**1989:** The IsoSpin Laboratory (ISL) Steering Committee founded, drafted LRP language "Whole new vistas would be opened by a radioactive nuclear (RNB) accelerator", set RNB facility as one of highest priorities for new construction in LRP

**1991:** The IsoSpin Laboratory, ISL Steering Committee (report)

**1995:** TUNL Town Meeting, January 19-21, 1995. Report endorsing ISOL

**1995:** Overview of Research Opportunities with Radioactive Nuclear Beams, An Update (ISL)

**1995:** Argonne Yellow Book: ANL-ATLAS Exotic Beam Facility

**1996:** LRP: "We strongly recommend development of a cost-effective plan for a next generation ISOL-type facility"

**1997:** Columbus White paper: Scientific Opportunities with an Advanced ISOL Facility

**1997:** ISOL Task Force Report to NSAC: Opportunity: Rare Isotope Accelerator (RIA) Facility

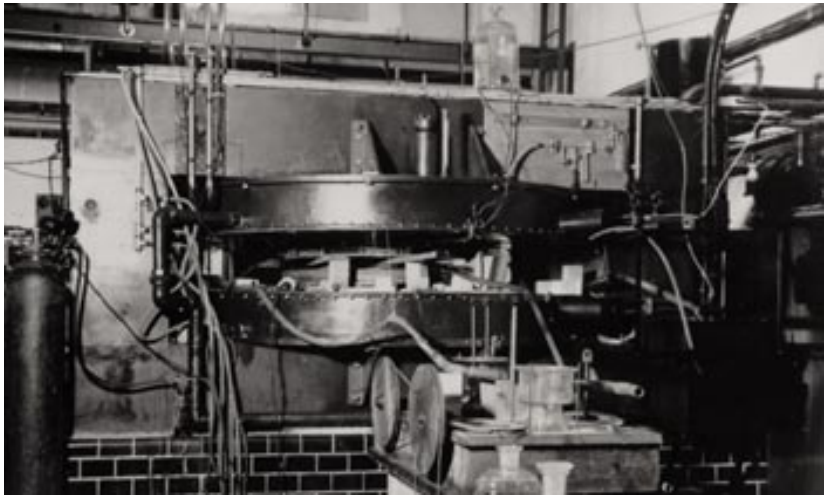
**1999:** "Nuclear Physics: The Core of Matter, The Fuel of Stars", National Academy Report

# First radioactive beam experiment

## Short-Lived Krypton Isotopes and Their Daughter Substances

O. KOFOED-HANSEN AND K. O. NIELSEN
*Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark*
(Received February 9, 1951)

THE isotopes $Kr^{89}$, $Kr^{90}$, $Kr^{91}$, and their daughter substances have been investigated. Krypton formed in fission of uranium was pumped through a 10-m long tube directly from the cyclotron into the ion source of the isotope separator. The cyclotron and the isotope separator were operated simultaneously, and the counting could begin immediately after the interruption of the separation. The rubidium and strontium daughter substances were separated chemically; strontium was precipitated as carbonate. Half-lives were measured and an absorption analysis of the radiations was carried out. The results are given in Table I.



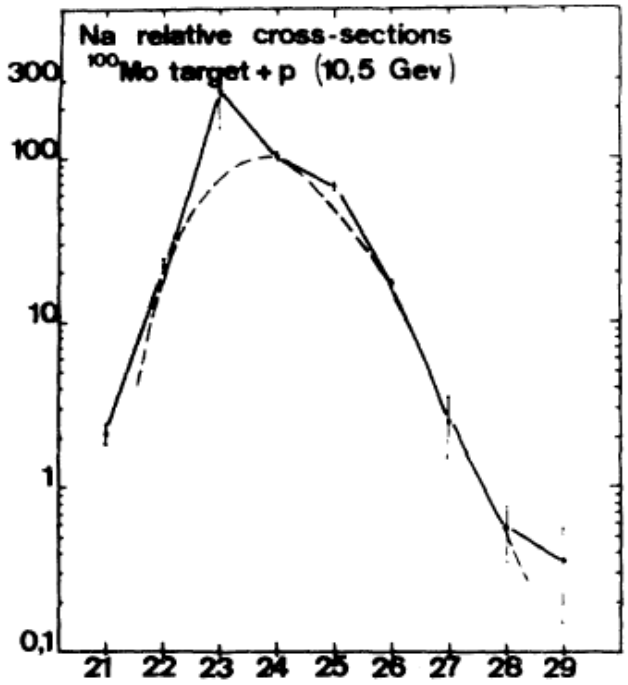


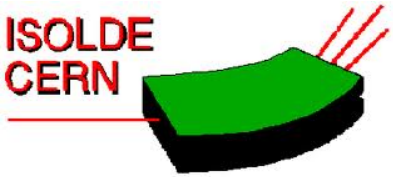
Phys. Rev. 82 (1951) 96

# Isotope Separation On-Line (ISOL)

ISOTOPIC DISTRIBUTION OF SODIUM FRAGMENTS
EMITTED IN HIGH-ENERGY NUCLEAR REACTIONS.
IDENTIFICATION OF $^{27}$Na AND POSSIBLE EXISTENCE OF HEAVIER Na ISOTOPES

R. Klapisch, C. Philippe, J. Suchorzewska,* C. Detraz, and R. Bernas
Institut de Physique Nucléaire and Centre de Spectrométrie Nucléaire
et de Spectrométrie de Masse, Orsay, France
(Received 29 January 1968)



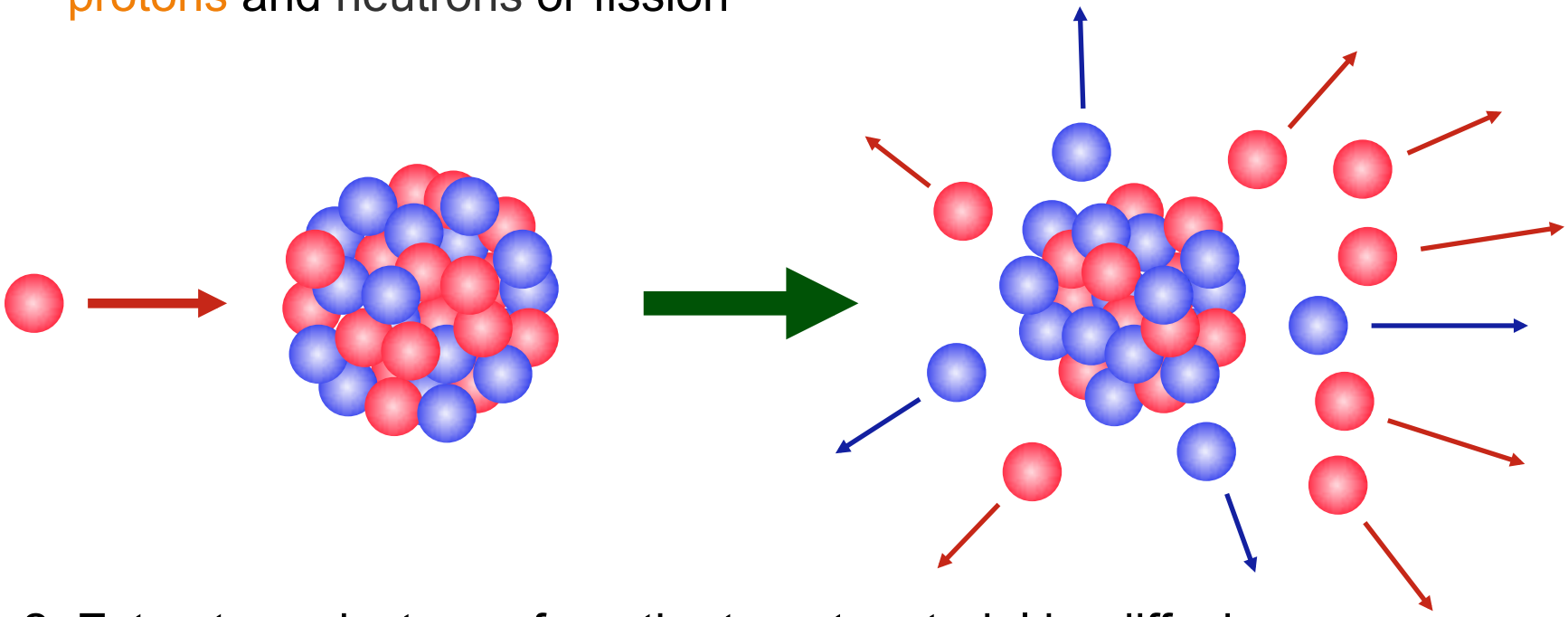

ISOLDE (Isotope Separation On-Line DEtector)



Phys. Rev. Lett. 20 (1968) 740

# Production of Rare Isotopes at Rest
## (ISOL technique)

1. Bombard a thick target of heavy nuclei with energetic light particles, e.g. 1 GeV protons, to achieve random removal of protons and neutrons or fission



2. Extract rare isotopes from the target material by diffusion or effusion; ionize and accelerate them to the desired energy → beam of high quality

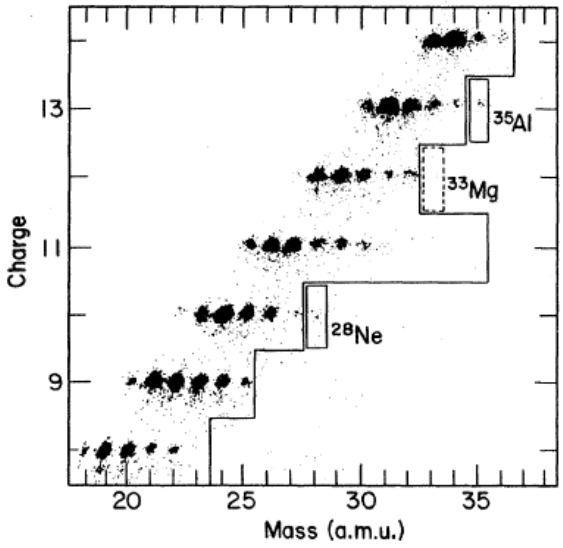
# Projectile fragmentation

**Observation of New Neutron-Rich Isotopes by Fragmentation of 205-MeV/Nucleon $^{40}$Ar Ions**

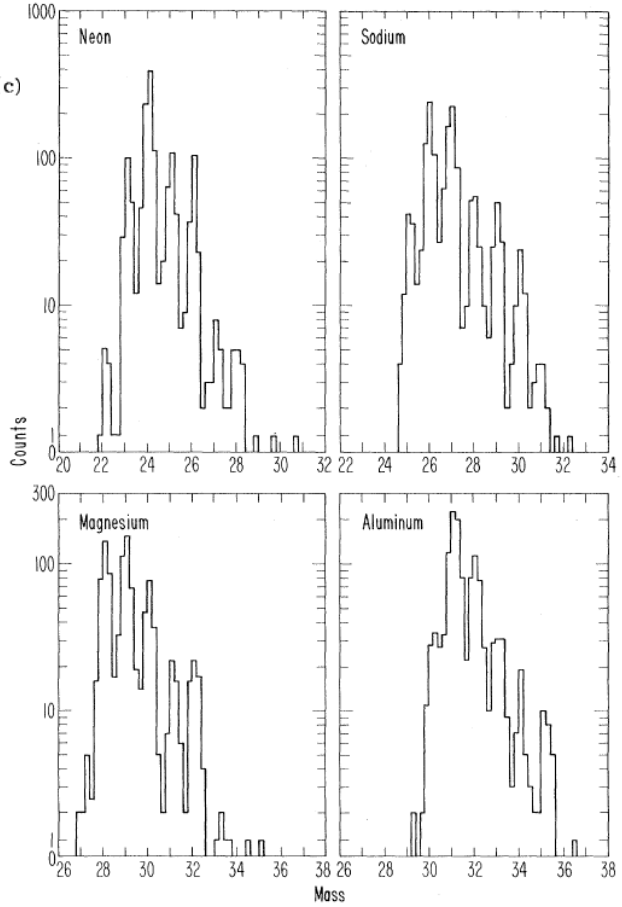
T. J. M. Symons, Y. P. Viyogi,[a] G. D. Westfall, P. Doll,[b] D. E. Greiner, H. Faraggi,[c] P. J. Lindstrom, and D. K. Scott
*Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720*

and

H. J. Crawford and C. McParland
*Space Sciences Laboratory, University of California, Berkeley, California 94720*
(Received 1 November 1978)




Fragments were detected in a zero-degree magnetic spectrometer and identified in a ΔE-E silicon detector telescope

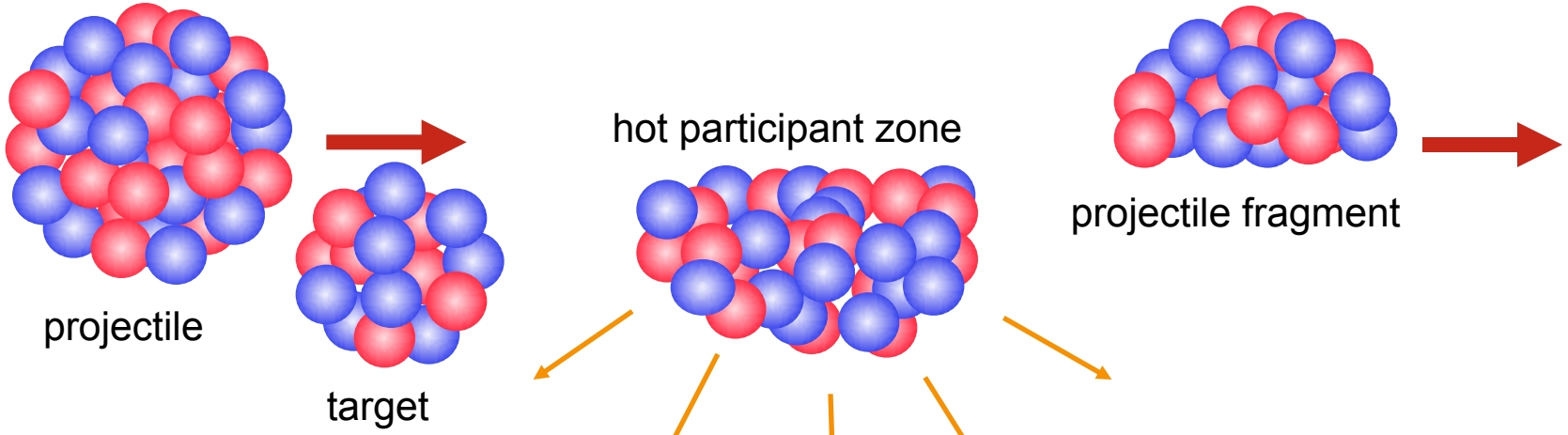




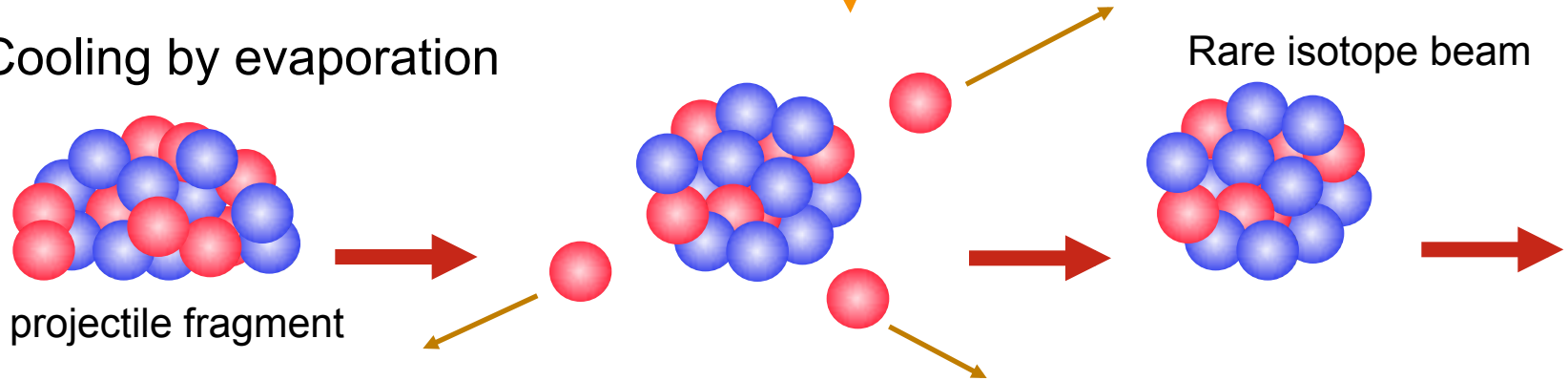

Phys. Rev. Lett. 42 (1979) 40

# Production of Rare Isotopes in Flight

1. Accelerate heavy ion beam to high energy and pass through a thin target to achieve random removal of protons and neutrons in flight




2. Cooling by evaporation



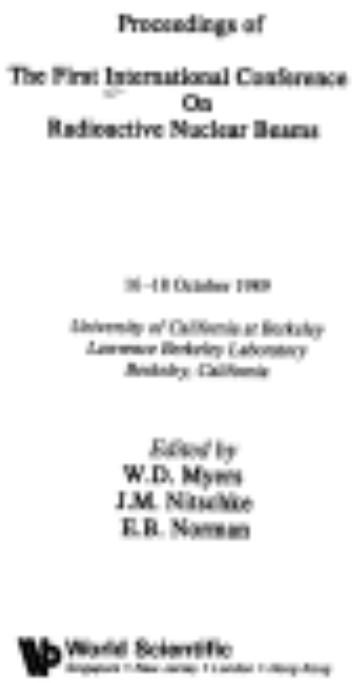
# First ideas for a dedicated facility

**1984:** Workshop on Prospects for Research with Radioactive Beams from Heavy Ion Accelerators in Washington, DC

**1985:** A proposal for an intense radioactive beams facility at TRIUMF

**1989:** First International Conference on Radioactive Nuclear Beams, October 16-18, Berkeley (Earthquake Meeting)

**1989:** The IsoSpin Laboratory (ISL) Steering Committee founded


Proceedings of

The First International Conference On Radioactive Nuclear Beams

16–18 October 1989

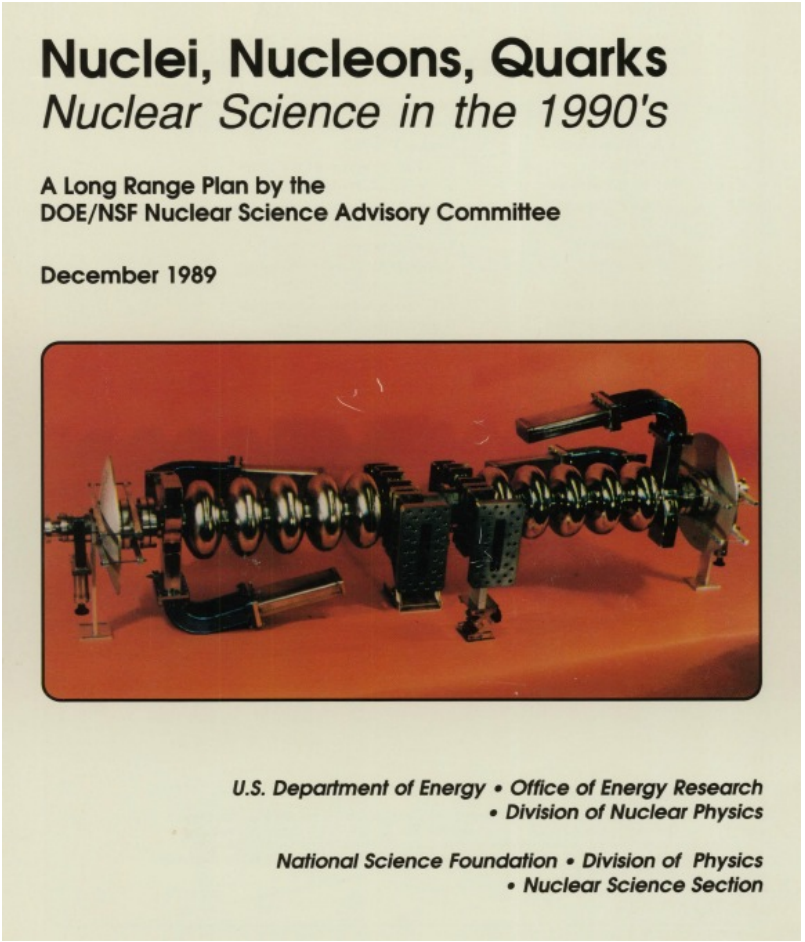
University of California at Berkeley
Lawrence Berkeley Laboratory
Berkeley, California

Edited by
W.D. Myers
J.M. Nitschke
E.B. Norman

World Scientific

Used on Amazon for $27.64

# Long Range Plans




"Whole new vistas would be opened by a radioactive nuclear beam (RNB) accelerator"

# “White” papers

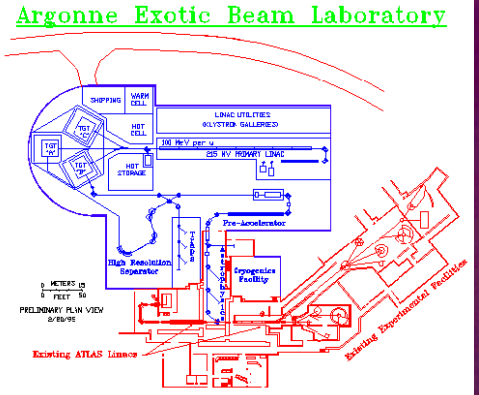

## The IsoSpin Laboratory (ISL)

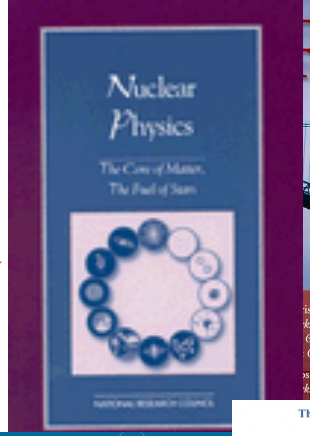
### Research Opportunities with Radioactive Nuclear Beams

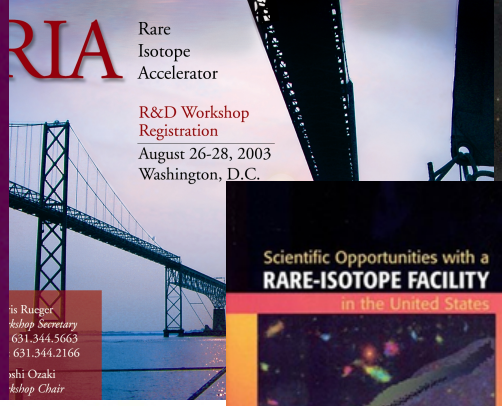
Prepared by the
North American Steering Committee

with portions also contributed by
J. A. Sawicki, K. E. Gregorich, L. Buchmann,
G.J. Mathews, L. Orozco, G. D. Sprouse,
M. Hass, and J. M. Wouters

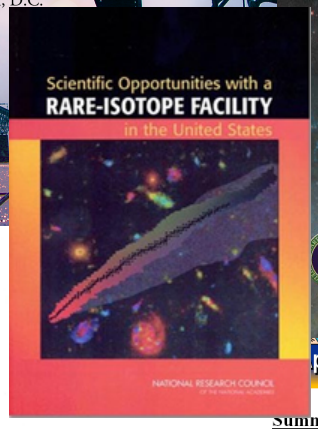
1991

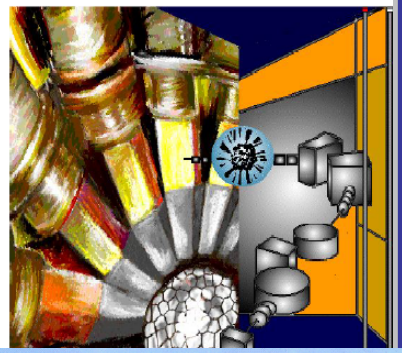



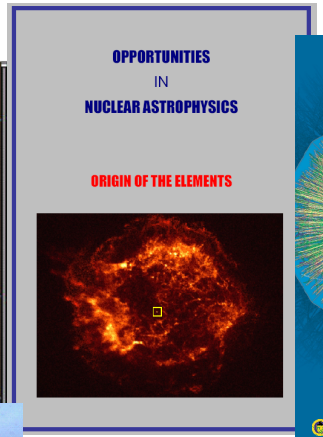



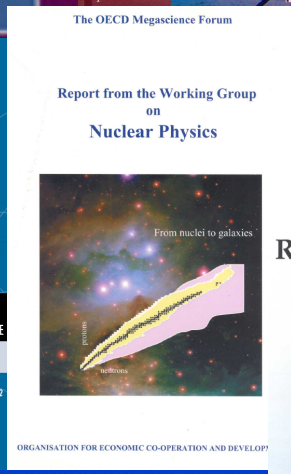








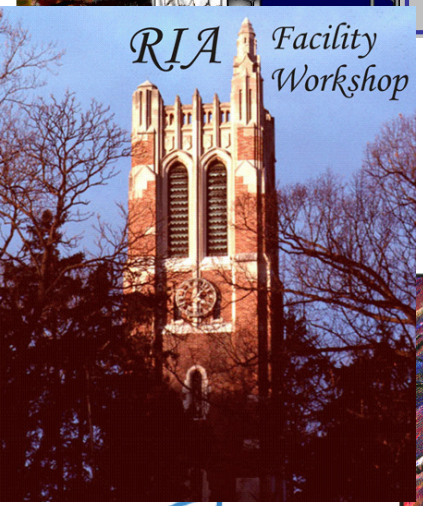




**Summary of the RIA Applications Workshop**

**RIA Physics White Paper**

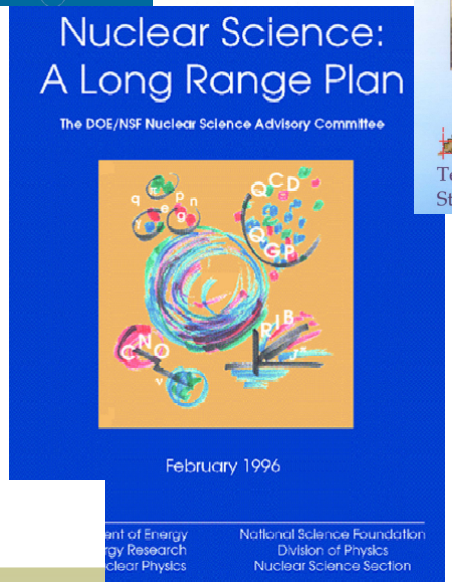
**October 30-31, 2000**
**Los Alamos National Laboratory**

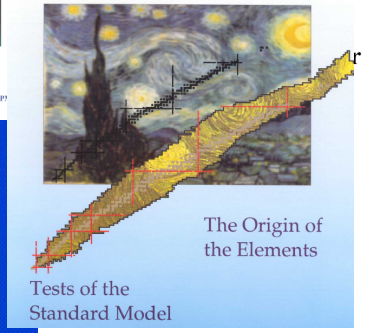



**Scientific Opportuniti**

**with an**

**Advanced ISOL Facility**



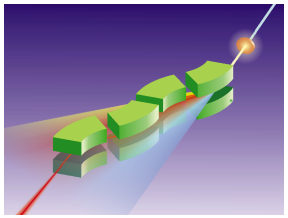

**r Structure and Astrophysics**
**Town Meeting**

Draft 2.0

Oakland, CA

November 9-12, 2000

**Scientific Opportunities with**
**Fast Fragmentation Beams from RIA**



*National Superconducting Cyclotron Laboratory*
*Michigan State University*

Ode to Nature: IV, Copyright Julio Mateo, 1985
Used by permission from the artist. www.mateo.net

# Town (hall) meetings

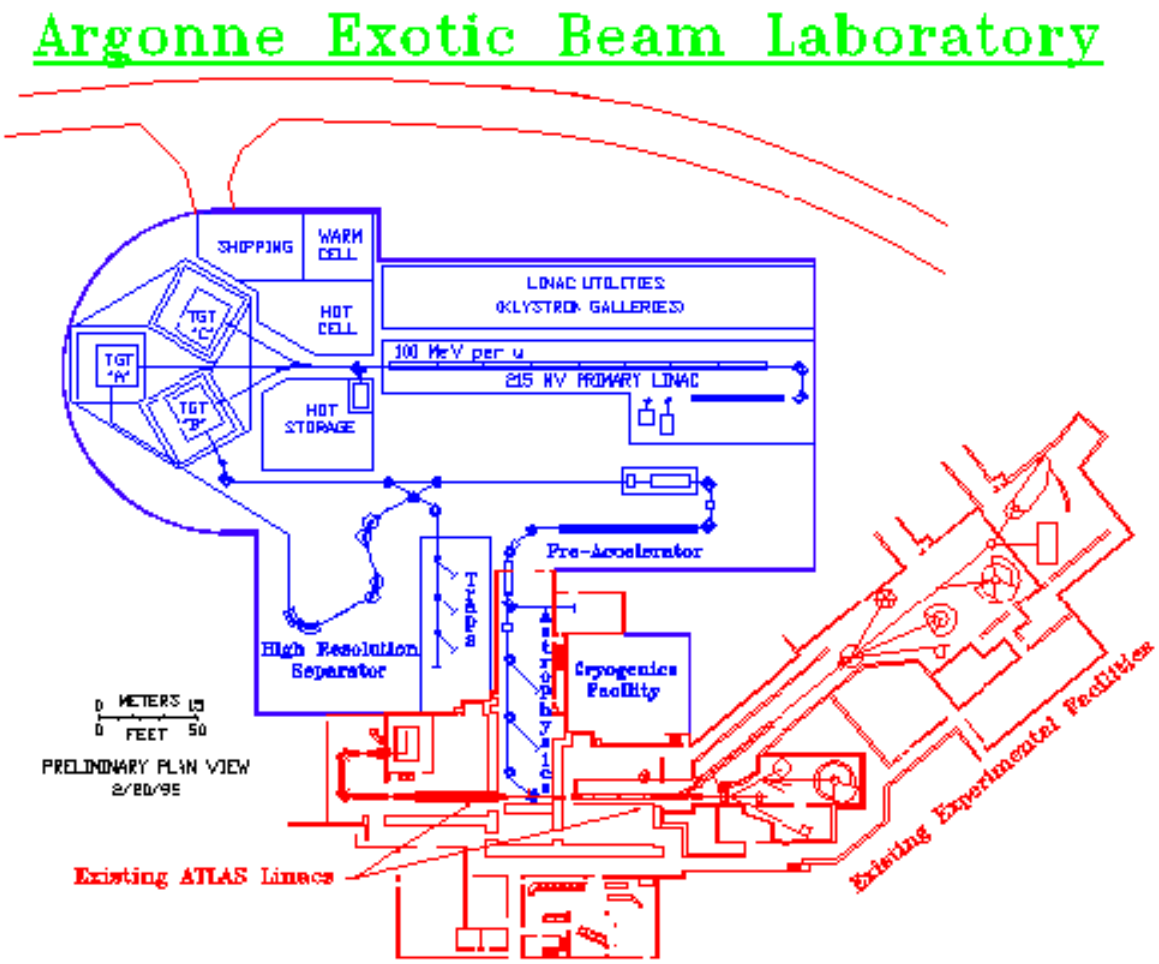
**OVERVIEW OF RESEARCH OPPORTUNITIES WITH RADIOACTIVE NUCLEAR BEAMS**

**An Update--1995**

**Prepared by the**
**ISL Steering Committee**
**February 1995**

TUNL Town Meeting,
January 19-21, 1995
Report endorsing ISOL

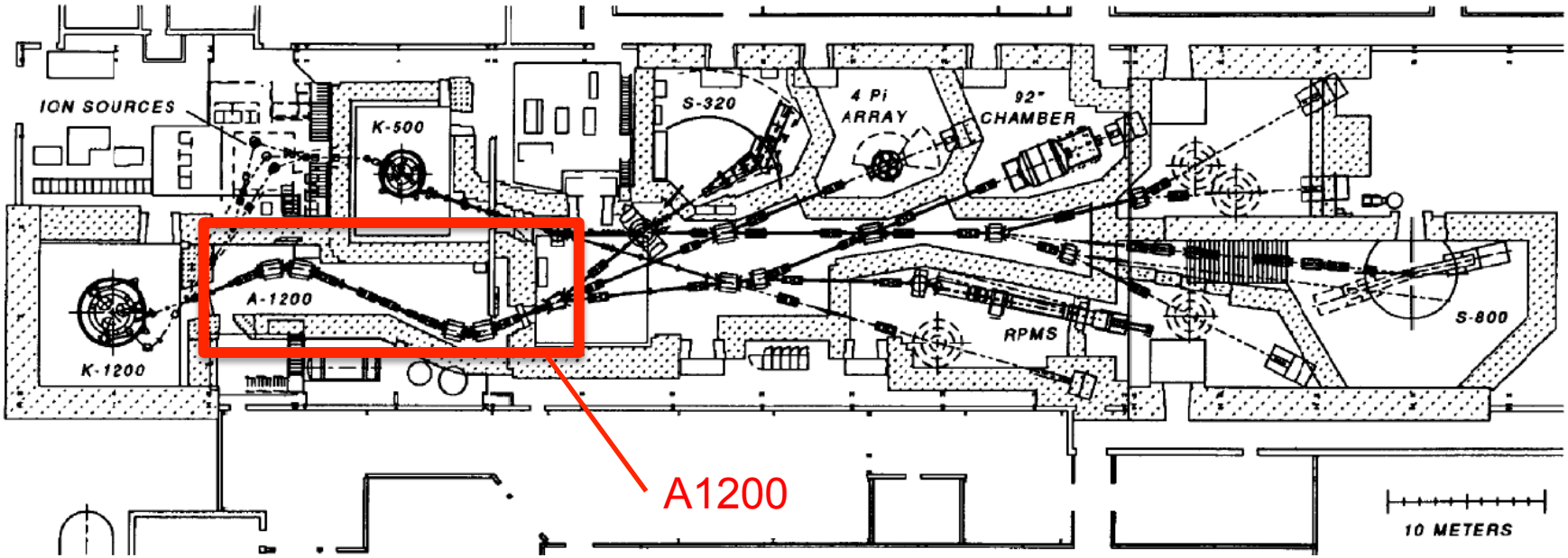
# Advanced exotic beam facility at ATLAS



# Projectile fragmentation facilities

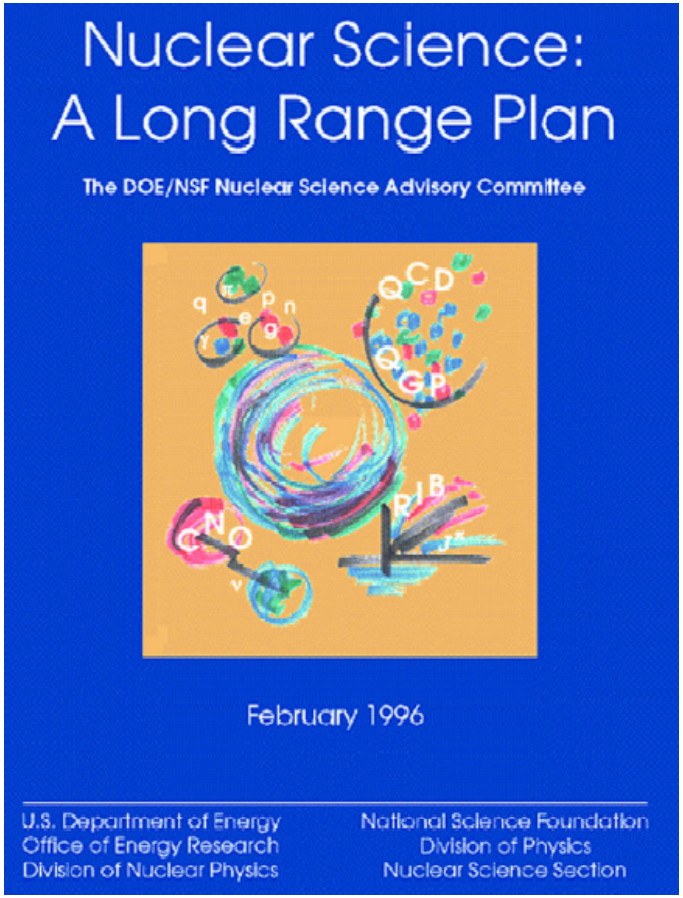
Continued development of spectrometers in the 1980/90s.
For example: LISE at GANIL, FRS at GSI, RIPS at RIKEN, and the A1200 at MSU

Conversion into radioactive beam facilities by making the separators part of the beam distribution system




NSCL at MSU

# 1996 Long Range Plan




3. The scientific opportunities made available by world-class radioactive beams are extremely compelling and merit very high priority. The U.S. is well-positioned for a leadership role in this important area; accordingly

- We strongly recommend the immediate upgrade of the MSU facility to provide intense beams of radioactive nuclei via fragmentation.
- We strongly recommend development of a cost-effective plan for a next generation ISOL-type facility and its construction when RHIC construction is substantially complete.

# “Columbus” whitepaper

**Scientific Opportunities**

**with an**

**Advanced ISOL Facility**

**NOVEMBER 1997**

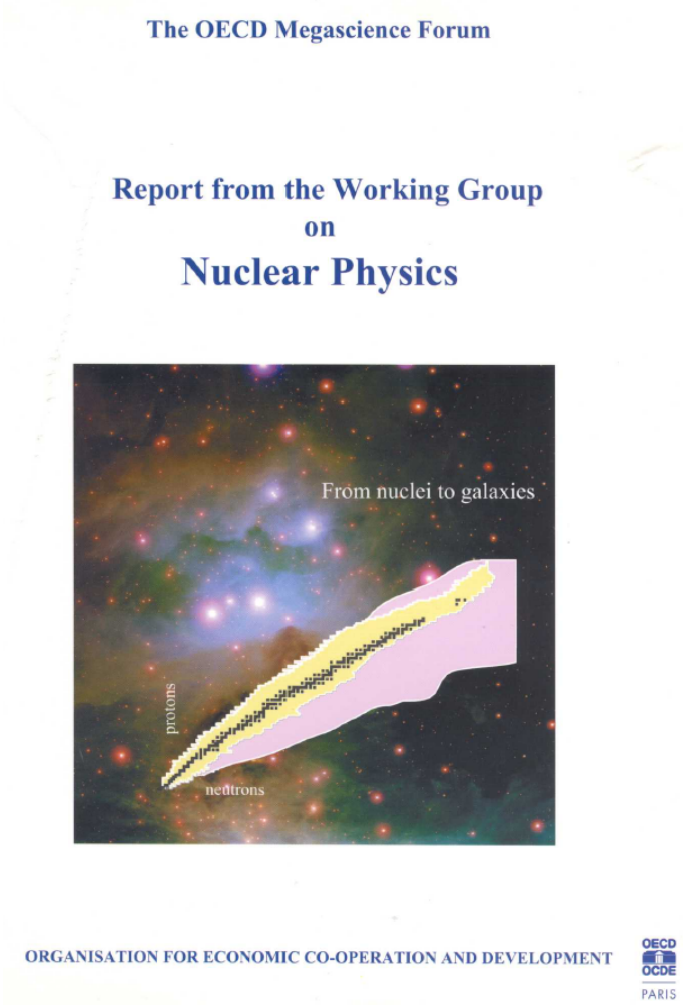
Workshop, July 30 – August 1, 1997, Columbus, Ohio

This Report presents the scientific case for an advanced, two-stage accelerator facility of the ISOL (Isotope Separation On-Line) type to provide intense, high-quality beams of short-lived. unstable (radioactive) nuclei for research in nuclear physics and related fields in the US. The opportunities offered by beams of exotic nuclei for research in the areas of nuclear structure physics, nucleosynthesis and nuclear astrophysics, and for critical tests of fundamental symmetries are both timely and exciting. The enormous worldwide activity in the construction of different types of radioactive beam facilities reflects the strong scientific interest in the physics that can be probed with such beams. The need for advanced facilities of the ISOL-type is clear and several countries are embarking on proposals that either constitute such facilities or are upgradable into them.

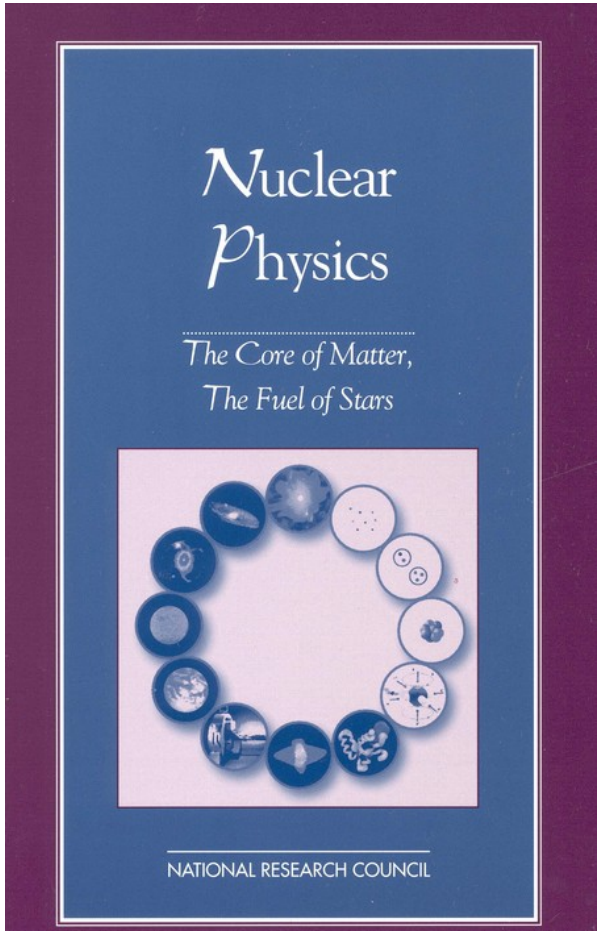
# Organization for Economic Cooperation and Development (OECD)

1998 Megascience forum
Working group on nuclear physics
Study group on radioactive nuclear beams

**…No single world-wide facility would be able to provide the required experimental tools**. Moreover, no single facility could possibly accommodate the intense research activity that this field encompasses. **It is thus essential that several complementary high-intensity, next-generation RNB facilities be built world-wide.**



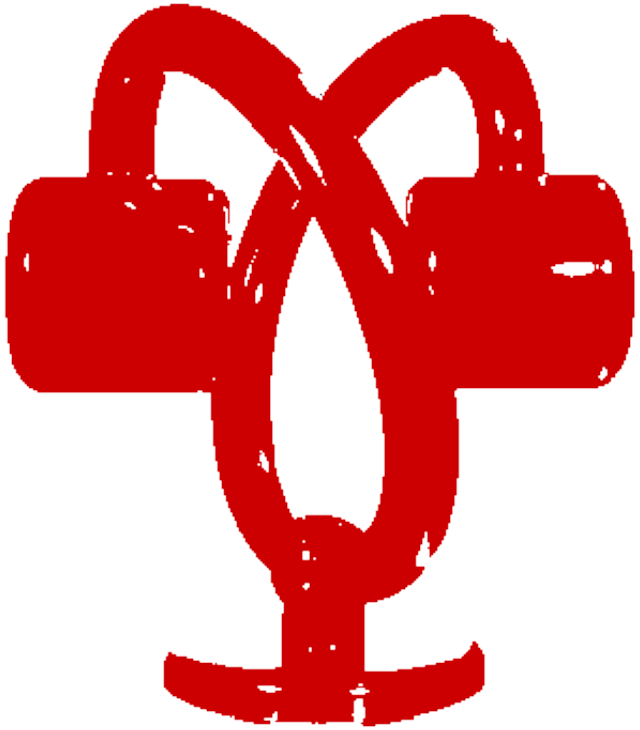
# 1999 National Academy Report



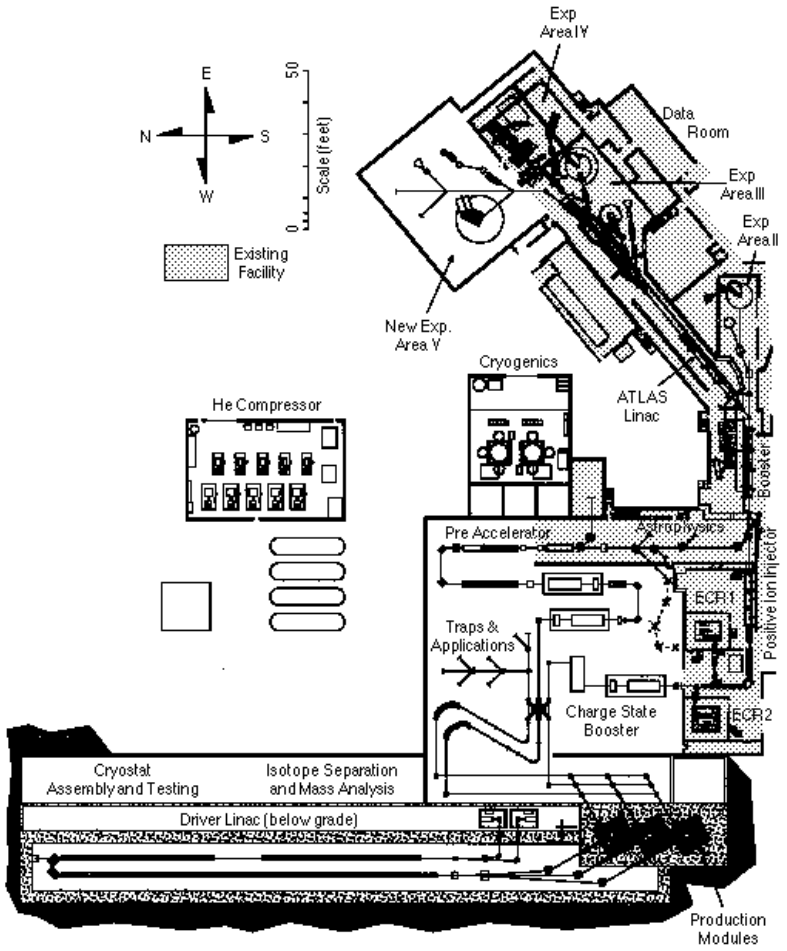

***Recommendation II: The committee recommends the construction of a dedicated, high-intensity accelerator facility to produce beams of short-lived nuclei. Such a facility will open up a new frontier in nuclear structure near the limits of nuclear binding and will strengthen our understanding of nuclear properties relevant to explosive nucleosynthesis and other aspects of the physics governing the cosmos.***

# Argonne ISOL Facility

**Report to Users**
**ATLAS FACILITY**
March 1999

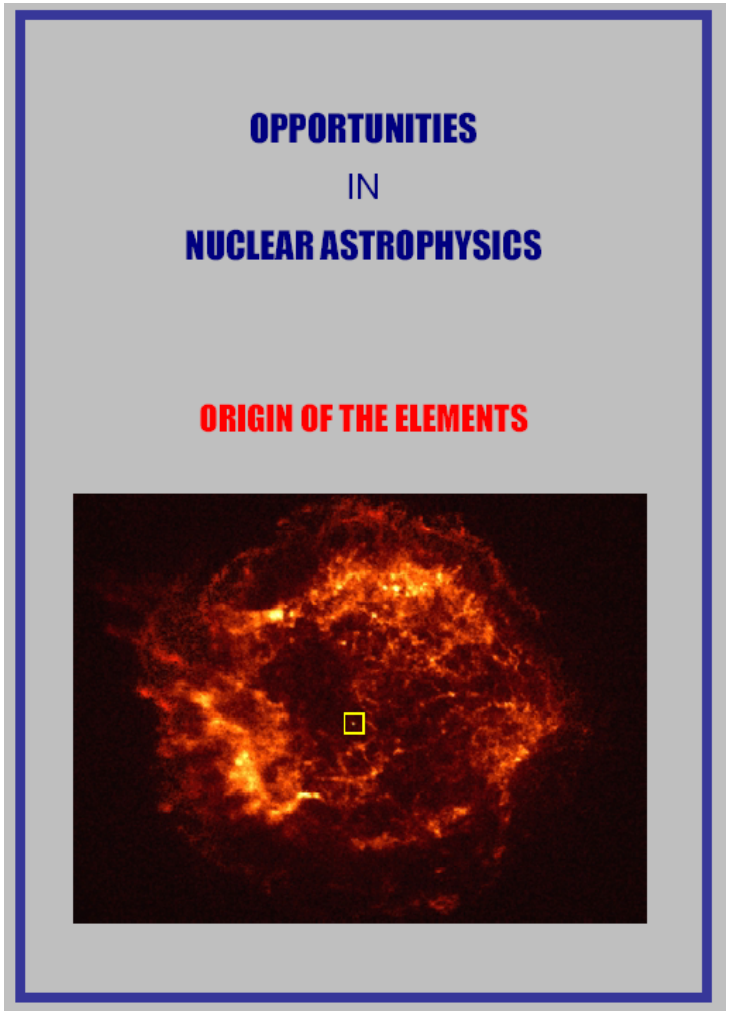


Edited by: Irshad Ahmad and David Hofman




Layout of the Proposed Argonne ISOL Facility

# Nuclear Astrophysics




June 7-8, 1999,
Town meeting at the University of Notre Dame

An enhanced program in nuclear astrophysics, theoretical and experimental, will greatly advance our understanding of the cosmos. It will strengthen observational and computational programs by providing the essential foundation necessary for the interpretation and simulation of new results.

A vigorous program of astrophysics studies at the new and upgraded radioactive ion beam facilities. Both fragmentation and ISOL facilities are necessary to obtain the required information.

# RIA: Rare Isotope Accelerator

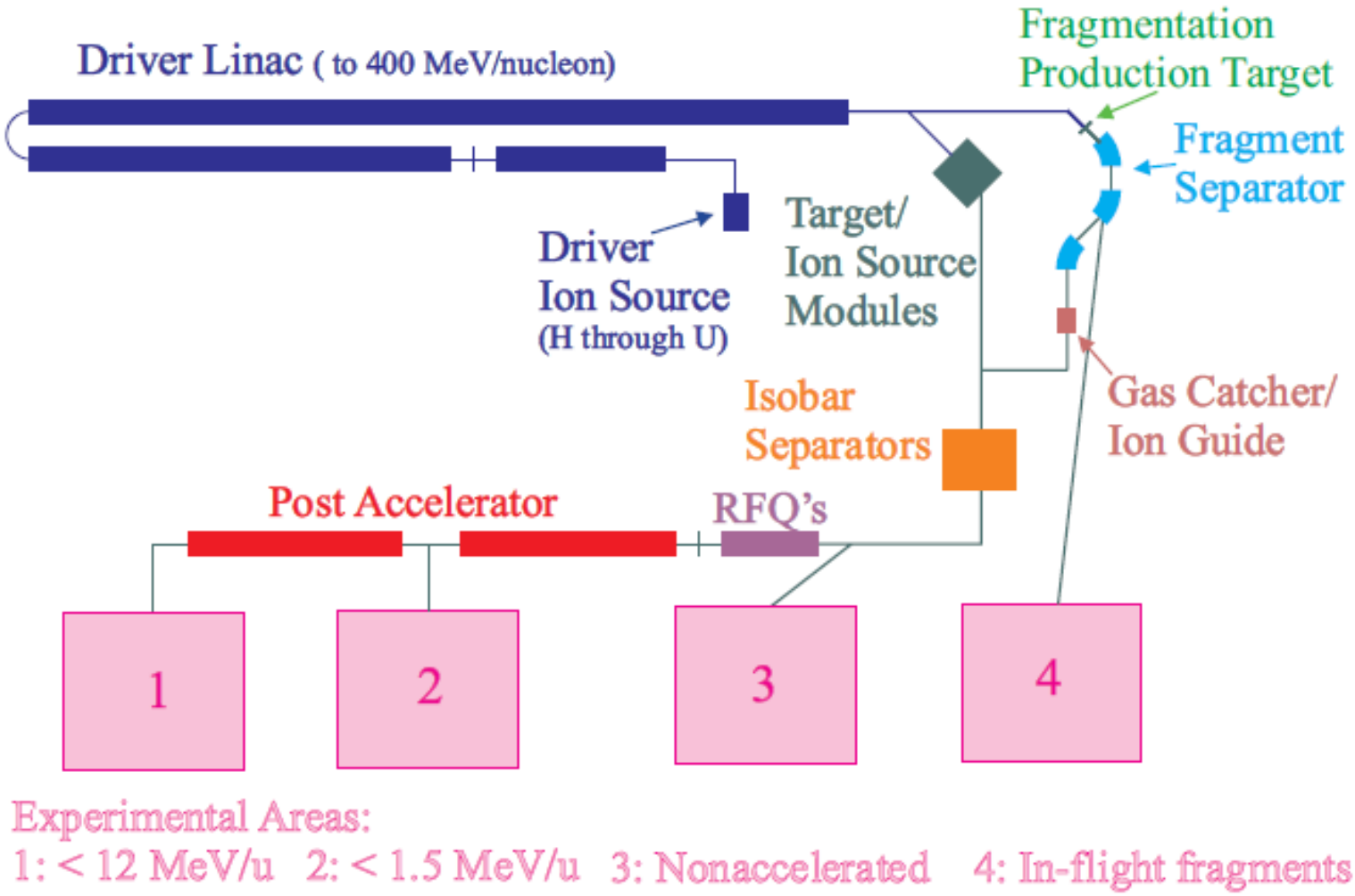
## ISOL Task Force
## Report to NSAC

November 22, 1999

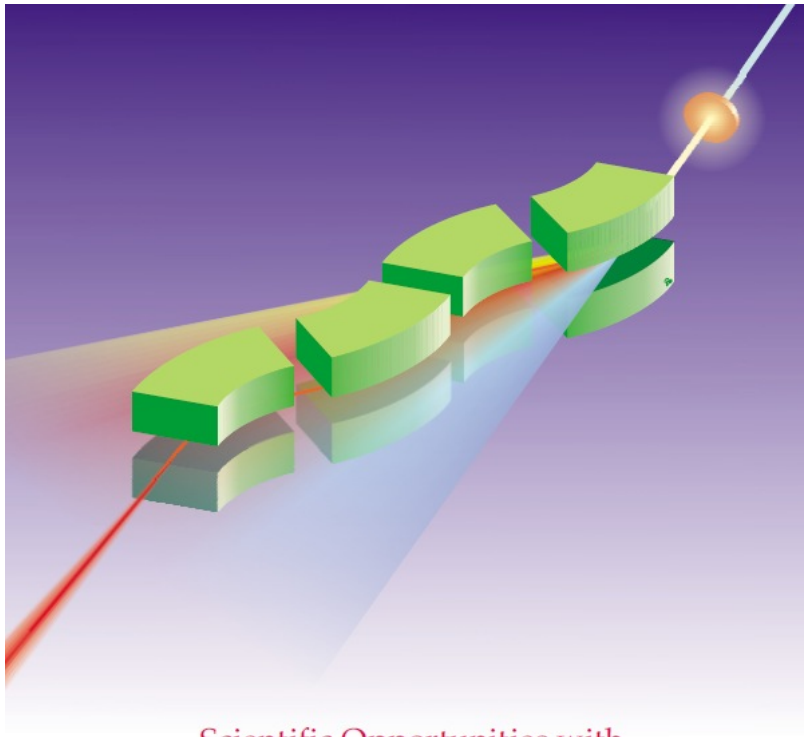
### Opportunity: Rare-Isotope Accelerator (RIA) Facility

We have unanimously concluded that the coming decade presents an important opportunity to construct a world-leading facility for the study of short-lived isotopes, which we call the Rare-Isotope Accelerator (RIA) facility. Such a facility will enable a program of experiments with the potential to revolutionize our understanding of the production of nuclei in stellar environments, to advance our knowledge of the structure of nuclei far from stability, and to make stringent tests of the standard model of elementary particles and their interactions.

# Combine ISOL and fragmentation



# 2000 NSCL/MSU Report

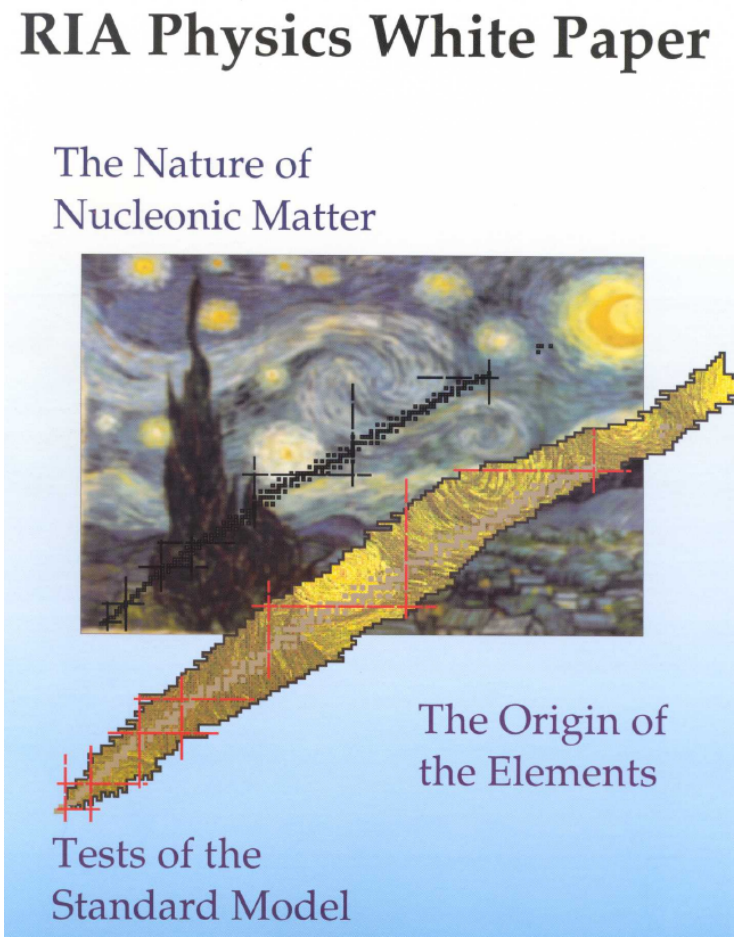



For medium-mass to heavy nuclei, fast beams will extend the study of very short-lived, neutron-rich nuclei into a region more than 10 neutrons further from the valley of stability than is presently possible and about 3 – 4 neutrons further than possible with re-accelerated (ISOL) beams. A compelling scientific case exists for the incorporation of an advanced fast fragmentation beam capability into the base plan of RIA.

# 2000 Durham white paper

July 24-26, 2000
Workshop in Durham, NC

RIA is an innovative, state-of-the-art-defining concept embodying the best features of both in-flight and ISOL techniques and providing both reaccelerated and fast beams. Owing to its greatly expanded capabilities relative to previous concepts, RIA will be the most powerful facility of its kind in the world. In view of these enhancements, it was decided to hold a Workshop, prior to the current Long Range Plan process, devoted to sharpening the scientific case for RIA and discussing the merits and urgency of this project.



# More workshops…


**Summary of the RIA Applications Workshop**

October 30-31, 2000
Los Alamos National Laboratory

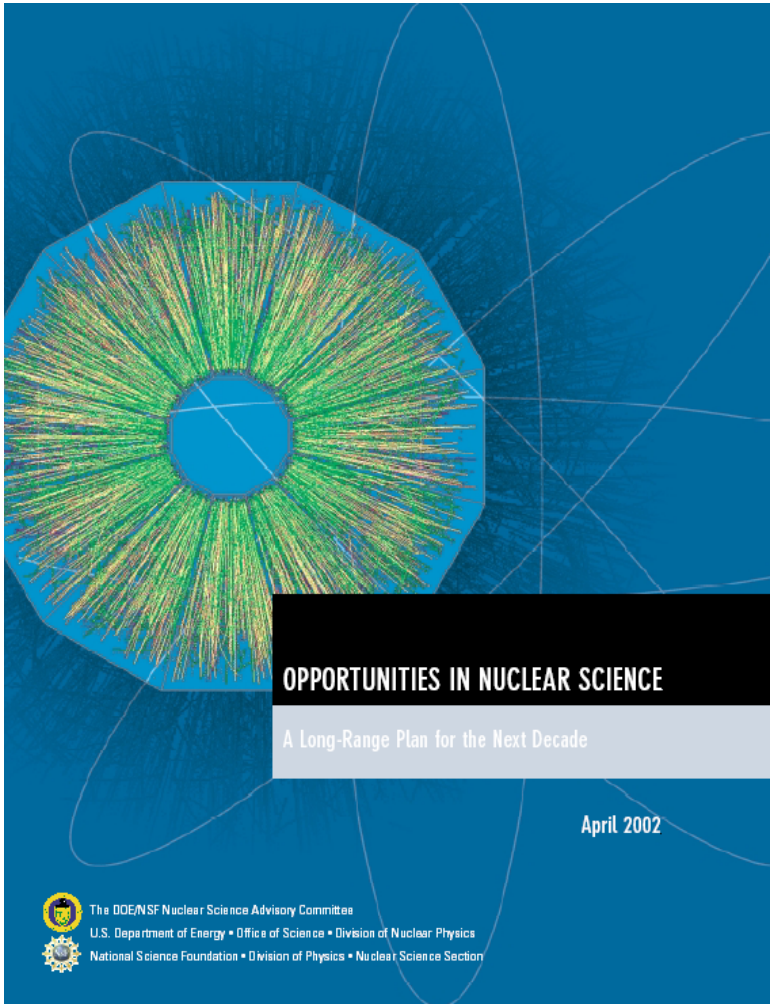
**Nuclear Structure and Astrophysics Town Meeting**

Draft 2.0

Oakland, CA

November 9-12, 2000

# 2002 Long Range Plan




RECOMMENDATION 2

*The Rare Isotope Accelerator (RIA) is our highest priority for major new construction. RIA will be the world-leading facility for research in nuclear structure and nuclear astrophysics.*

# 2002 White paper

The Intellectual Challenges of RIA

A White Paper from the RIA Users Community

This White Paper emerged from discussions of a group of representatives of the RIA Users community with Dr. Raymond Orbach, Director of the DOE Office of Science, on November 19, 2002.

*Worldwide, the study of exotic nuclei is in rapid advance. Major projects are planned or already underway in Europe and Japan. The field is vital and intensely active. Progress can be made, at a reduced level, of course, without RIA, but RIA stands alone, 1 – 2 orders of magnitude better than any existing, or ever envisioned, facility. RIA is, simply put, second to none. With RIA, the U.S. will maintain a world leadership position in nuclear physics for decades.*

*Today nuclear structure and astrophysics find themselves on the threshold of the most exciting era in decades, perhaps ever. We are poised to make extraordinary advances and to achieve a perspective so much broader than we have today. To realize such progress, RIA is essential.*

# DOE 20-year plan


**Priority: Tie for 3**

**Rare Isotope Accelerator (RIA)**

**The Facility:** The Rare Isotope Accelerator (RIA) will be the world's most powerful research facility dedicated to producing and exploring new rare isotopes that are not found naturally on earth.

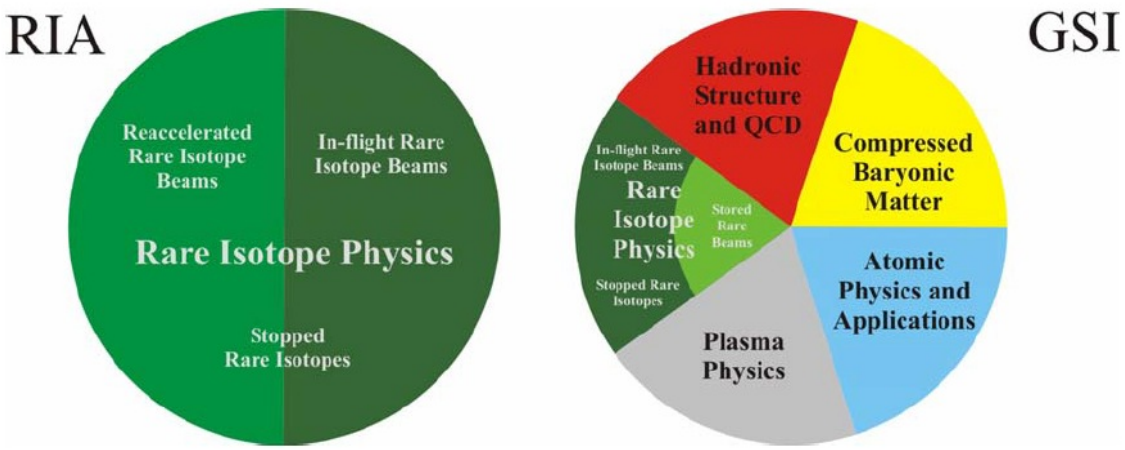
November 2003

# International competition

Report of the NSAC Subcommittee on

**Comparison of the Rare Isotope Accelerator (RIA) and the Gesellschaft für Schwerionenforschung (GSI) Future Facility**

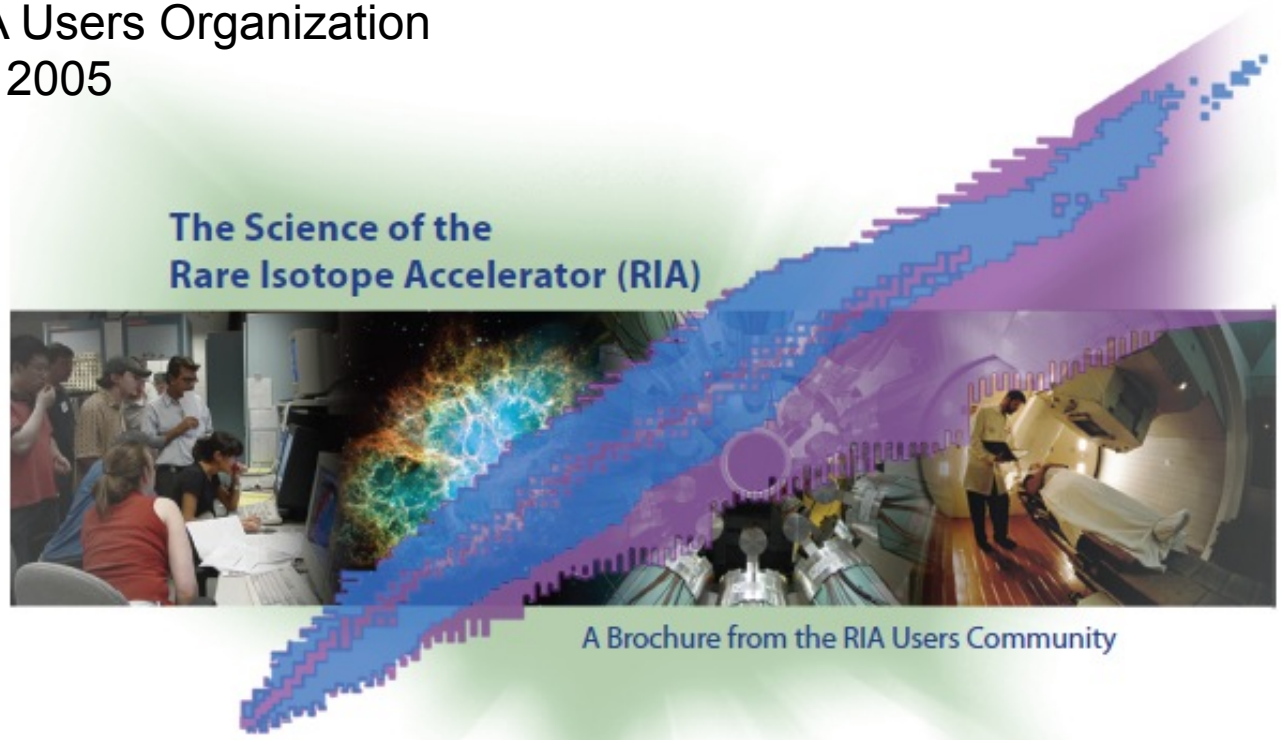
February 23, 2004




The RIA and GSI facilities are largely quite distinct in their strengths and are indeed, as the proponents claim, complementary.

# 2006 White paper

Meeting of the RIA Users Organization
September 10-11, 2005
Detroit, MI



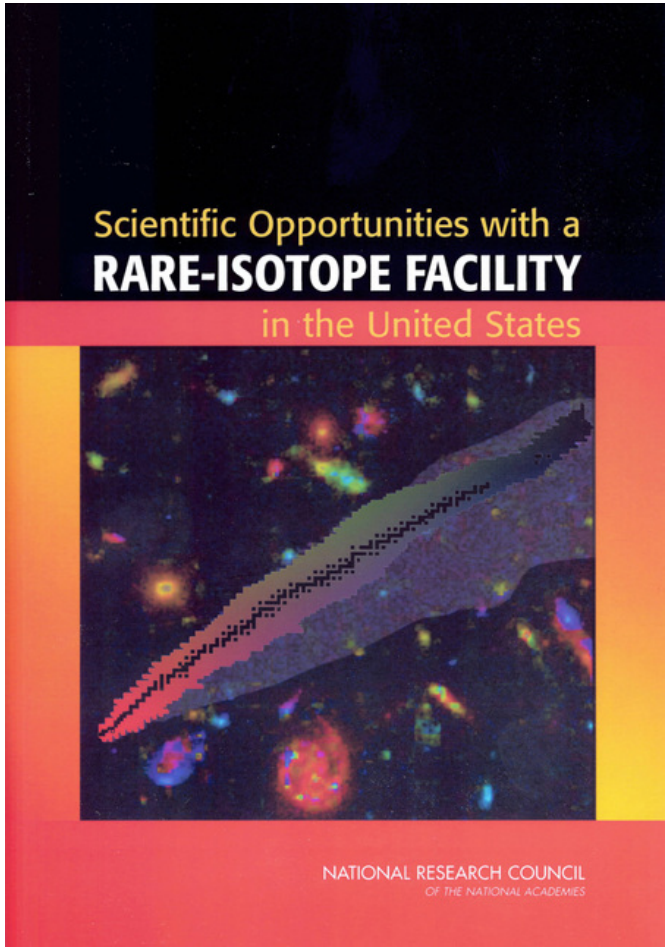

The Rare Isotope Accelerator (RIA) will be a key tool for nuclear science that promises to change the way we view and describe the nucleus. RIA will produce key new rare isotopes of atomic nuclei that are essential for our understanding of the universe.

# Short life of RIA

| | |
|---|---|
| October 2004: | DOE issued a draft RFP (request for proposals) |
| March 2005: | DOE cancels RFP |
| June 23, 2005: | NSAC report: Guidance for Implementing the 2002 Long Range Plan:<br>"If the budget projections that require closing CEBAF or RHIC, and abandoning plans for RIA become reality, U.S. nuclear science will suffer an extraordinary loss of discovery potential. But the message that this will send to potential future nuclear scientists may be even more damaging to the country in the long run." |
| December 2005: | NRC convenes the Rare Isotope Science Assessment Committee (RISAC) in response to a request from DOE and the White House Office of Management and Budget |
| July 17, 2006: | DOE charges NSAC to establish a task force to evaluate the scientific reach and technical options for a world-class rare isotope beam facility up to half the cost of RIA. |

# 2006 MSU “Blue Book”

# 2007 RISAC Report




July 2007

The committee concluded that 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.

# NSAC Task Force

Report to NSAC of the
Rare-Isotope Beam Task Force

August 20, 2007


**We recommend that DOE and NSF proceed with solicitation of proposals for a FRIB based on the 200 MeV, 400 kW superconducting heavy-ion driver linac at the earliest opportunity.**
This unique facility will have outstanding capabilities for fast, stopped, and reaccelerated beams. It will be complementary in reach to other facilities existing and planned, world-wide.

# 20-year outlook update

Four Years Later: An Interim Report on
*Facilities for the Future of Science: A Twenty-Year Outlook*
August 2007


August 2007

## Status of Facilities in 20-Year Outlook

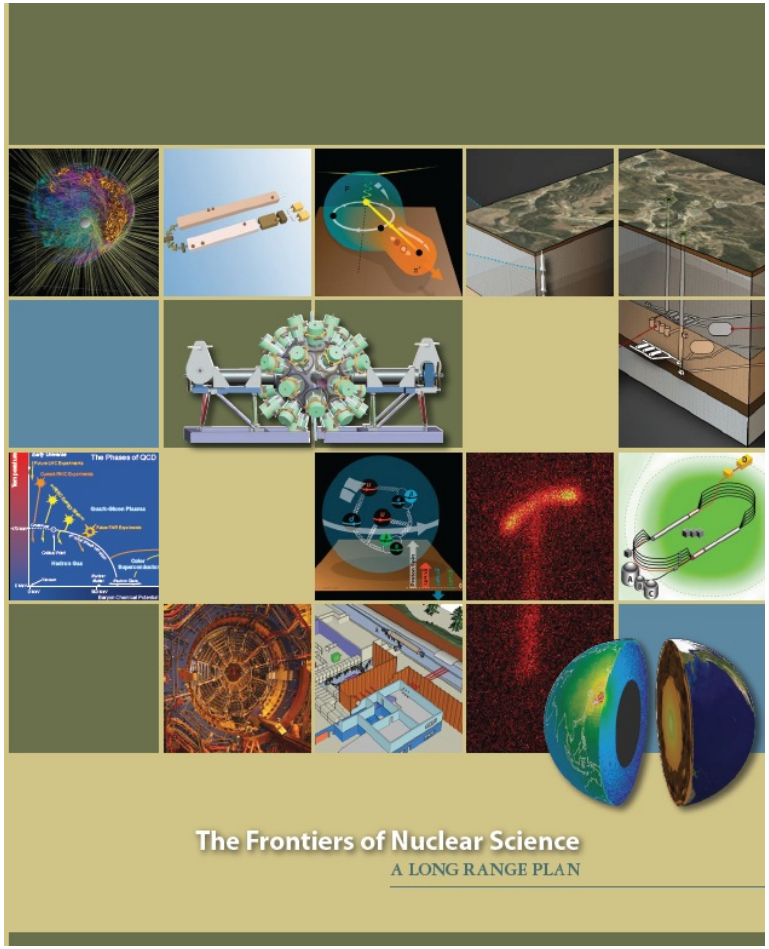
**By the end of FY 2008**

| Priority | Program | Facility | | R&D | Conceptual Design | Engineering Design | Construction | Operation |
|---|---|---|---|---|---|---|---|---|
| 1 | FES | ITER | | | | | | |
| 2 | ASCR | UltraScale Scientific Computing Capability | | | | | | |
| Tie for 3 | HEP | Joint Dark Energy Mission | | | | | | |
| | BES | Linac Coherent Light Source | | | | | | |
| | BER | Protein Production and Tags | → Bioenergy Research Centers* | | | | | |
| | NP | Rare Isotope Beam Facility (previously RIA) # | | | | | | |

75-100% 50-75% 25-50% > 0% complete

** technological readiness change*
*# changed due to planned facility abroad*

# 2007 Long Range Plan




December 2007

"We recommend construction of the Facility for Rare Isotopes Beams (FRIB), a world leading facility for the study of nuclear structure, reactions, and astrophysics."

# 2008: FRIB

**FINANCIAL ASSISTANCE**
**FUNDING OPPORTUNITY ANNOUNCEMENT**

**U. S. Department of Energy**

**Office of Nuclear Physics**

**Facility for Rare Isotope Beams**

**Funding Opportunity Number: DE-PS02-08ER41535**

**Announcement Type: Initial**

**CFDA Number: 81.049**

| | |
|---|---|
| **Issue Date:** | **05/20/2008** |
| **Letter of Intent Due Date:** | **Not Applicable** |
| **Pre-Application Due Date:** | **Not Applicable** |
| **Application Due Date:** | **07/21/2008** |

Following a merit review and evaluation process DOE selects the MSU application on December 11, 2008

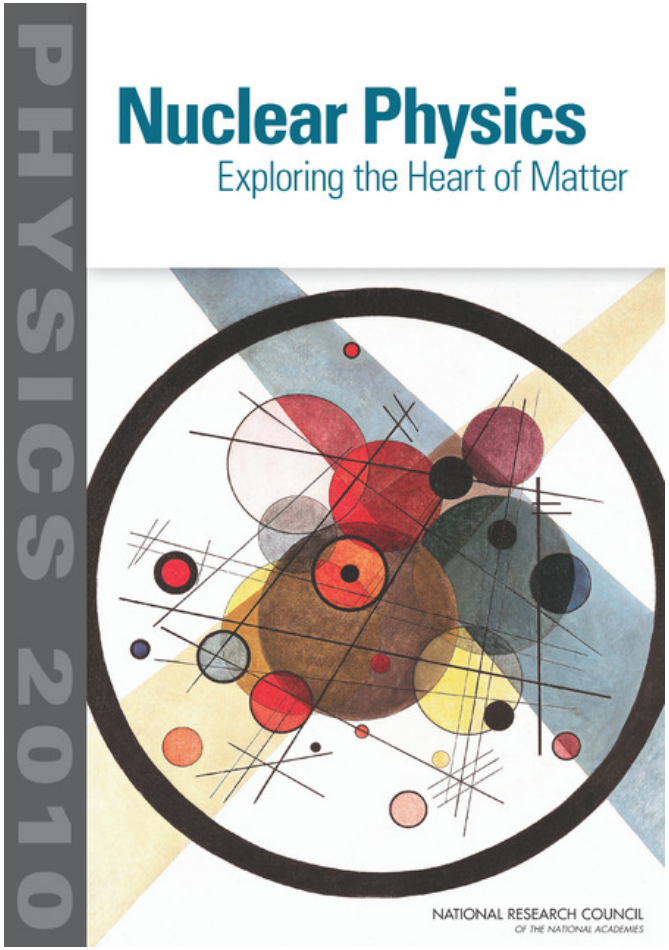
# 2012 NSAC Charge

U.S. Department of Energy
and the
National Science Foundation

April 5, 2012

We seek advice from NSAC on implementing the priorities and recommendations of the 2007 Long Range Plan in light of projected budgetary constraints and for guidance on developing a plan to implement the highest priority science in the context of likely available funding and world-wide capabilities.

# 2012 NRC nuclear physics report




June 2012

Finding: The Facility for Rare Isotope Beams is a major new strategic investment in nuclear science. It will have unique capabilities and will offer opportunities to answer fundamental questions about the inner workings of the atomic nucleus, the formation of the elements in our universe, and the evolution of the cosmos.
Recommendation: The Department of Energy's Office of Science, in conjunction with the state of Michigan and Michigan State University, should work toward the timely completion of the Facility for Rare Isotope Beams and the initiation of its physics program.

# 2012 FRIB white paper for the LRP Implementation Subcommittee

**FRIB: Opening New Frontiers in Nuclear Science**

*Moving Forward with the Long Range Plan*


Prepared by members of the FRIB Users Organization for the
NSAC Long Range Plan Implementation Subcommittee

August 2012

# 2013 NSAC Report

Report to the
Nuclear Science Advisory Committee

Implementing the 2007 Long Range Plan

January 31, 2013

If a decision were made to force the U.S. nuclear science community to downsize through budgets that provide no growth over the next four years, a choice would have to be made that would fundamentally change the direction of what remained of the field. Because of the superb science lost in either shutting down RHIC or terminating construction on FRIB, the committee was not able to make a choice based on scientific merit alone. Based on additional considerations of timing of the budget crisis relative to the status of the ongoing construction initiative, the subcommittee vote, while closely split, resulted in a slight preference for the choice that proceeds with FRIB.

# 2015 Long Range Plan

**Four major town meetings, several white papers:**

**The FRIB Theory Center**

**The Hot QCD White Paper:**

**Exploring the Phases of QCD at RHIC and the LHC**

**Joint Executive Summary from the Nuclear Astrophysics and Low-Energy Nuclear Physics Town Meetings**

Fundamental symmetries, neutrinos, neutrons, and astrophysics: a White Paper on progress and prospects



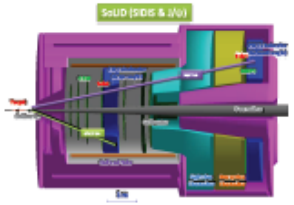
**Computational Nuclear Physics Meeting**
**SURA Headquarters, Washington DC, July 14-15, 2014**

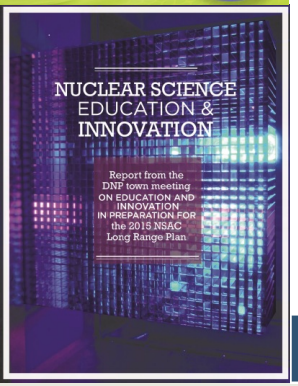
The Scientific and Educational Impact of the University-Based Accelerator Laboratories ARUNA

A white paper submitted to NSAC in January 2015

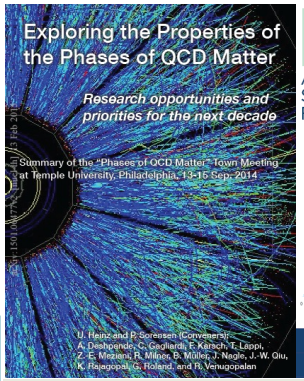
**A Whitepaper on SoLID**
**(Solenoidal Large Intensity Device)**

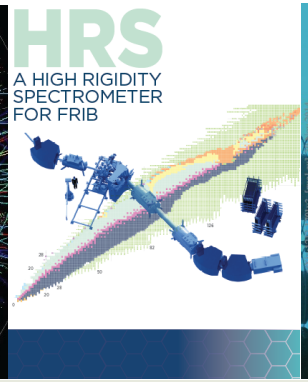
The SoLID Collaboration at Jefferson Lab

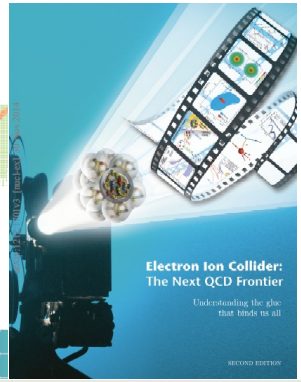


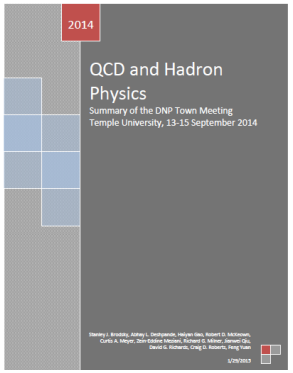







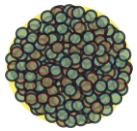




FRIB

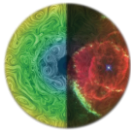
Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

# The Science of FRIB



## Properties of nucleonic matter

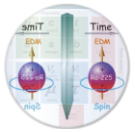
- Many-body quantum problem: intellectual overlap to mesoscopic science – how to understand the world from simple building blocks



## Nuclear processes in the universe

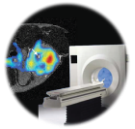
- Nuclei determine the chemical history of the Universe
  Connection of models of supernovae, X-ray bursts

## Tests of fundamental symmetries

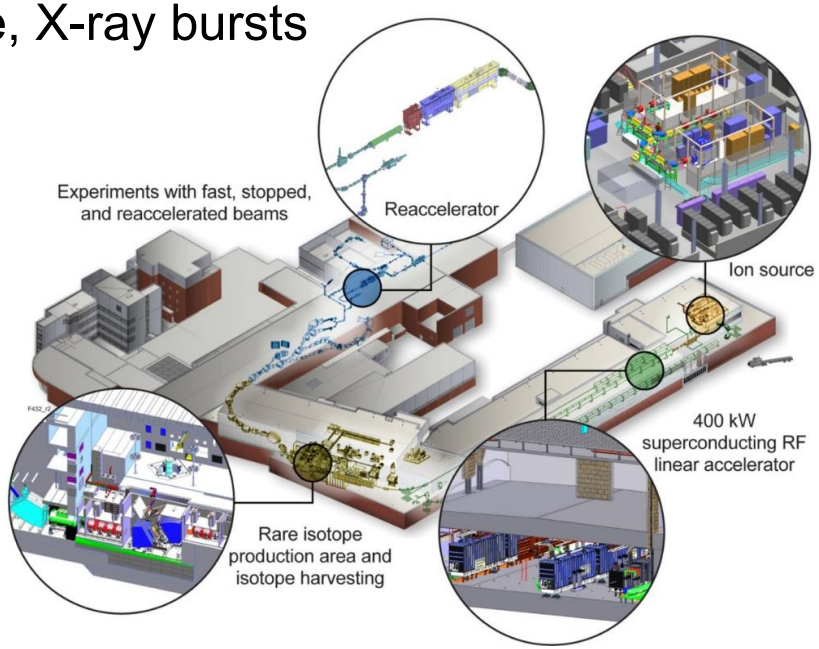


- Effects of symmetry violations are amplified in certain nuclei

## Societal applications and benefits



- Bio-medicine, energy, material sciences, national security



# FRIB is needed to understand atomic nuclei

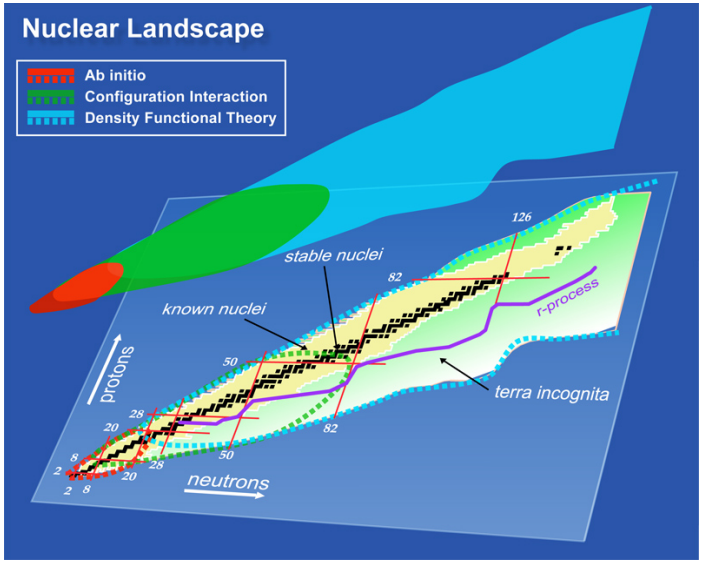
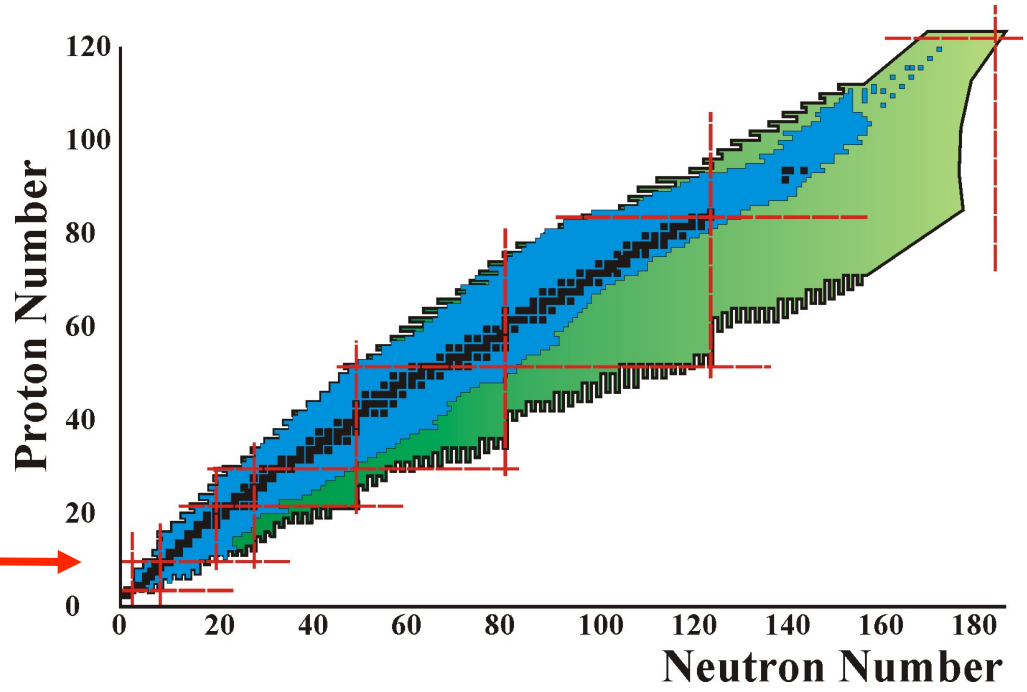



Figure adapted from
www.scidacreview.org/0704/html/unedf.html

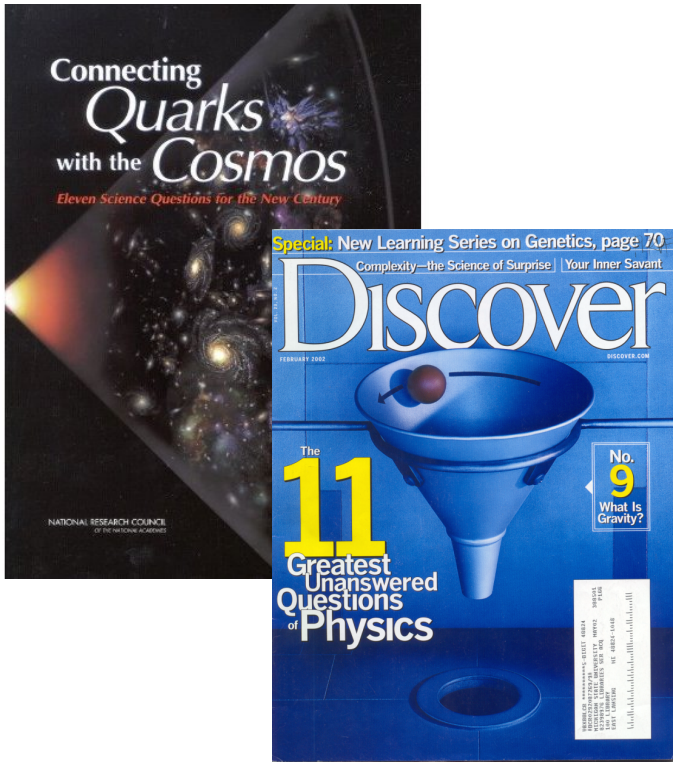
- A quantitative model of atomic nuclei with predictive power does not yet exist

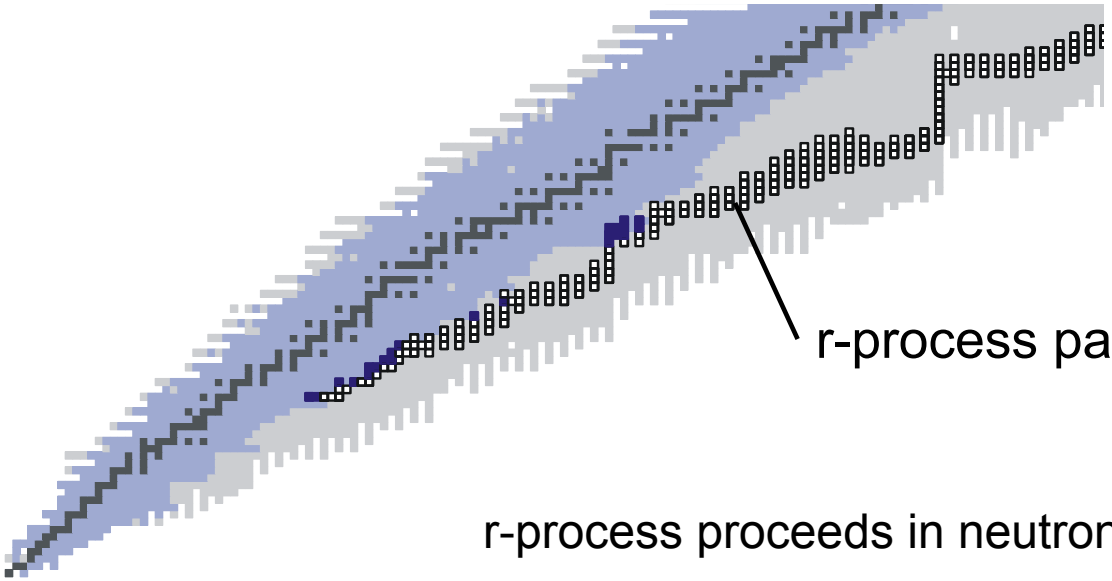



**The neutron-rich limit is only known up to oxygen**

# FRIB is needed to understand the origin of the elements

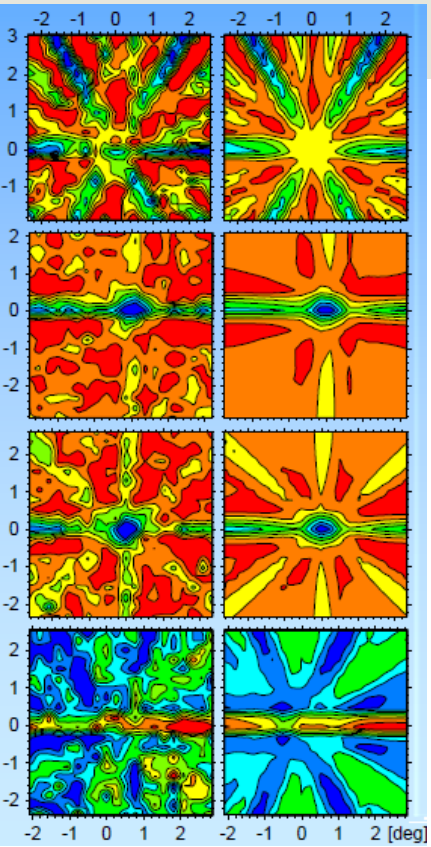
- How were the elements from iron to uranium made?
- Where and how does the r-process occur?



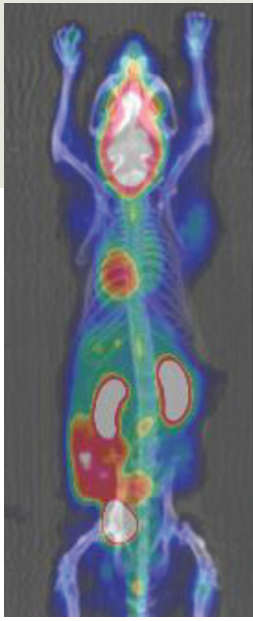

r-process proceeds in neutron-rich nuclei

# Applications

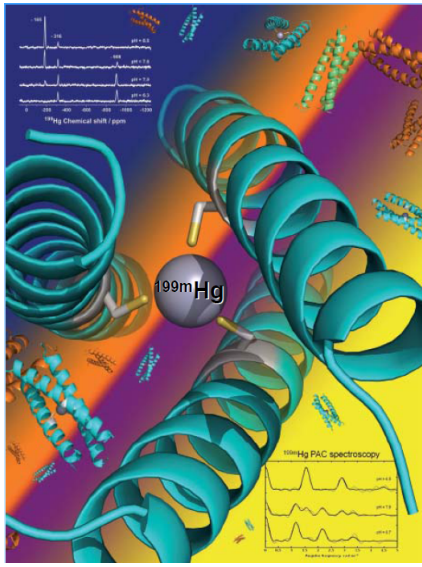



β⁻ emission channeling at ISOLDE/CERN: $^{24}$Na site changes in ZnO semiconductor

- Isotopes for medical research
- Isotopes for national security
- Isotopes for biochemistry and ecology research
- Isotopes for energy industry
- Isotopes for nanoscience, material science and engineering

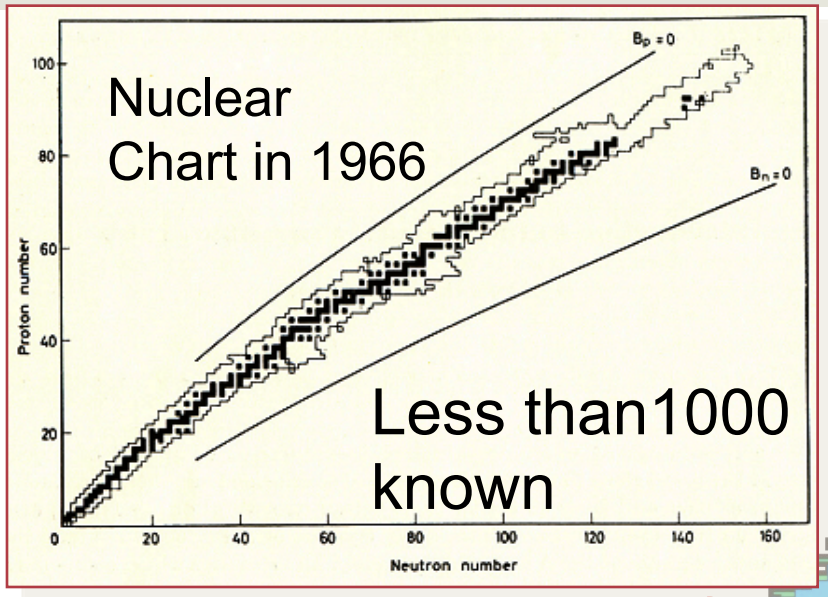


Preclinical research: PET-CT image




Attaching radioisotopes to biomolecules at ISOLDE/ CERN: understanding enzymatic mercury detoxification

# FRIB: Facility for Rare Isotope Beams




Available today

New territory to be explored

today about 3000 known isotopes

# Discovery of isotopes



LETTERS TO THE EDITOR.

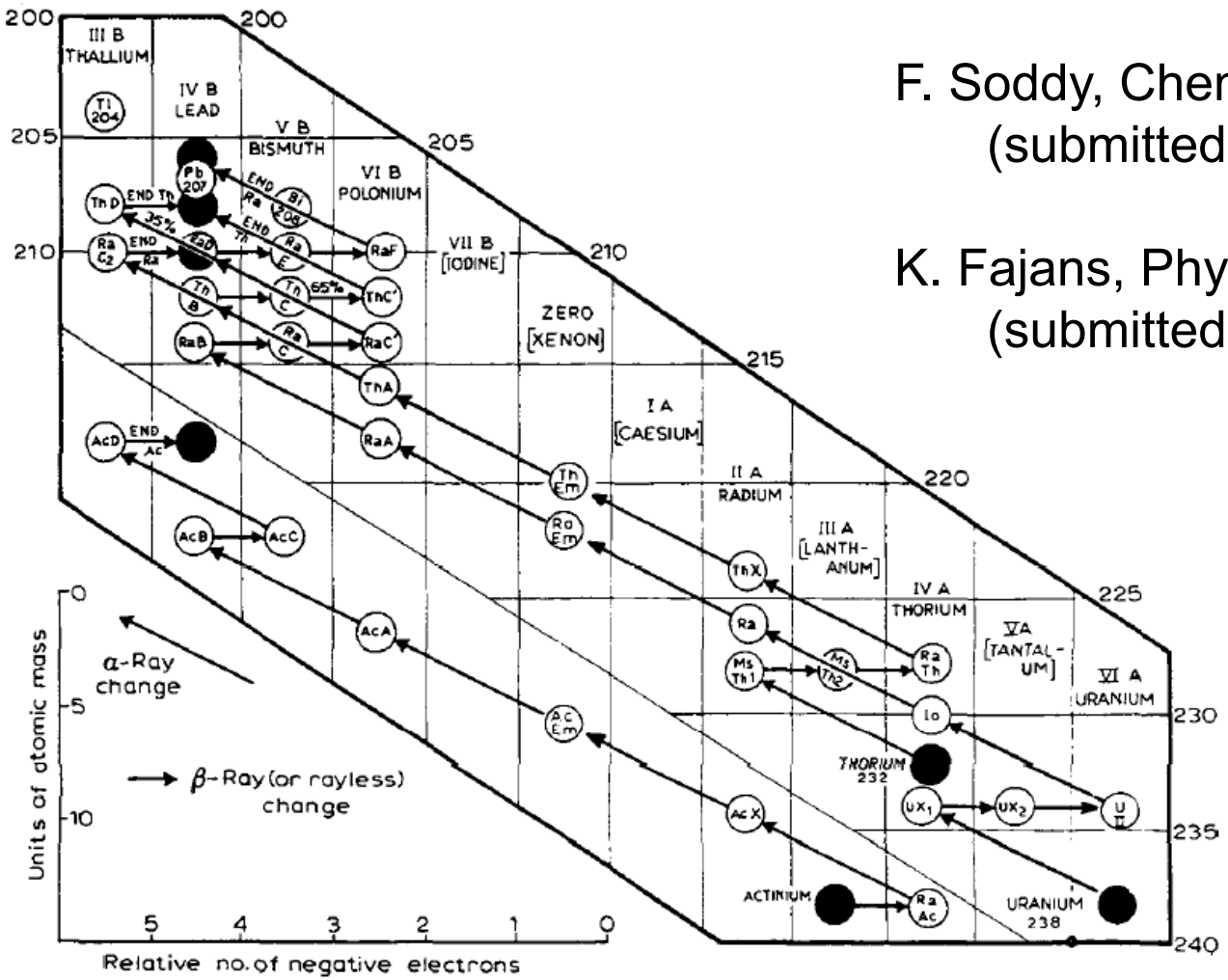
So far as I personally am concerned, this has resulted in a great clarification of my ideas, and it may be helpful to others, though no doubt there is little originality in it. The same algebraic sum of the positive and negative charges in the nucleus, when the arithmetical sum is different, gives what I call "isotopes" or "isotopic elements," because they occupy the same place in the periodic table. They are chemically identical, and save only as regards the relatively few physical properties which depend upon atomic mass directly, physically identical also. Unit changes of this nuclear charge, so reckoned algebraic-

growing ova by nurse cells, the latter being phagocytes which capture other cells and stuff them into the

the action of the enzyme which caused it, but also that if these products reached a certain concentration, the enzyme instead of producing further hydrolysis

(NATURE, November 27, p. 372), is strongly supported by the recent generalisation as to the radio-elements and the periodic law. The successive expulsion of one

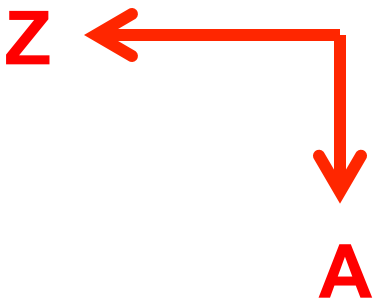
# Explanation of the decay chains




F. Soddy, Chem. News **107** (1913) 97
(submitted Feb. 18, 1913)

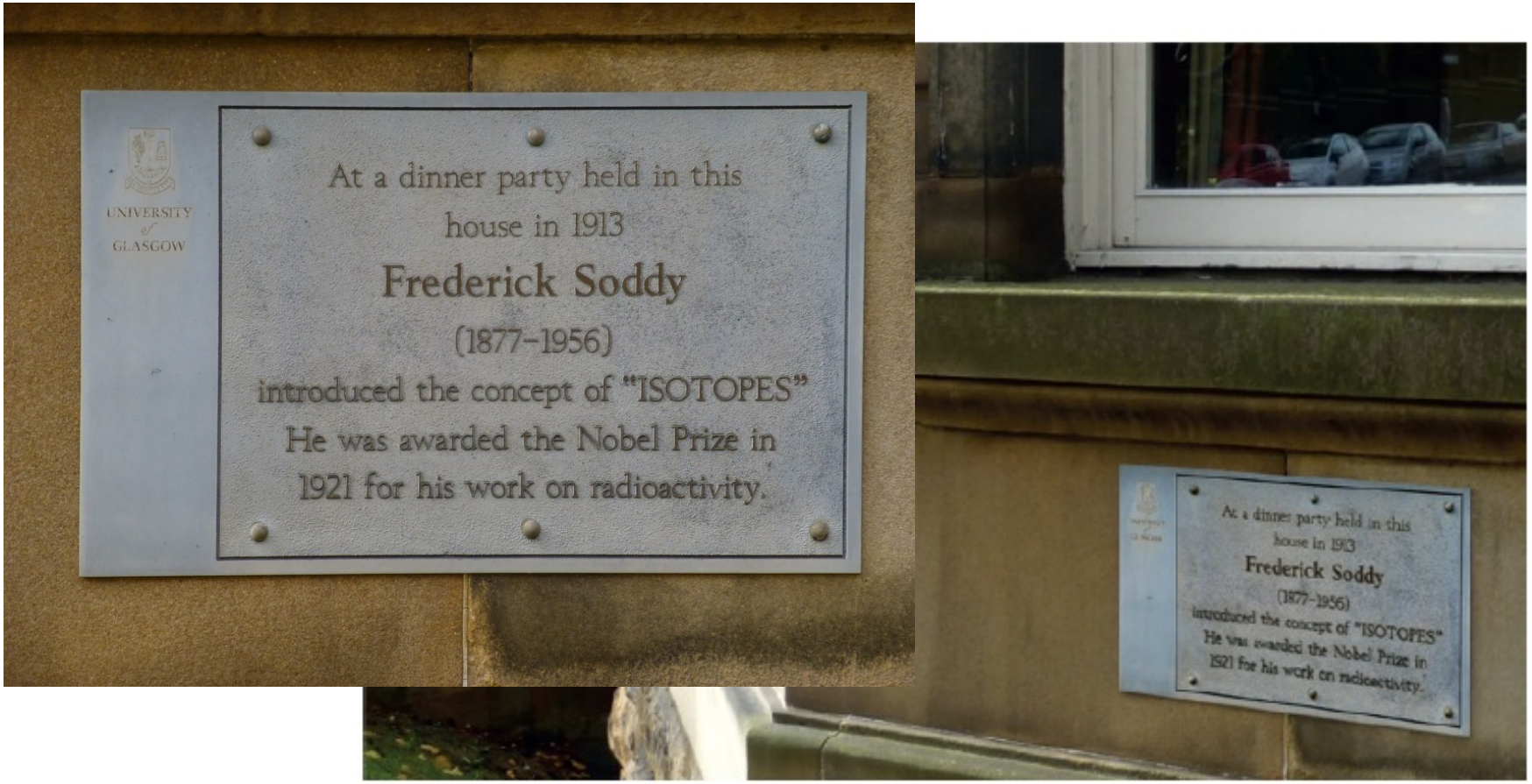
K. Fajans, Physik. Z. **14** (1913) 131
(submitted Dec. 31, 1912)

F. Soddy,
Nobel Lecture, 1922



# Soddy in Glasgow

http://blogs.nature.com/thescepticalchymist/2013/11/isotope-day.html




B. F. Thornton and Shawn C. Burdette, Nature Chemistry **5** (2013) 979

# December 4: Isotope Day

University of Glasgow | The Hunterian

Enter your keywords here Search

Home > The Hunterian > Visit > Events

The Hunterian

- About Us
- Learning
- Collections
- Visit
  - Our Venues
  - Opening Hours
  - Admission Charges
  - Notices
  - Getting Here
  - Exhibitions
  - What's New
  - Events

## Isotope Day - 4 December 2013

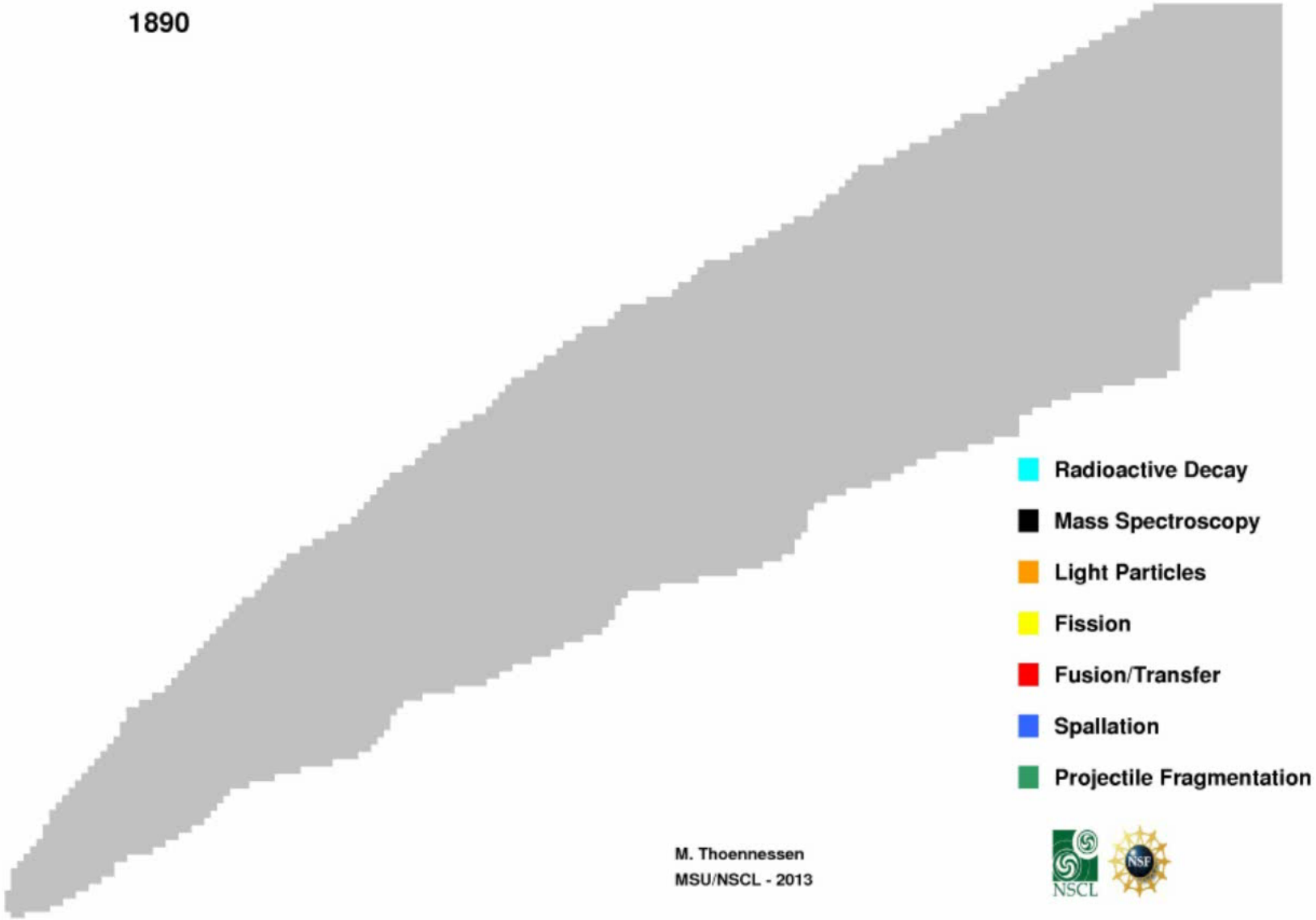
Isotopes were introduced to the world in a letter to the journal 'Nature', published on 4 December 1913 by University of Glasgow chemist Frederick Soddy.

He realised that a single chemical element could occur as atoms with different atomic weights, with different nuclear properties, such as radioactive half-life. He thus reconciled the periodic table with the newly-discovered phenomena of radioactivity, and atomic transformation. He later received the Nobel Prize in Chemistry for this work.

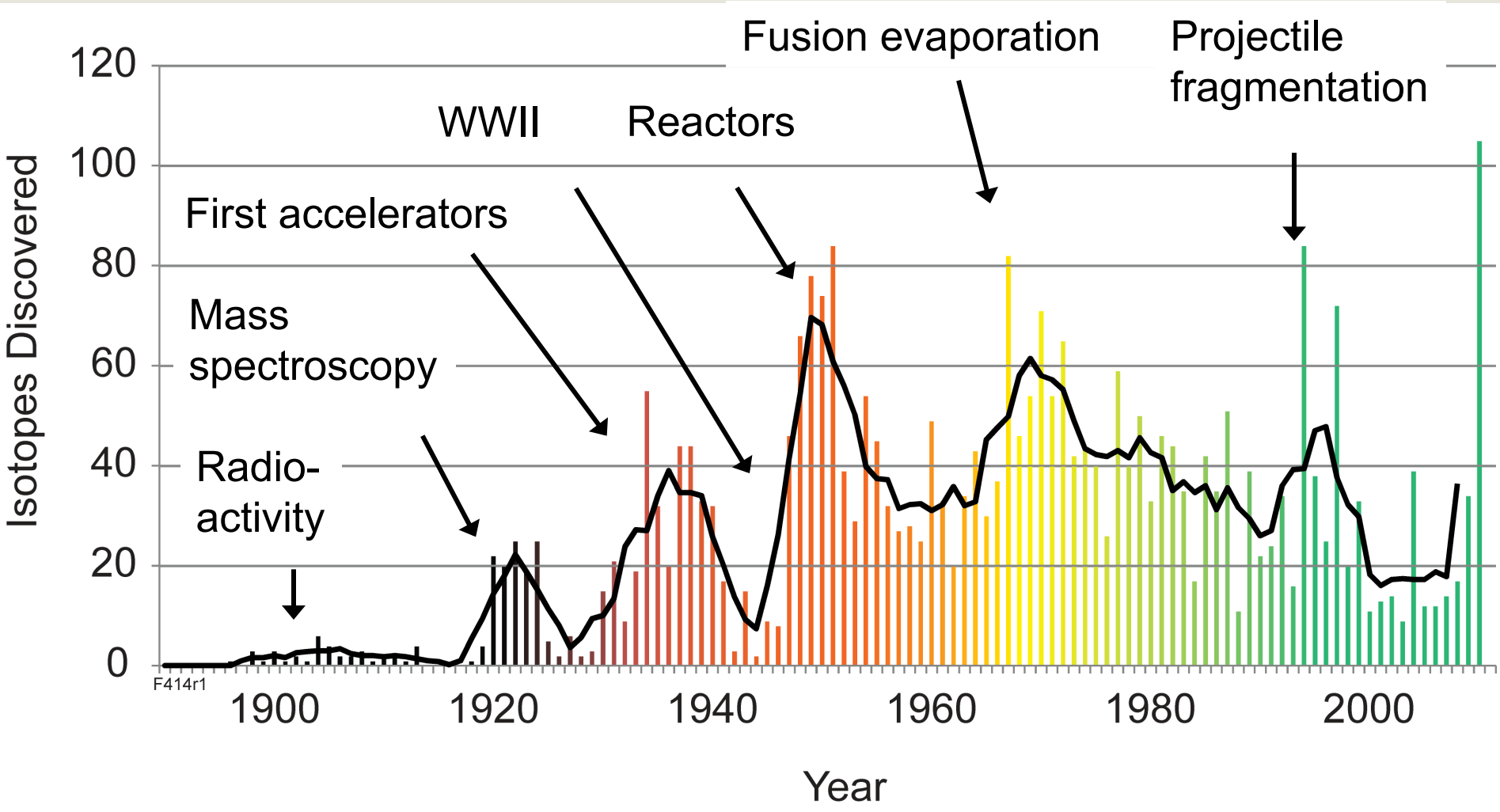
The word 'isotope' itself had been suggested to him by Margaret Todd, a Glasgow GP, during a dinner at 11 University Gardens. Isotope science was truly born at the University of Glasgow.

http://www.gla.ac.uk/hunterian/visit/events/headline_296351_en.html

http://www.nscl.msu.edu/~thoennes/isotopes



# Discoveries are driven by new technologies





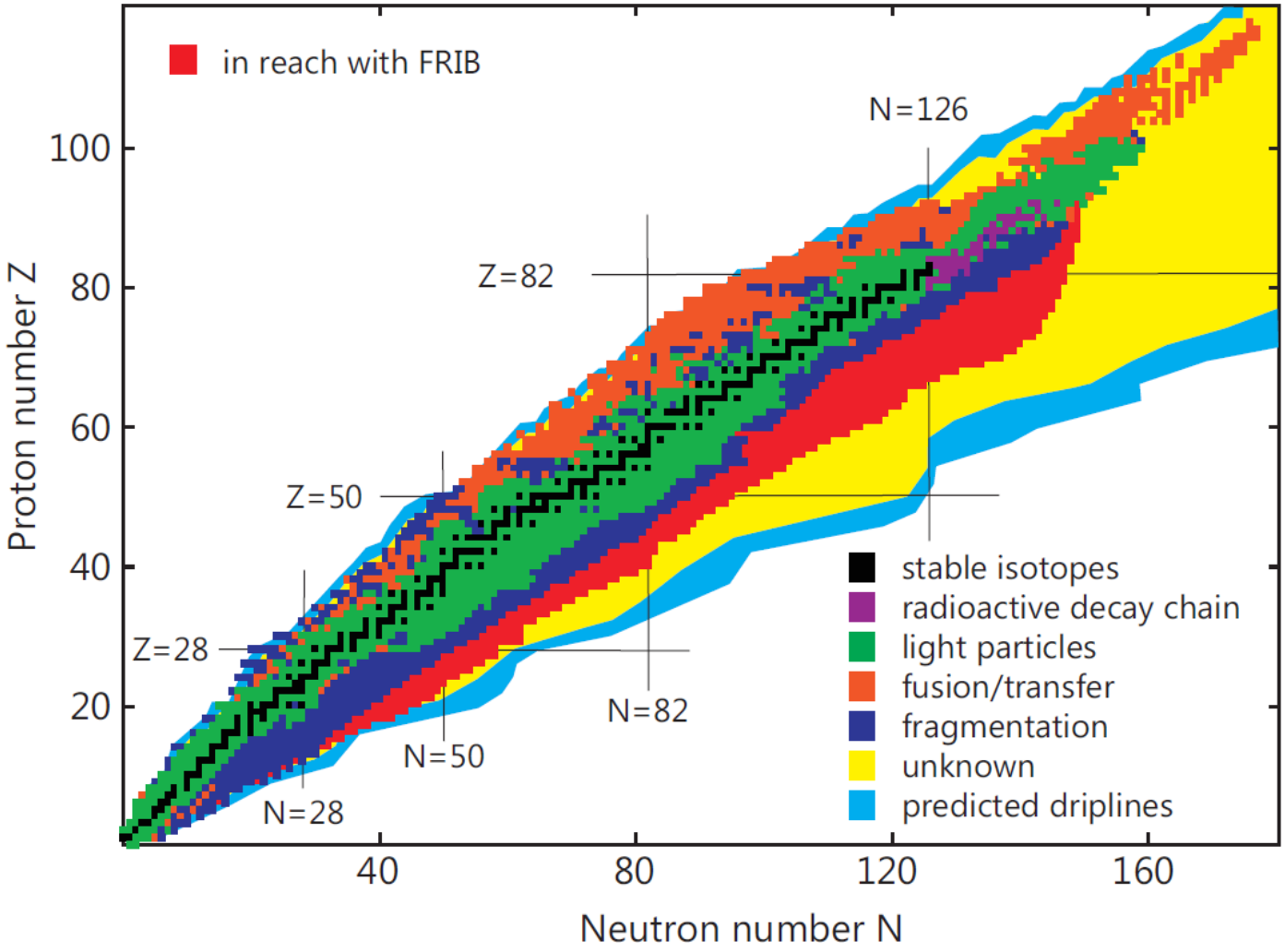

M. T. and B.M. Sherrill, Nature 473 (2011) 25

# Exploration of rare isotopes

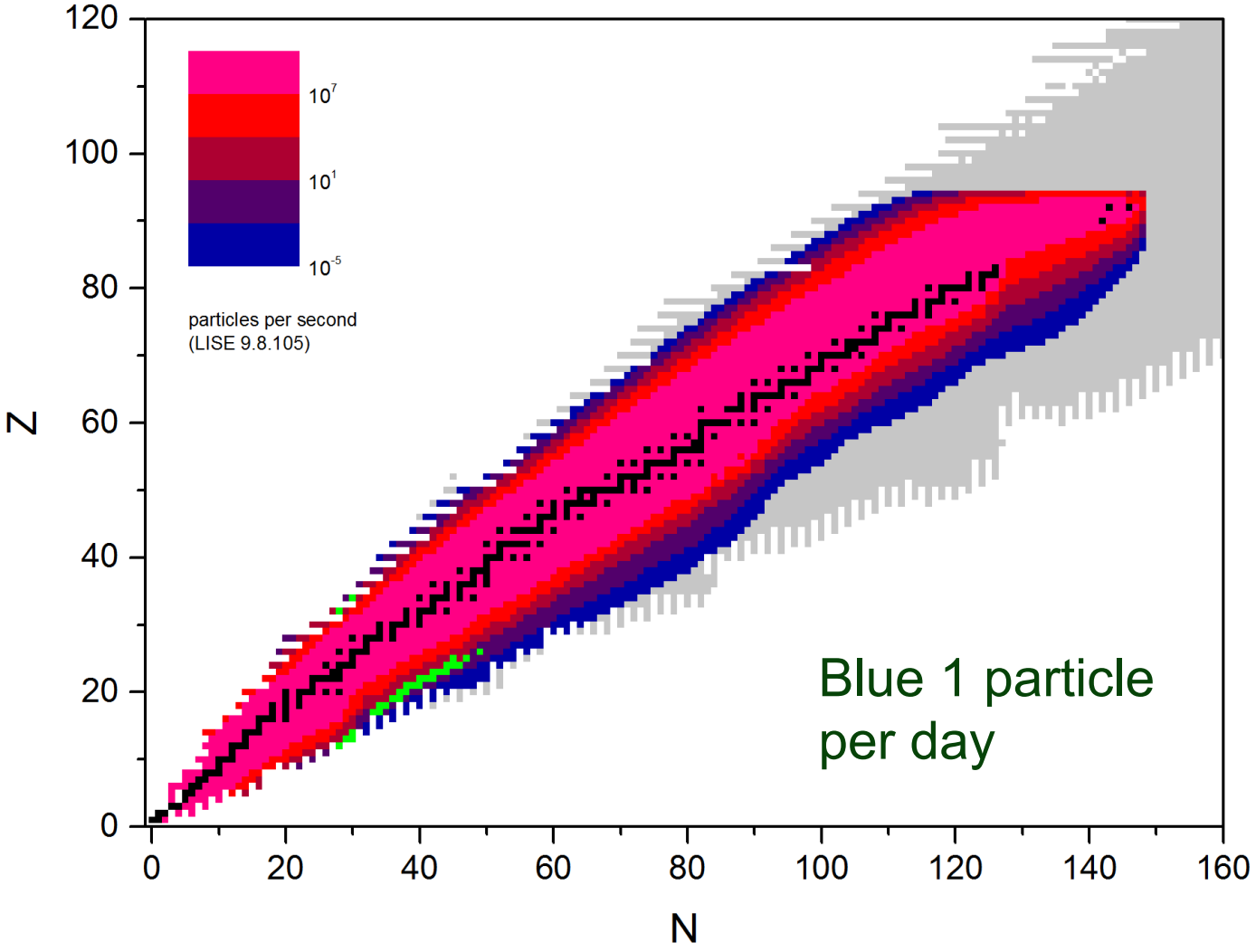
"Owing to the rapid advance in research on disintegration and the theory of nuclear structure, the existence or non-existence of rare isotopes has acquired an entirely unexpected importance and calls for a short review of their present situation."

F.W. Aston, Nature **137**, 613 (1936)

# Reach of FRIB for neutron-rich nuclei



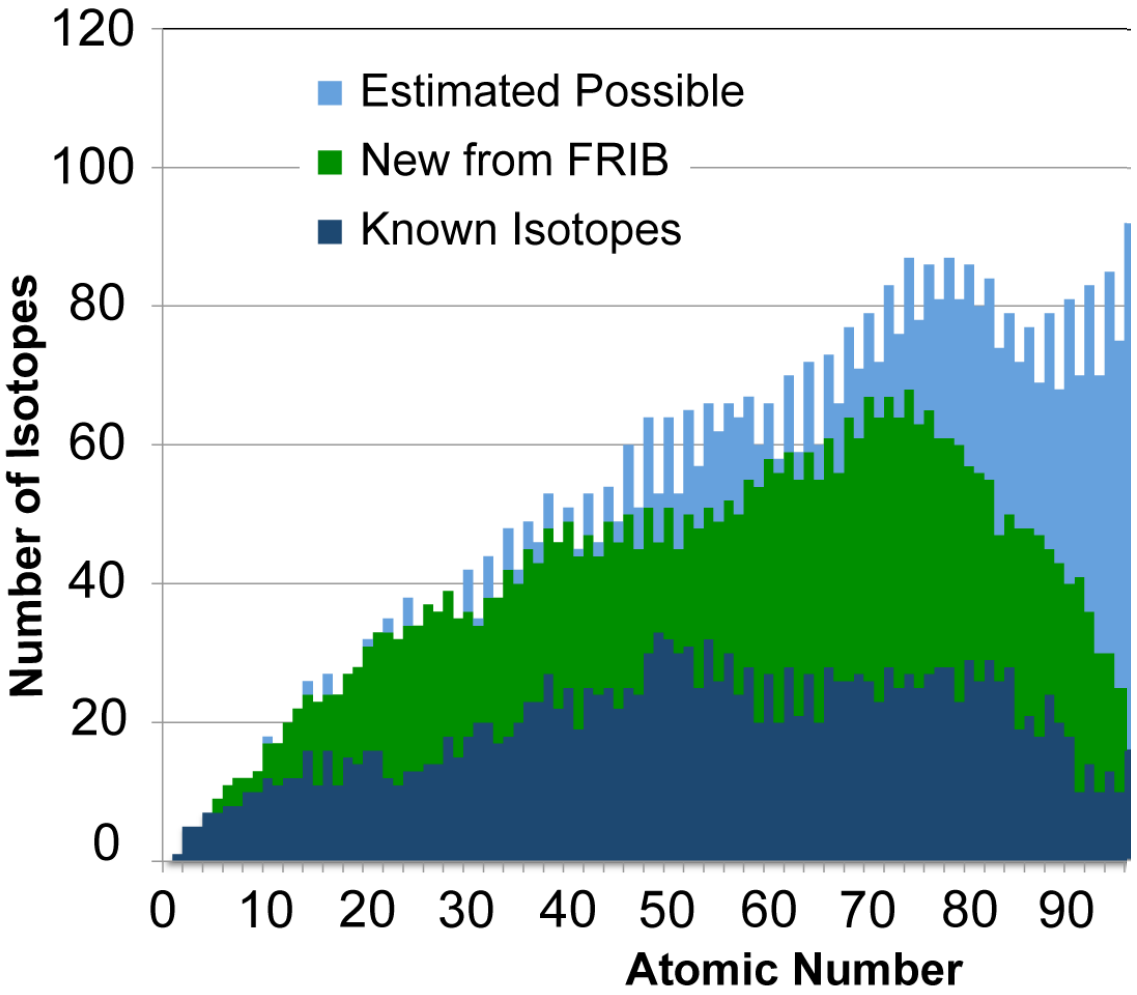
# FRIB projected production rates






O. Tarasov, T. Baumann

# New nuclides with FRIB



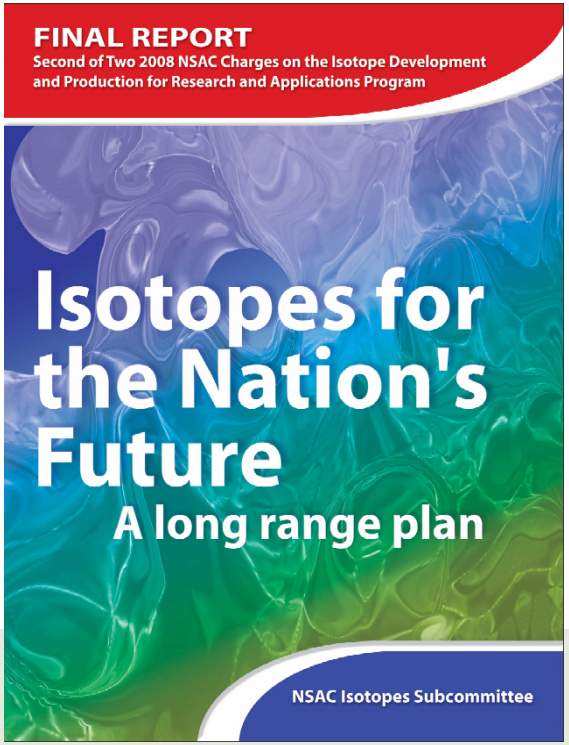

~80% of all isotopes for Z<92

# Isotope production at FRIB

*"Most of the isotopes in use today in practical settings were developed as long as 50 years ago. With few exceptions (e.g., $^{82}$Sr and $^{90}$Y) there are no new products or services that use isotopes developed in the past 20 years. Without the availability of research isotopes, it is not possible to develop new science or new applications based on isotopes. This problem is extreme in the case of accelerator isotopes …"*

Subcommittee Finding
Isotopes for the Nation's Future
NSAC Long Range Plan Study 2008

| Isotope | Half-life | Application |
|---|---|---|
| $^{32}$Si | 132 y | **Tracer, geology and botany** |
| $^{44}$Ti | 60 y | **Medicine, astrophysics, nuclear structure** |
| $^{48}$V | 16 d | **Stockpile Stewardship** |
| $^{67}$Cu | 2.6 d | **Medicine** |
| $^{85}$Kr | 10.0 d | **Stockpile stewardship, astrophysics** |
| $^{147\text{-}154}$Eu | | **Stockpile stewardship, astrophysics** |
| $^{211}$Rn | 14.6 h | **Medicine** |
| $^{225}$Ra | 14.9 d | **Medicine, Electric Dipole Moment** |
| $^{225}$Ac | 10.0 d | **Medicine** |

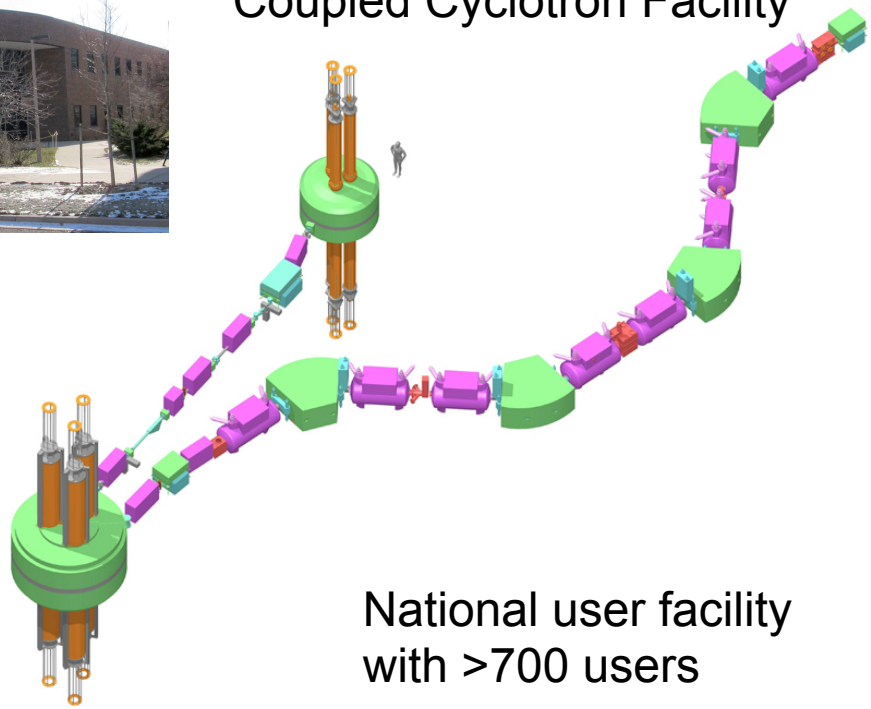


# FRIB at MSU

National Superconducting Cyclotron Laboratory

Located on the campus of
Michigan State University

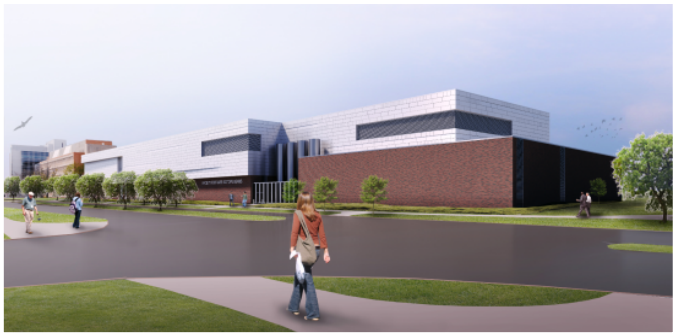
Coupled Cyclotron Facility



- 38 faculty
- 31 research associates
- 66 graduate students

National user facility
with >700 users

# Final civil design is complete



# Why FRIB?

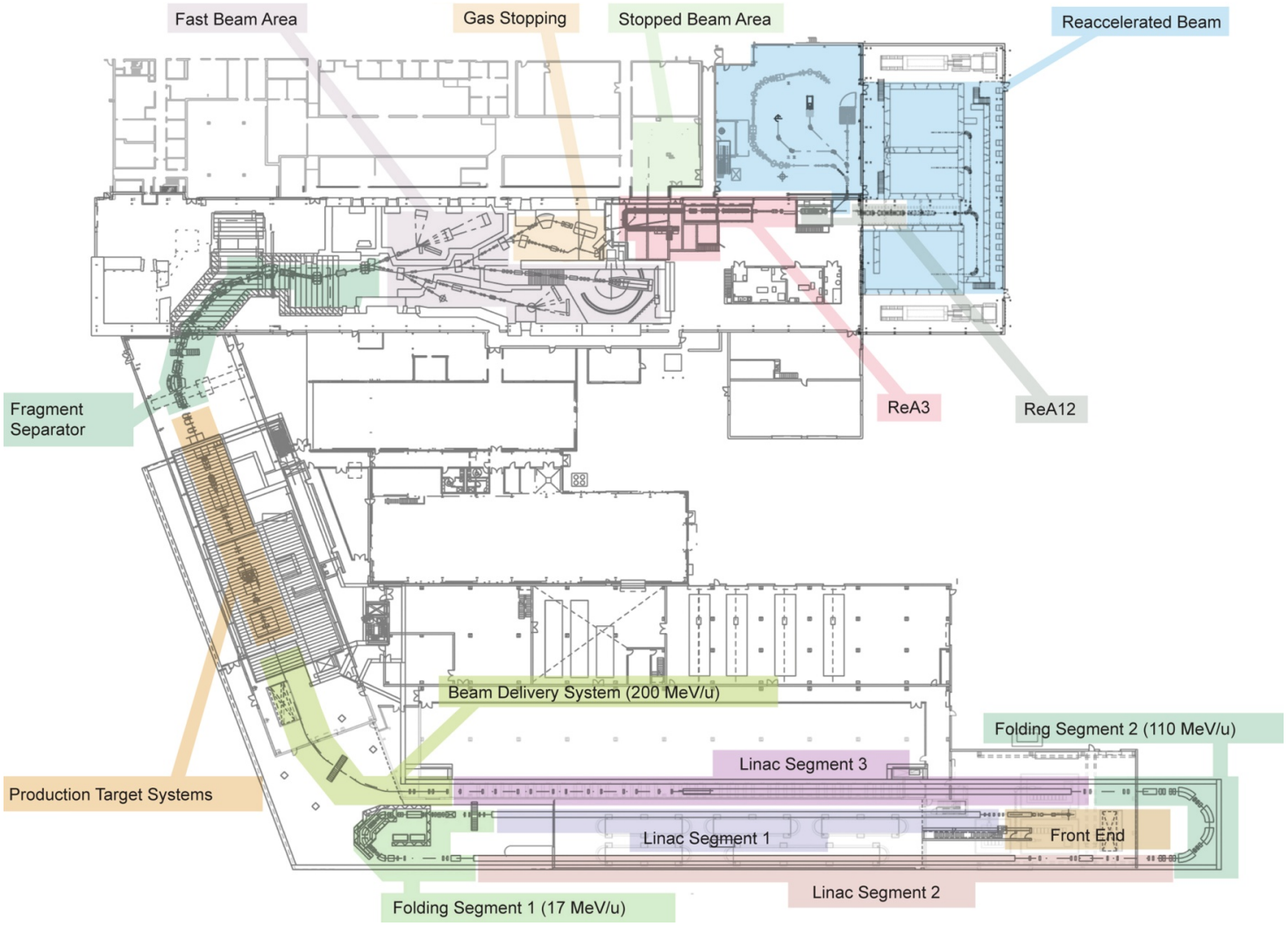
## Cyclotron

Garden hose

## FRIB (Linear Accelerator)

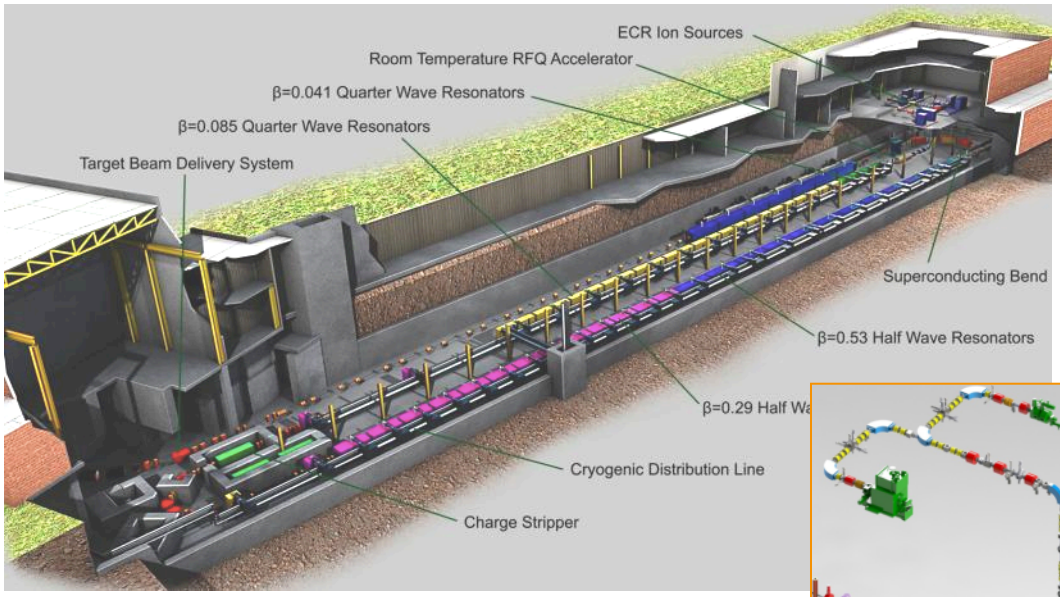
Fire hydrant

# New Accelerator and Present Experimental Areas

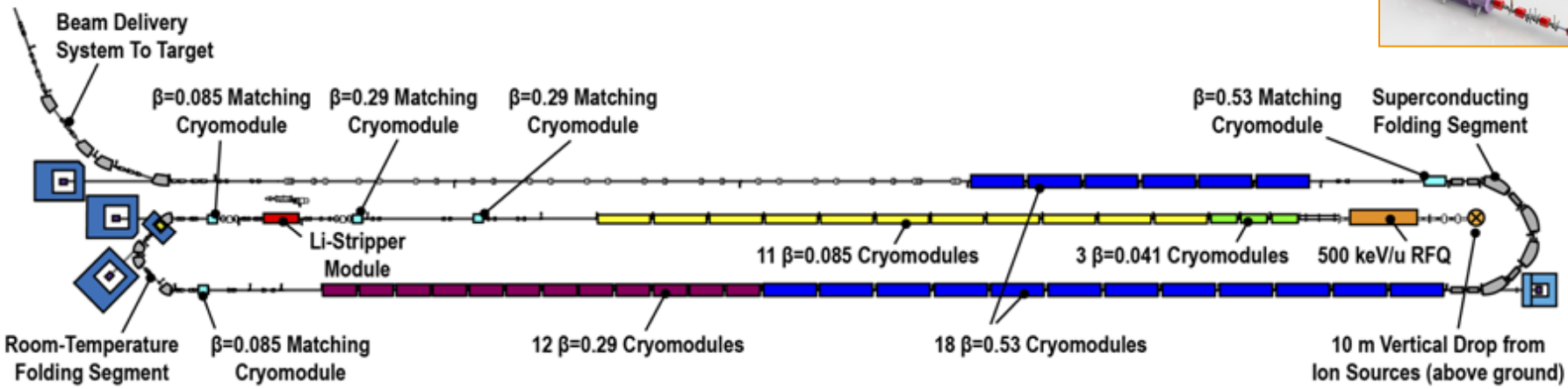


# Accelerator Systems: SRF Driver Linac

- Accelerate ion species up to $^{238}U$ with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
- Energy upgrade to 400 MeV/u for uranium by filling vacant slots with 12 SRF cryomodules

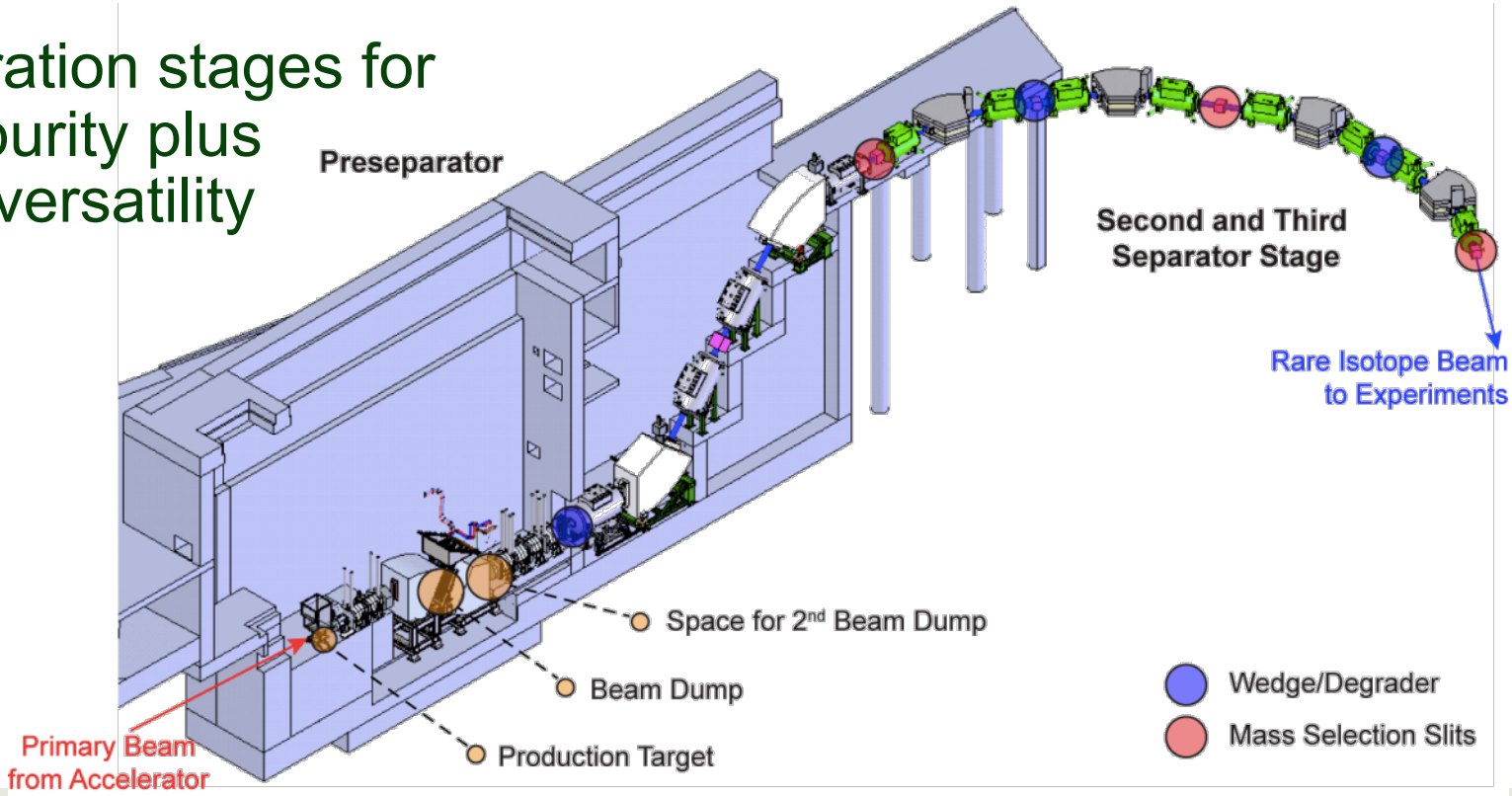




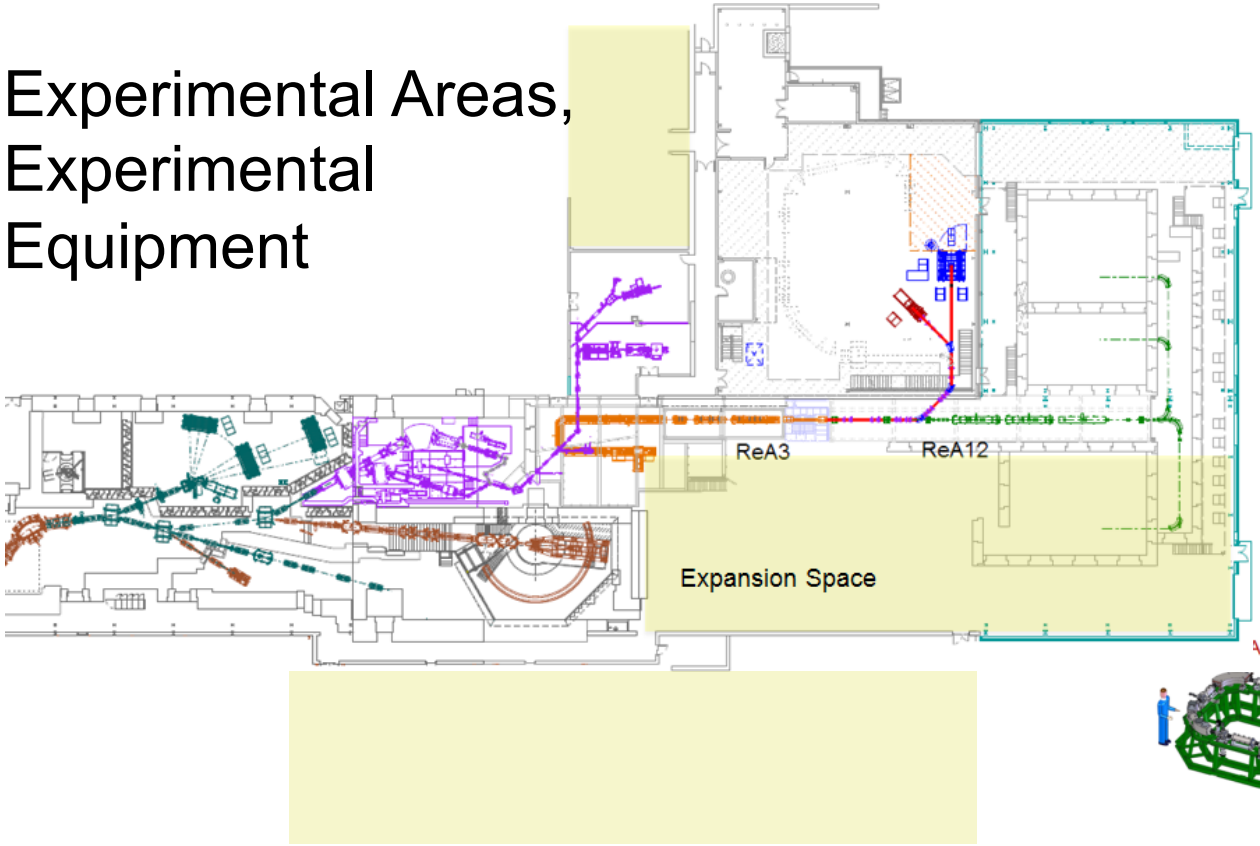
# Fragment Separator

- Production of rare isotope beams with 400 kW beam power using light to heavy ions up to $^{238}$U with energy ≥ 200 MeV/u
  - Large acceptance: ± 40 mrad (angular) and ± 5% (momentum)
  - High magnetic rigidity: 8 Tm after target
- Three separation stages for high beam purity plus operational versatility

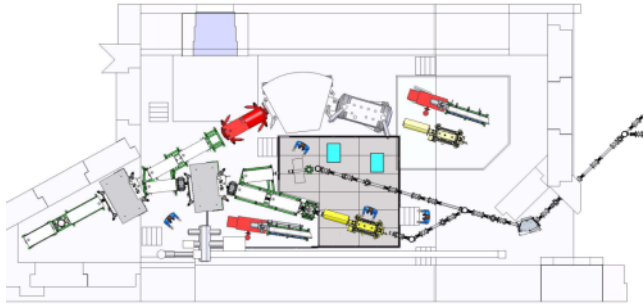


# Fast, Stopped, and Reaccelerated Beam Experimental Areas and Equipment

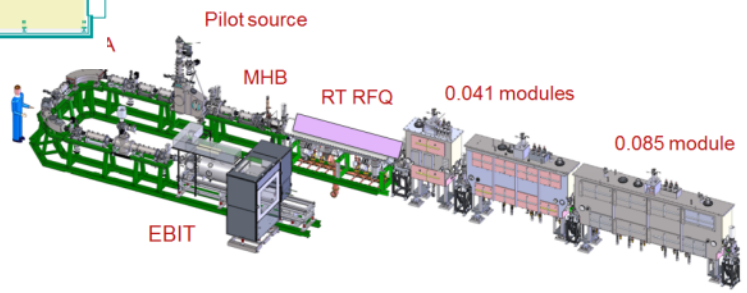
Experimental Areas, Experimental Equipment



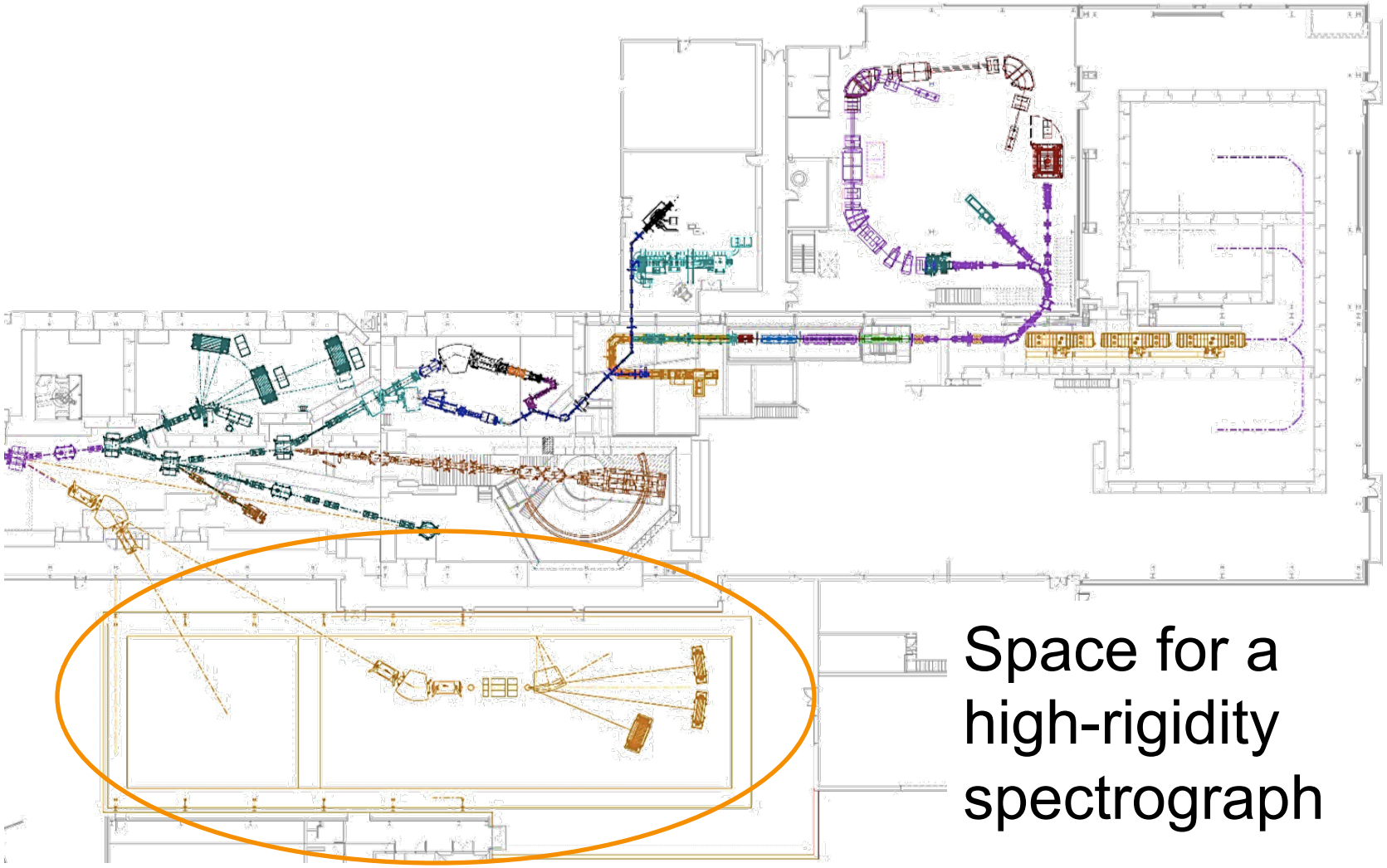

## Beam Stopping



## Reacceleration



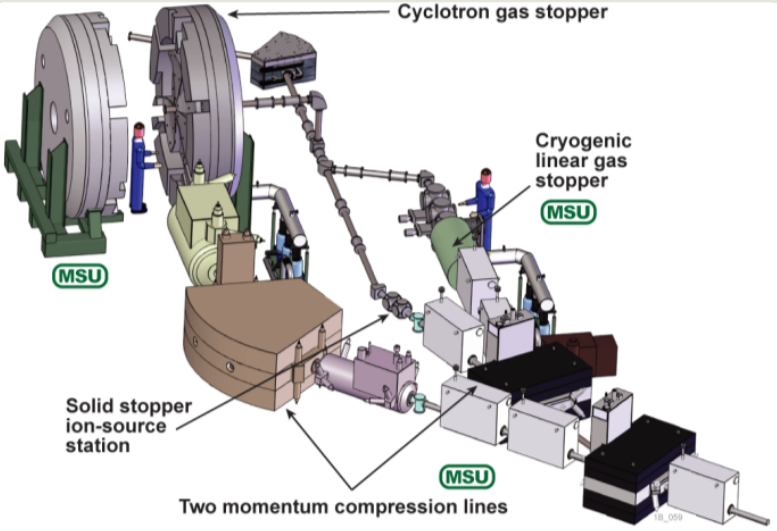
# Plans for fast beam extension



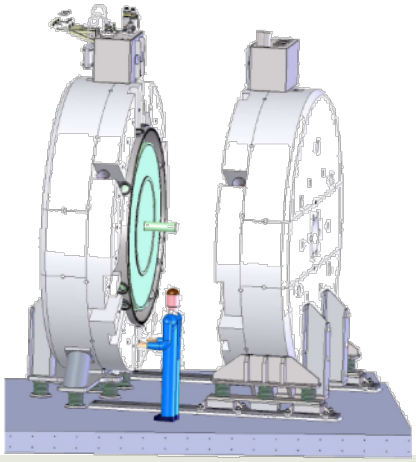
Space for a high-rigidity spectrograph

# Stopped Beams at NSCL and FRIB

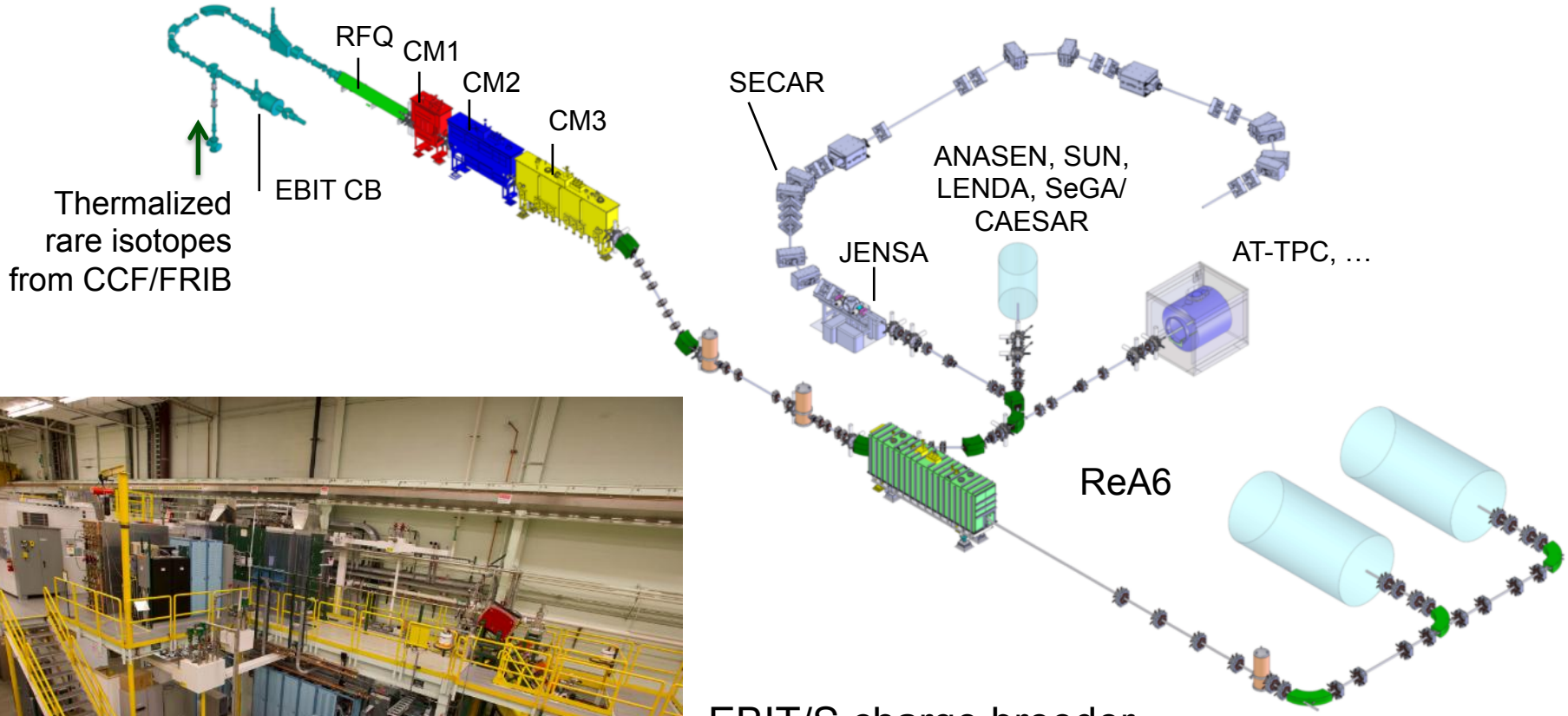
- Multifaceted approach
  - Linear gas stopper (heavier ion beams)
  - Cyclotron gas stopper (lighter ion beams)
  - Solid stopper (certain elements, highest intensity)
- Status
  - Linear gas catcher (ANL) in place and commissioning started
  - Cyclotron gas stopper construction started







# Reaccelerated Beams at NSCL and FRIB with ReA Facility





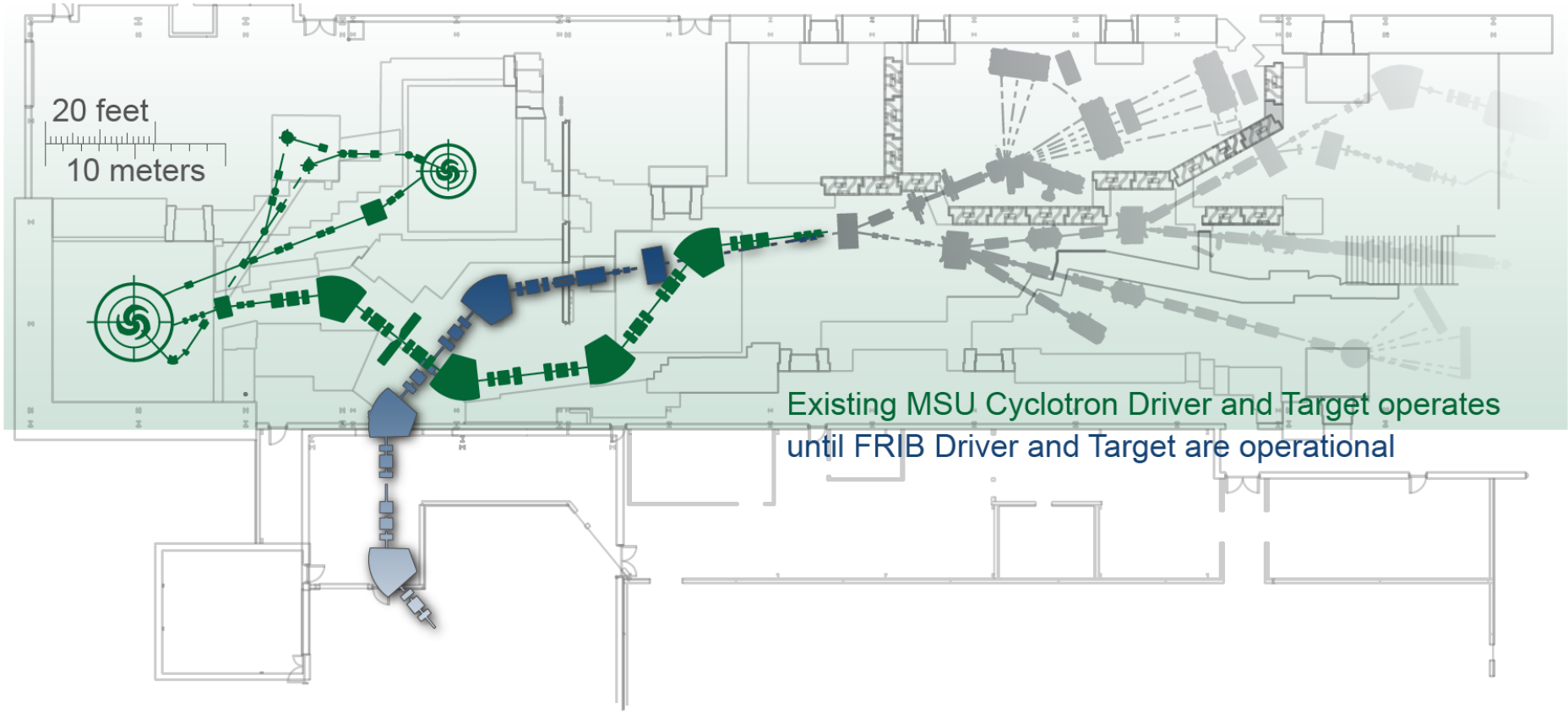

EBIT/S charge breeder

SRF linac

ReA3 – 3 MeV/u for $^{238}U$

Expandable to >12 MeV/u for $^{238}U$

# Transition from NSCL to FRIB




The NSCL Coupled Cyclotron Facility will operate until the FRIB driver is completed

# FRIB timeline

- 8 June 2009 – DOE-SC and MSU sign Cooperative Agreement
- September 2010 – CD-1 approved
- August 2013 – CD-2/3a (civil construction)
- March 2014 – Start civil construction
- August 2014 – CD-3b approved (technical construction)

---

- December 2020 – Early completion goal
- June 2022 – CD-4 (project completion)

# Ground breaking: March 17, 2014

# 2014 – 2015

April 24, 2014

April 16, 2015

# Aerial view of FRIB construction site

# Present status

June 17, 2015 www.frib.msu.edu

# Conventional facilities progress

Tunnel warm and painted
View inside linac tunnel from the west

View of target area from the north

# Conventional facilities site layout

# Conventional facilities site layout: Street view

# FRIB users are engaged and preparing for science

- Users are organized as part of the independent FRIB Users Organization
- FRIBUO has 1350 members (92 US Colleges and Universities, 10 National Laboratories, 53 countries) as of 25 November 2012
- Chartered organization with an elected executive committee
- Theory +20 equipment working groups


Low Energy Science Community Meeting, August 2012


Joint Users Meeting, August 2011

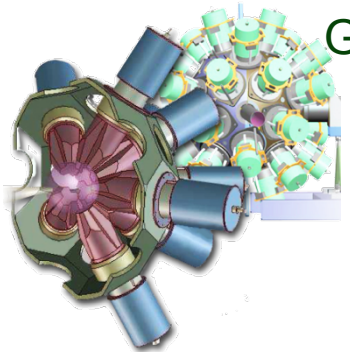

FRIB Equipment Workshop, February 2010

# FRIB Users Organization Working Groups

**www.fribusers.org**

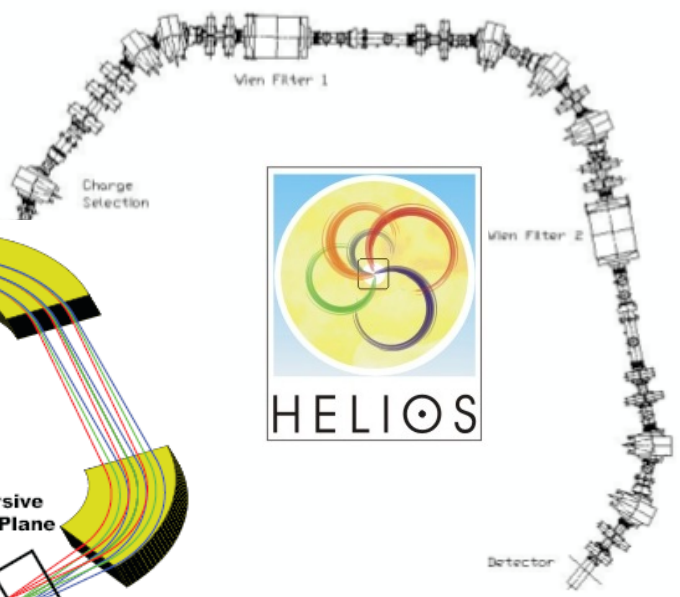
Examples:

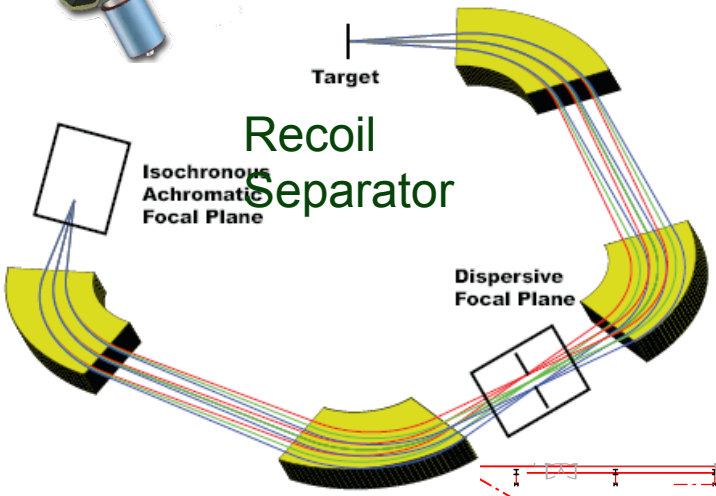
- FRIB Theory Users Group
- Astrophysics (SECAR)
- EoS physics
- GRETINA (+GRETA)
- Isotopes (and Applications)
- ReA12 Separator
- HELIOS
- High Rigidity Spectrometer
- AT-TPC (Time Projection Chamber / Active Target)



GRETA

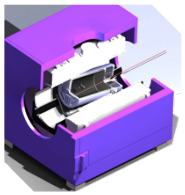
SECAR



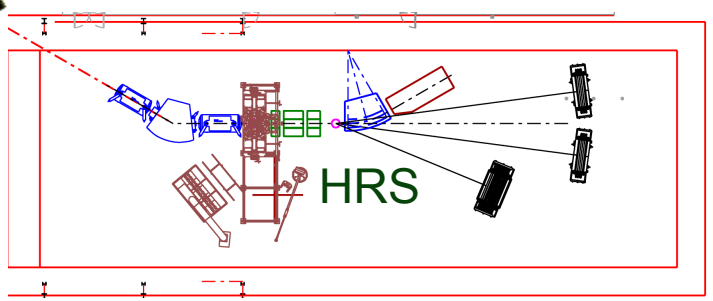









AT-TPC



HRS

# Summary and outlook

- Rare isotope research is very broad and has a bright future
- It has a tremendous discovery potential in nuclear science, nuclear astrophysics and applications
- FRIB construction is on schedule:
  - Project completion June 2022
  - Early completion in December 2020
- Research program is user driven
- Users are organized as part of the independent FRIB Users Organization with over 1400 members
- Please join at www.fribusers.org