The Facility for Rare Isotope Beams

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.

Update from yesterday:

PHYSICAL REVIEW C
nuclear physics

Highlights Recent Accepted Authors Referees Search About

Accepted Paper

Predicting the production of neutron-rich heavy nuclei in multinucleon transfer reactions using a semi-classical model including evaporation and fission competition, GRAZING-F

Phys. Rev. C

R. Yanez and W. Loveland

Accepted 1 April 2015

25 years ago: ISL white paper


LALP 91-51

The IsoSpin Laboratory

ISL

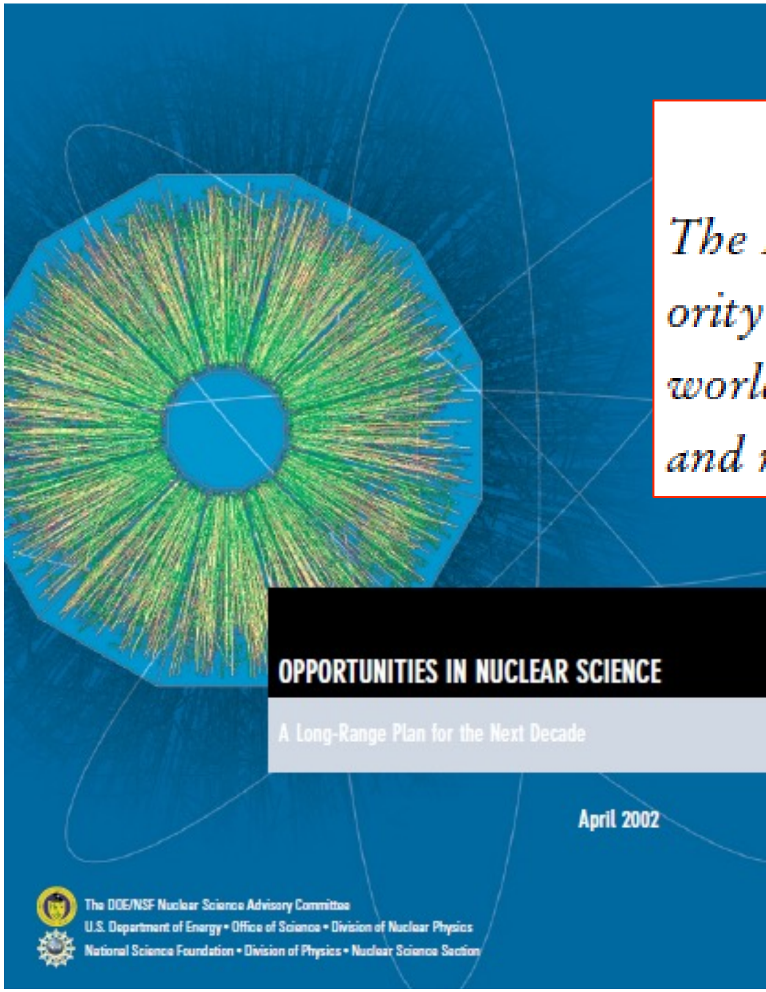
Research Opportunities with Radioactive Nuclear Beams

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

NSAC 2002 Long Range Plan

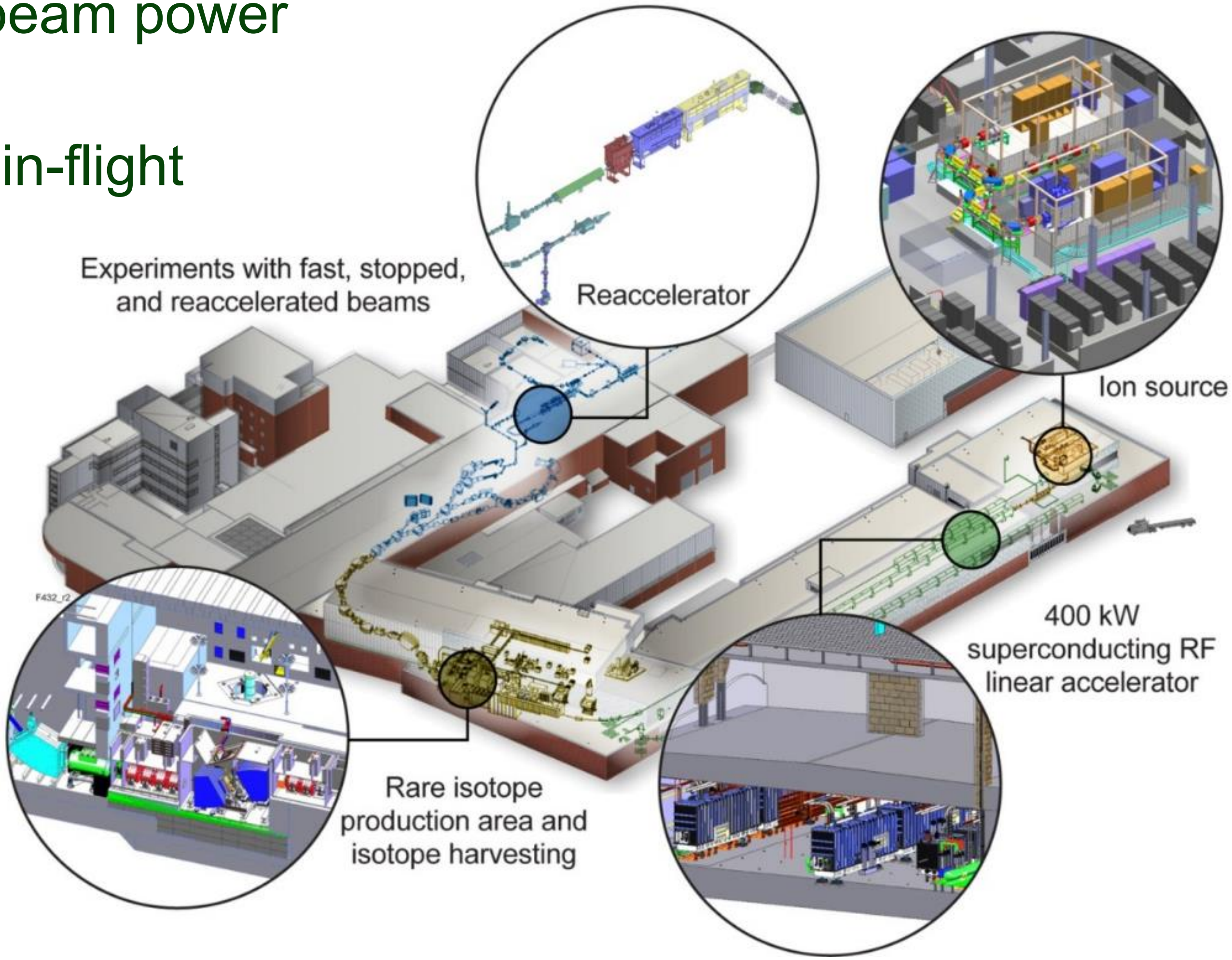


RECOMMENDATION 2

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.

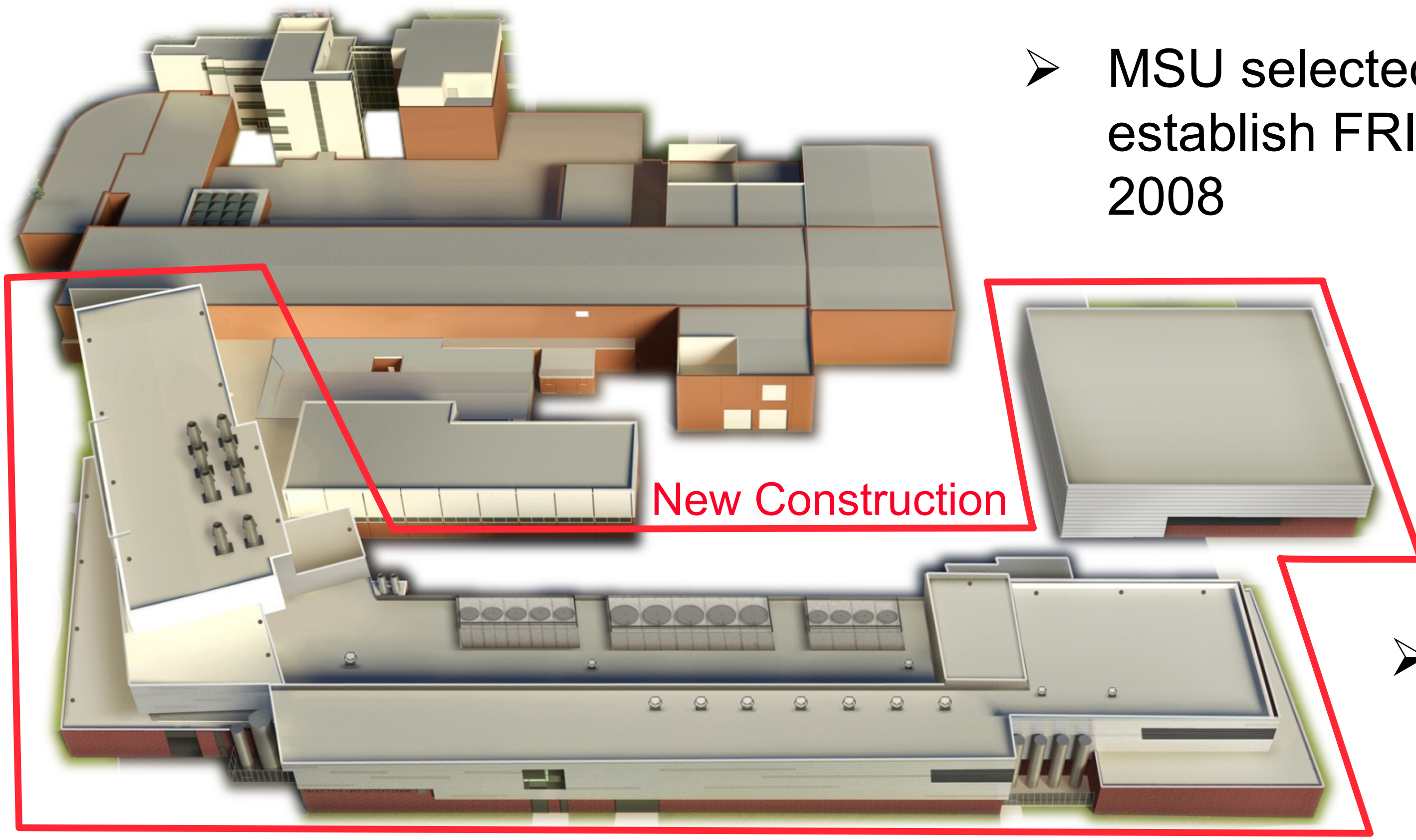
Facility for Rare Isotope Beams
A Future DOE-SC National User Facility

- Key feature is 400kW beam power (5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight
  - Fast development time for any isotope
  - Suited for all elements and short half-lives
- Reaccelerated beams (up to 12 MeV/u)



FRIB: Facility for Rare Isotope Beams

- FRIB is located on the campus of Michigan State University and funded by the U.S. Department of Energy

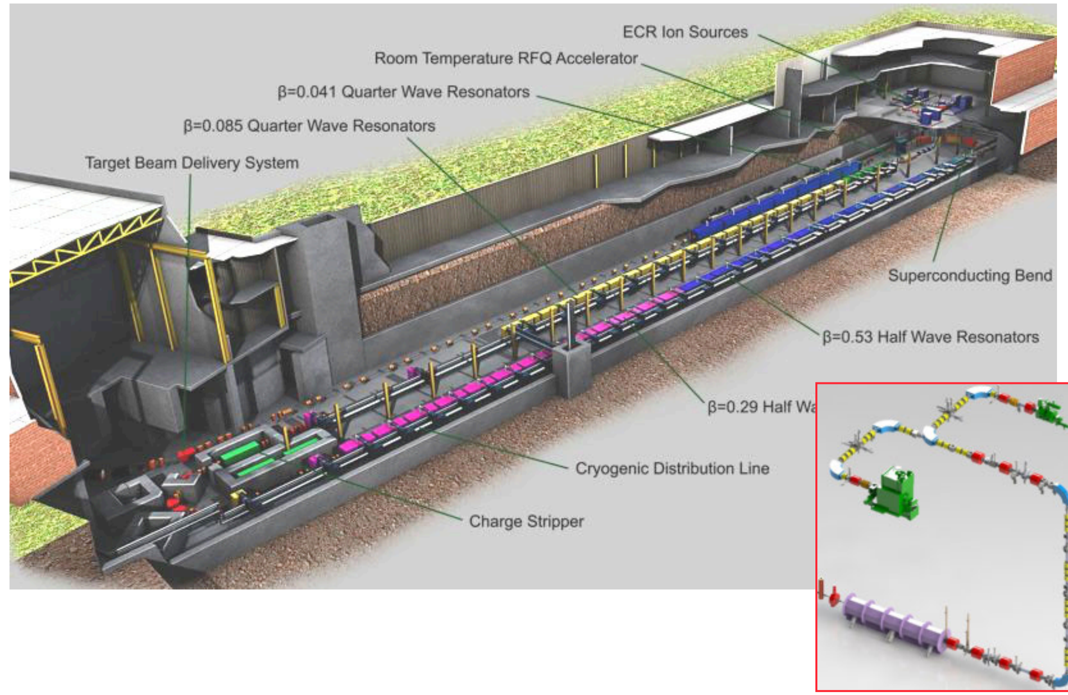


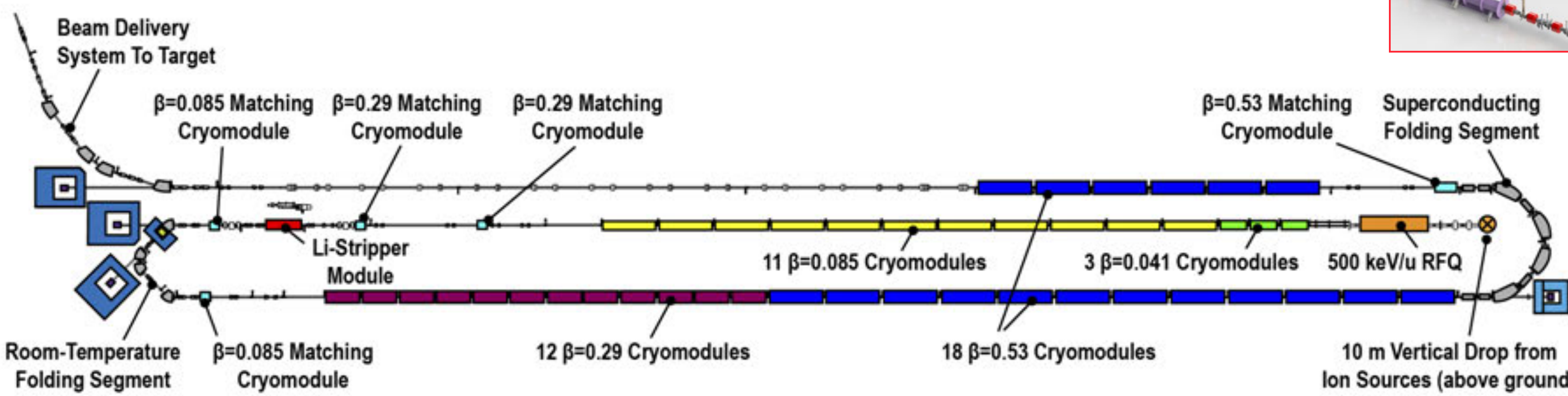
- MSU selected to design and establish FRIB in December 2008

- Project started in June 2009

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

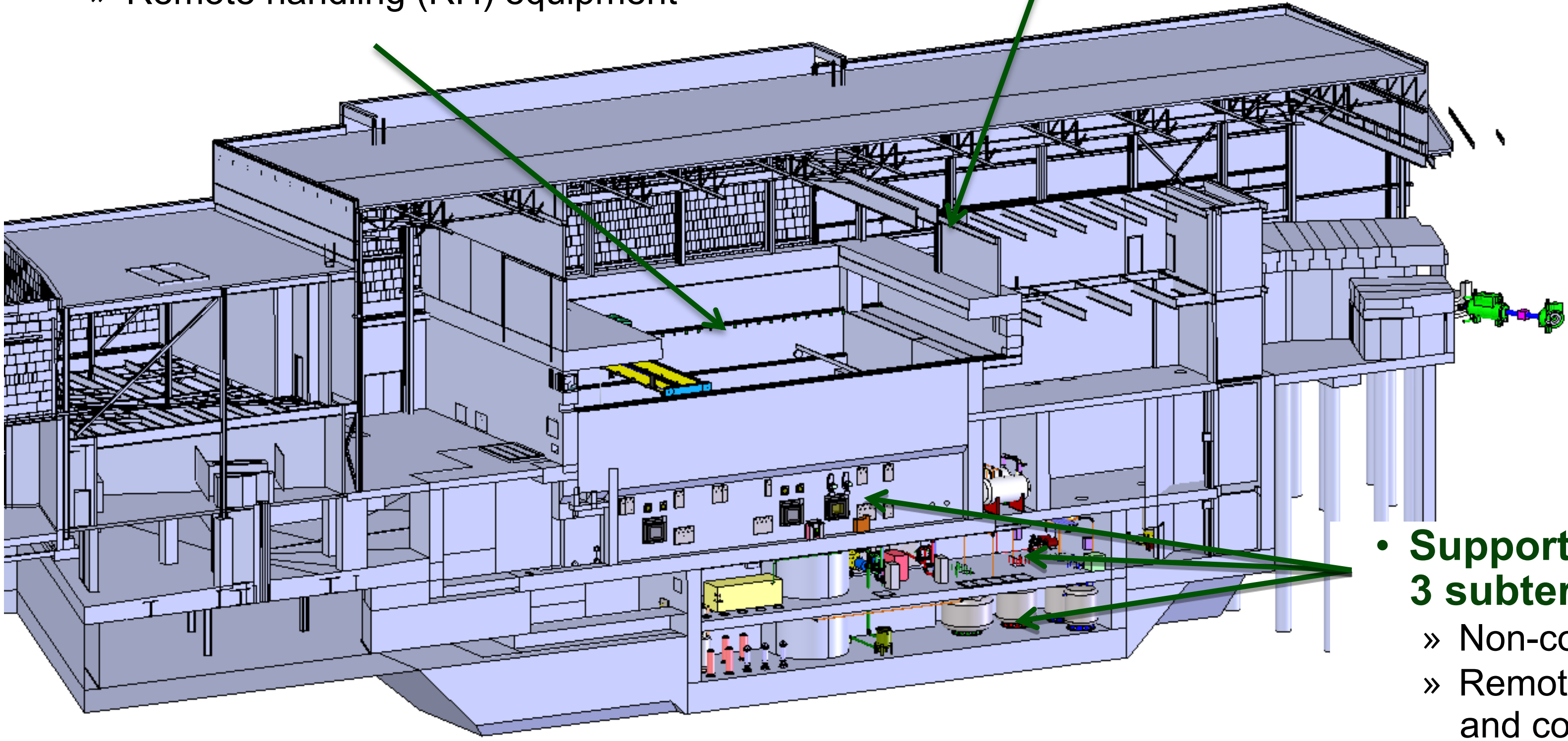




Rare Isotope Production Facility

- **Target hot cell, subterranean**
  - » Production target
  - » Fragment preseparator
  - » Primary beam dump(s)
  - » Remote handling (RH) equipment

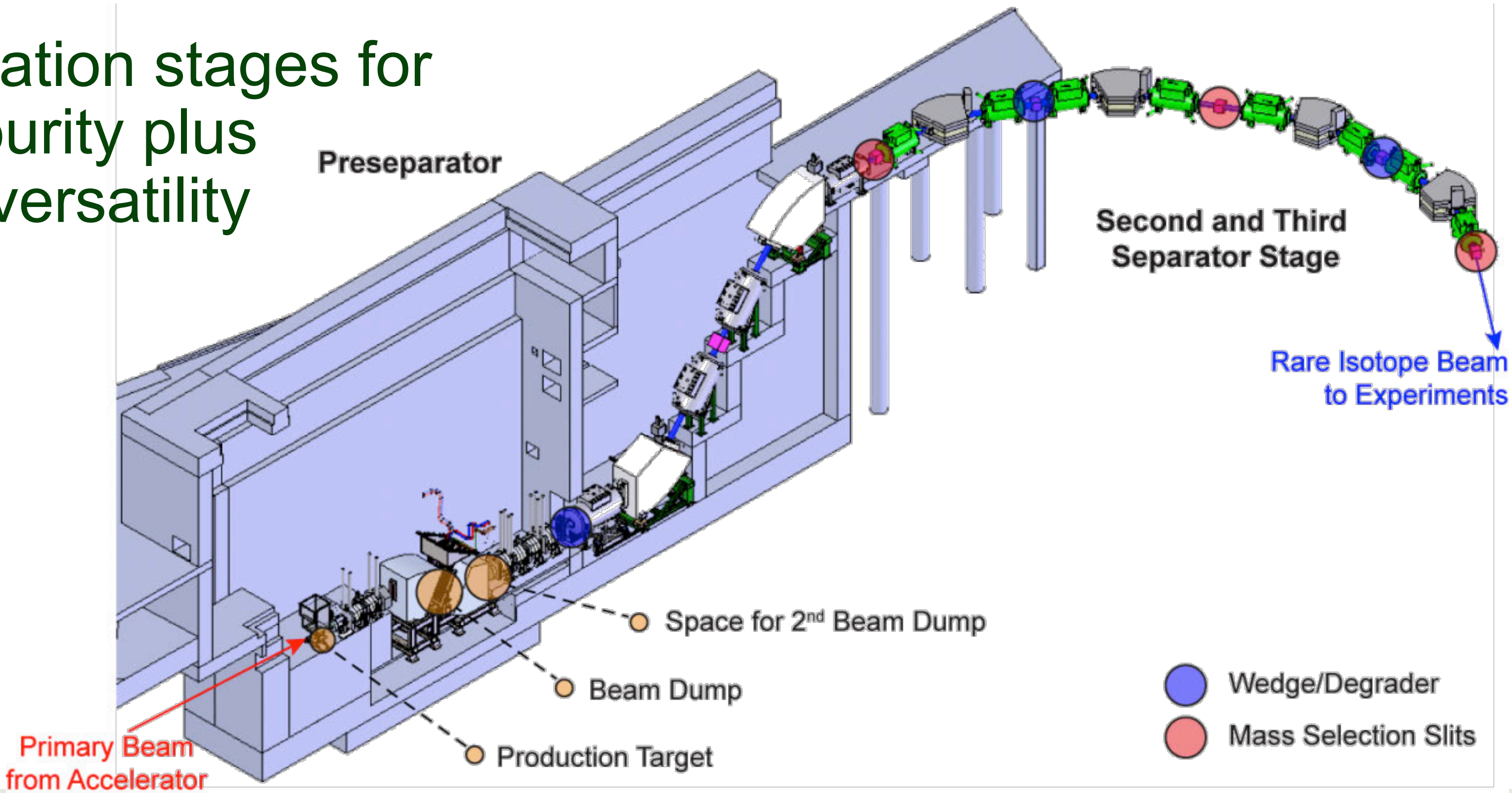
- **Target facility building high bay**
  - » Second and third stage of fragment separator
  - » 50 ton bridge crane
  - » Fragment separator power supplies



- **Support areas, 3 subterranean levels**
  - » Non-conventional utilities
  - » Remote handling gallery and control room
  - » Waste handling

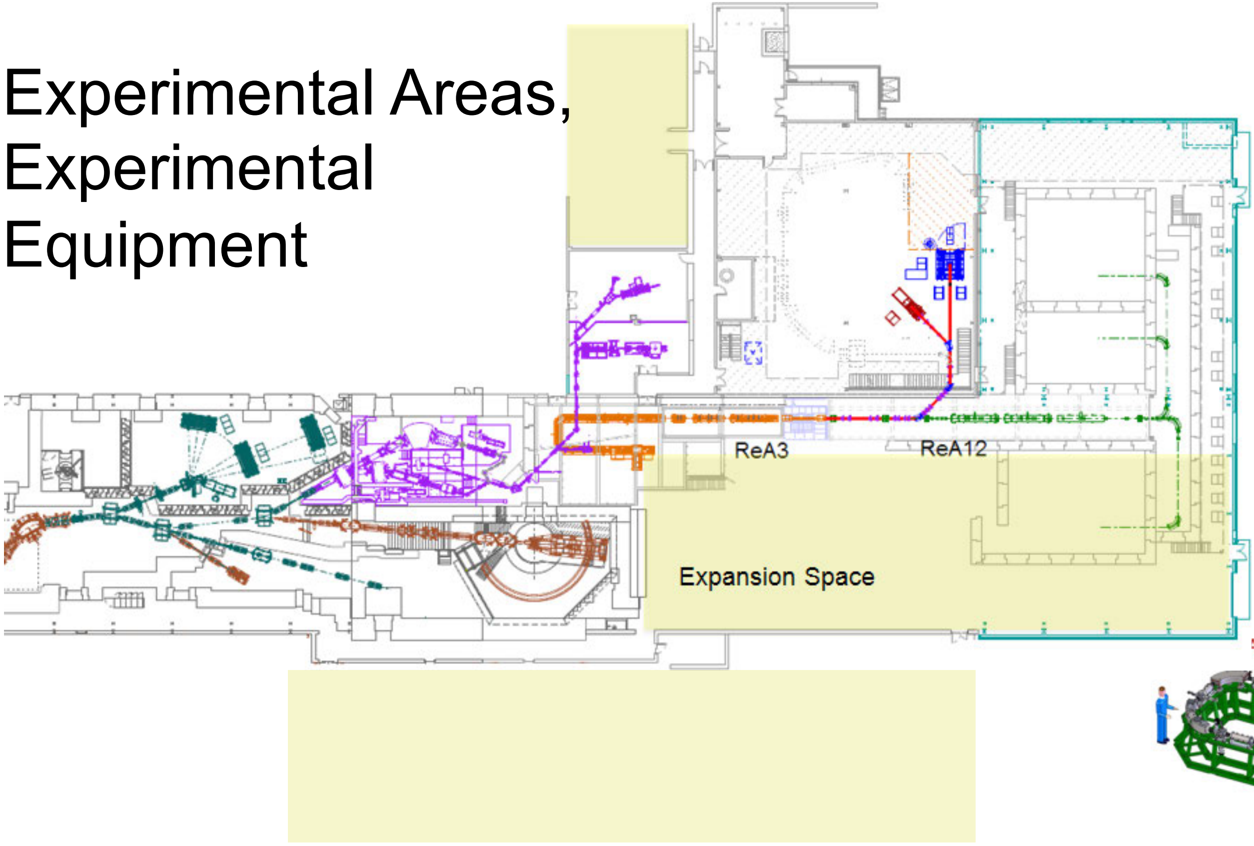
Fragment Separator

- 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

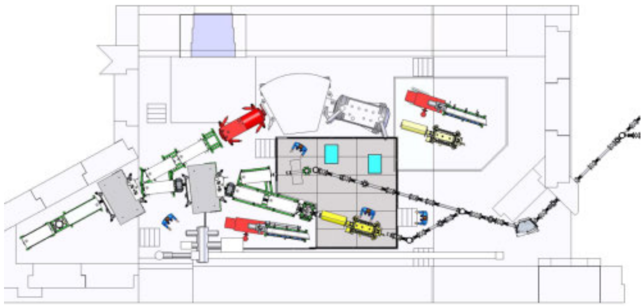


Fast, Stopped, and Reaccelerated Beam Experimental Areas and Equipment

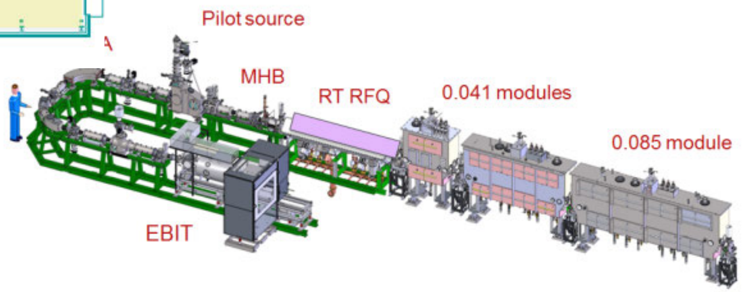
Experimental Areas, Experimental Equipment



Beam Stopping

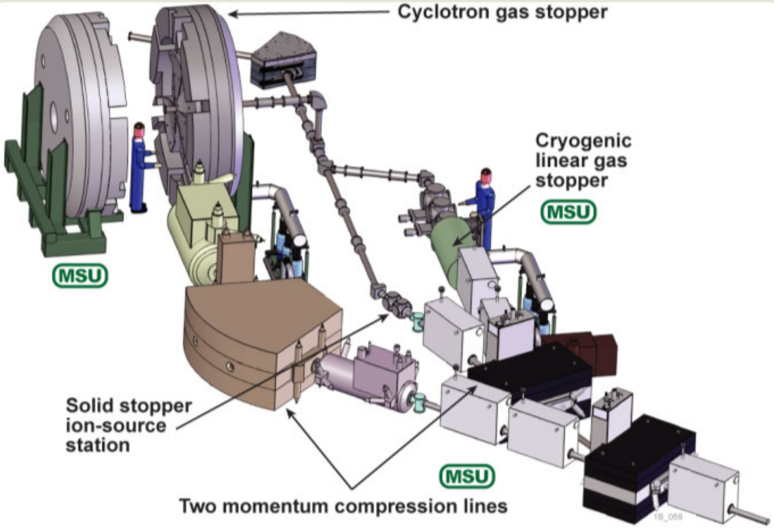


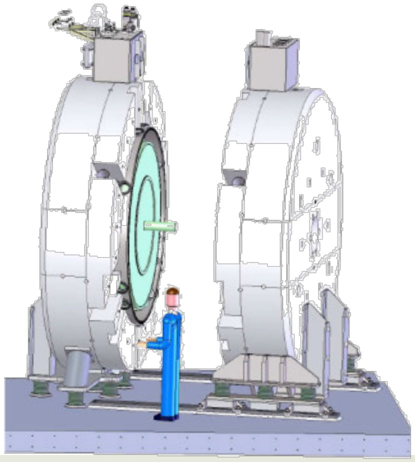
Reacceleration



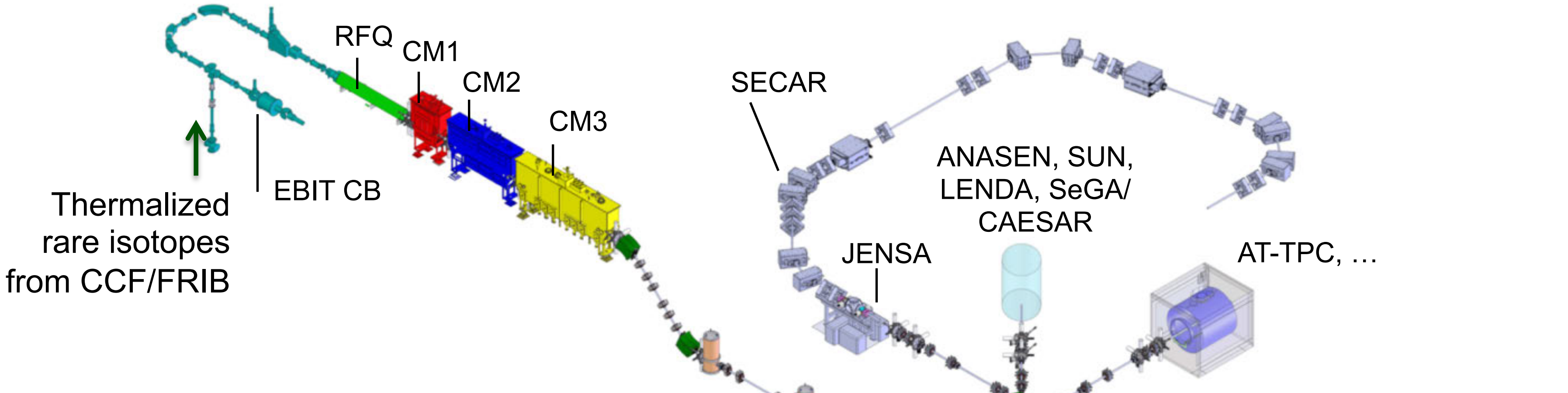
Stopped Beams at NSCL and FRIB

- 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



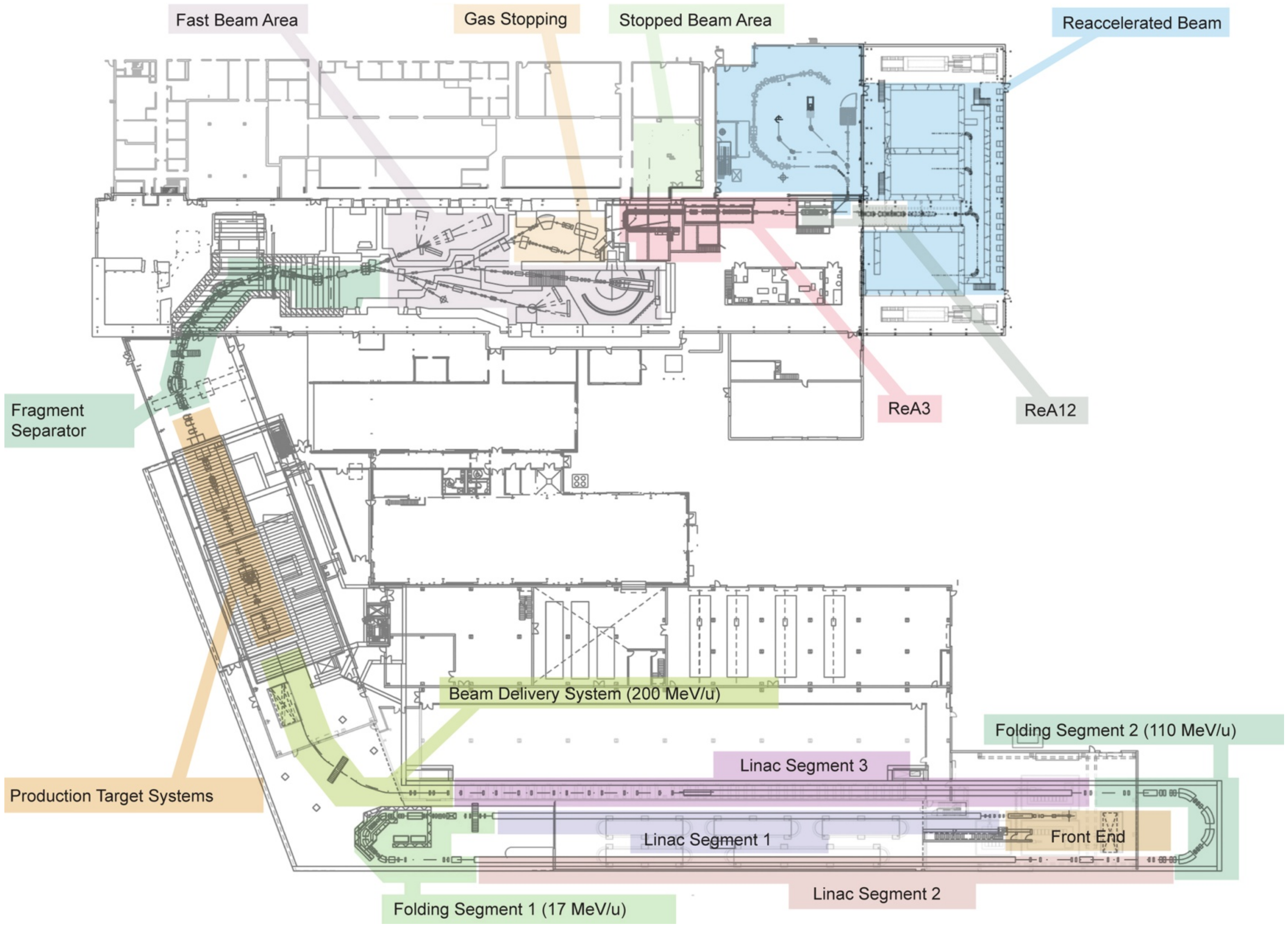
EBIT/S charge breeder

SRF linac

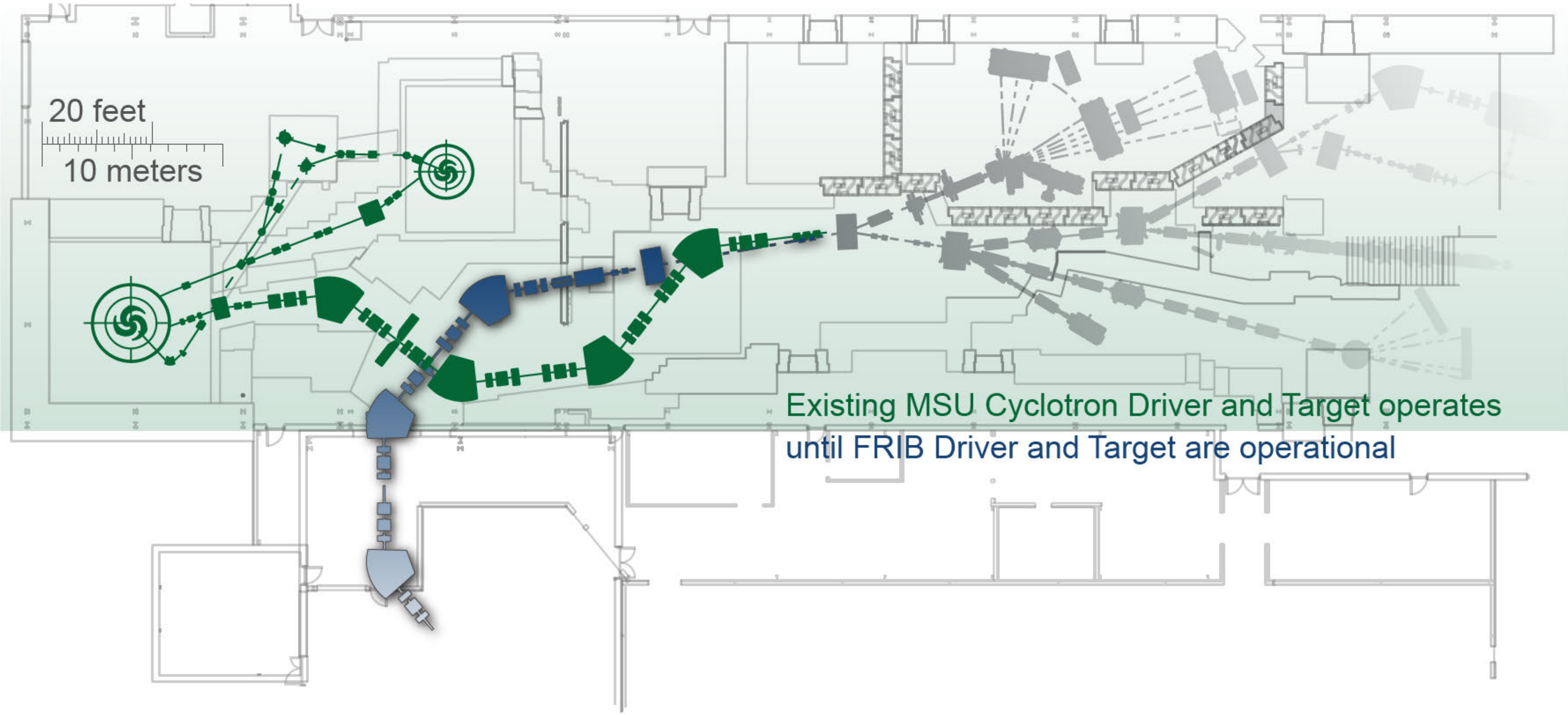
ReA3 – 3 MeV/u for ^{238}U

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

New accelerator and present experimental areas



Transition from NSCL to FRIB

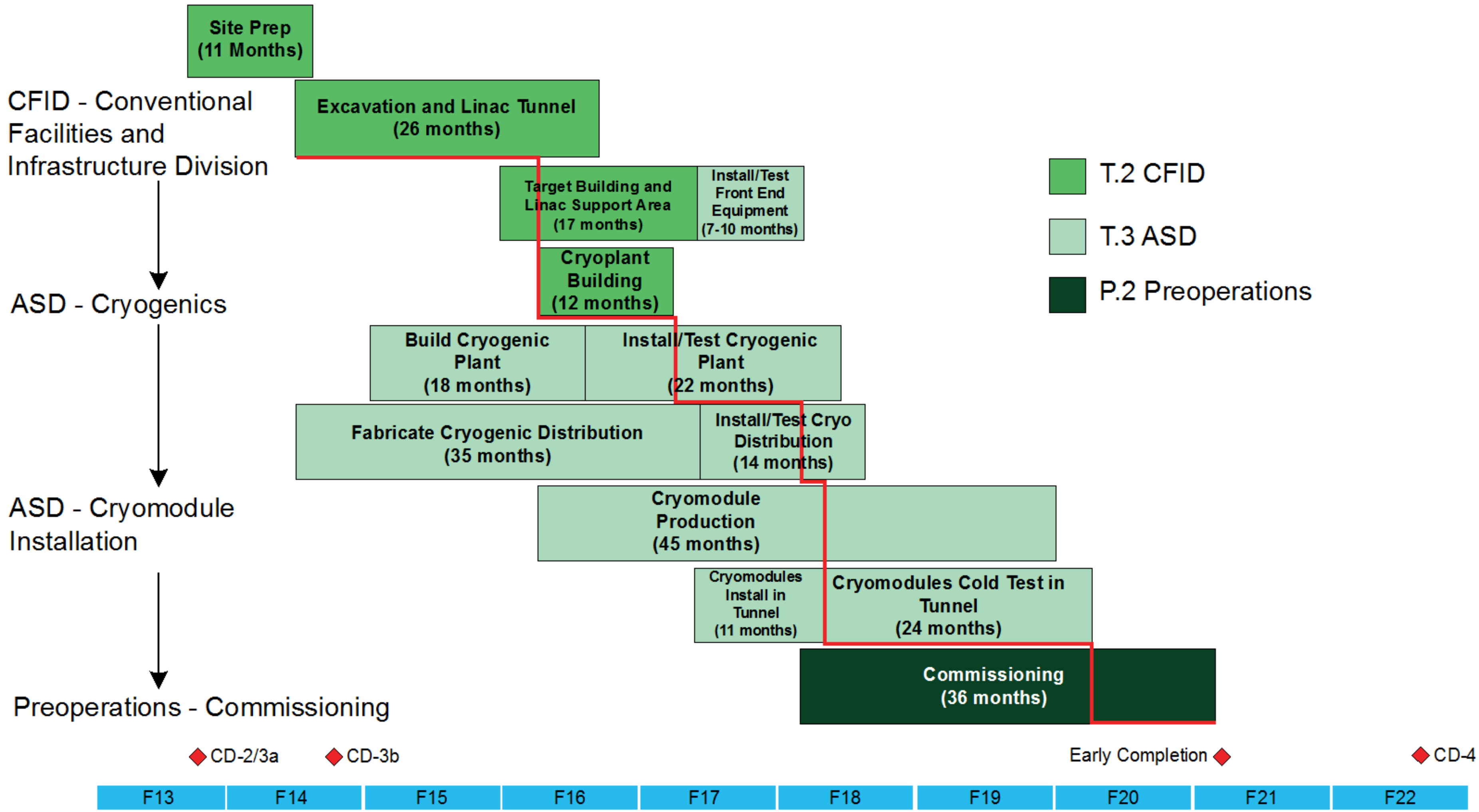


FRIB timeline

- 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)

Critical path



Ground breaking: March 17, 2014

Civil construction: 8 Weeks Ahead

Front-end building 16 months ahead of baseline

http://www.frib.msu.edu/

Aerial view of FRIB construction site

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 is needed to understand atomic nuclei

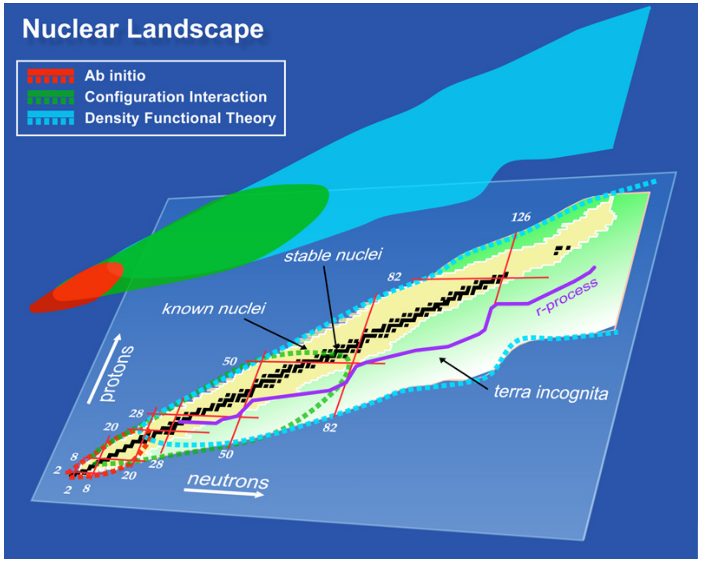
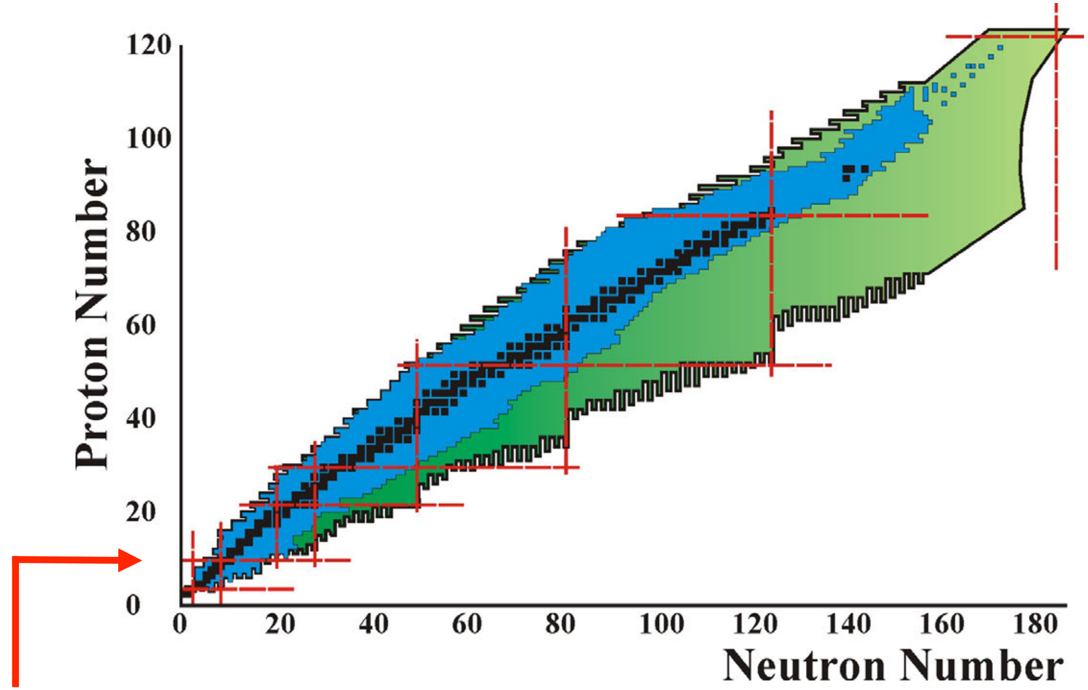


Figure adapted from
www.scidacreview.org/0704/html/unedf.html

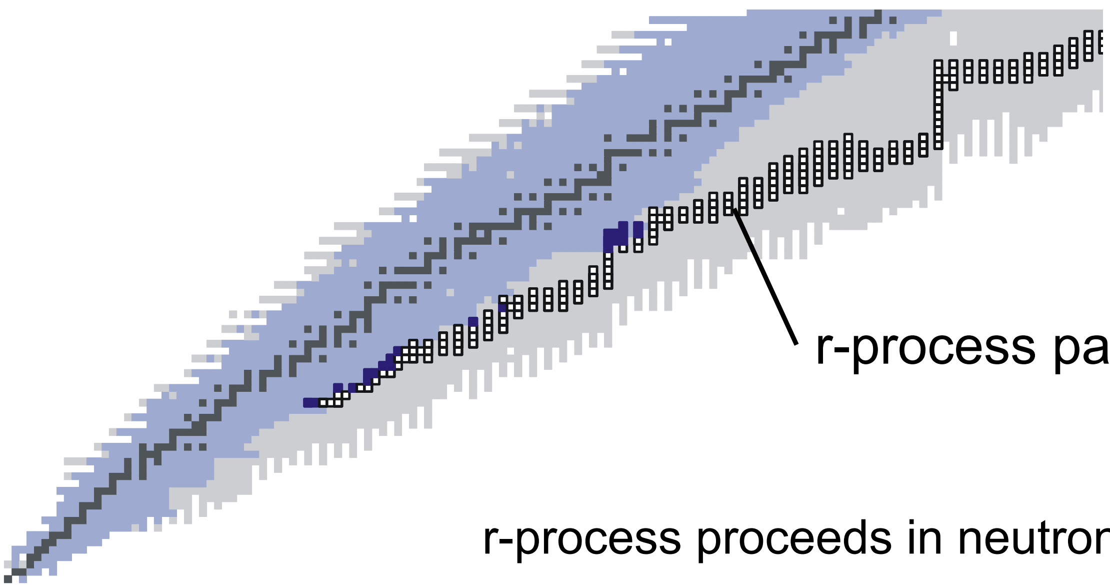
- A quantitative model of atomic nuclei with predictive power does not yet exist



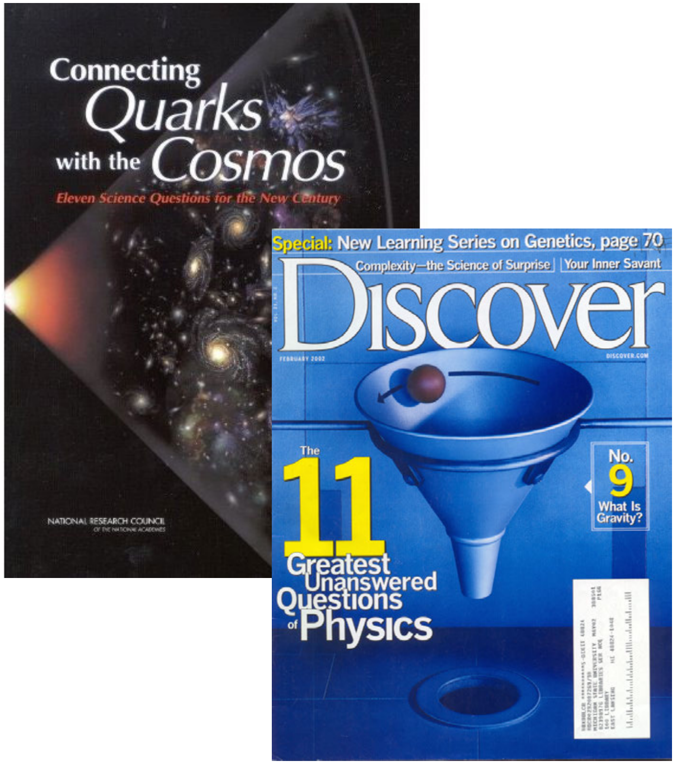
The neutron-rich limit is only known up to oxygen

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?

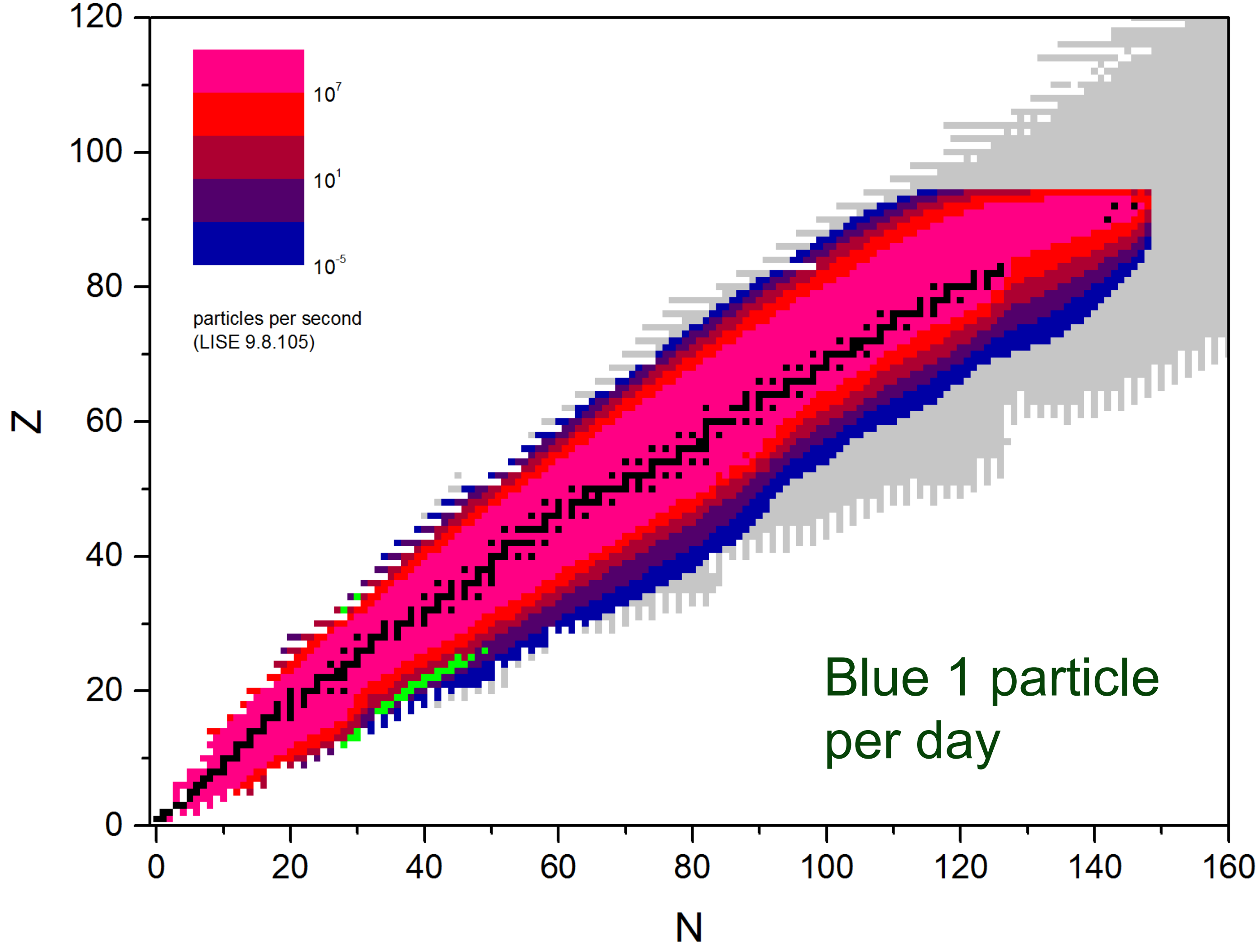


r-process path



r-process proceeds in neutron-rich nuclei

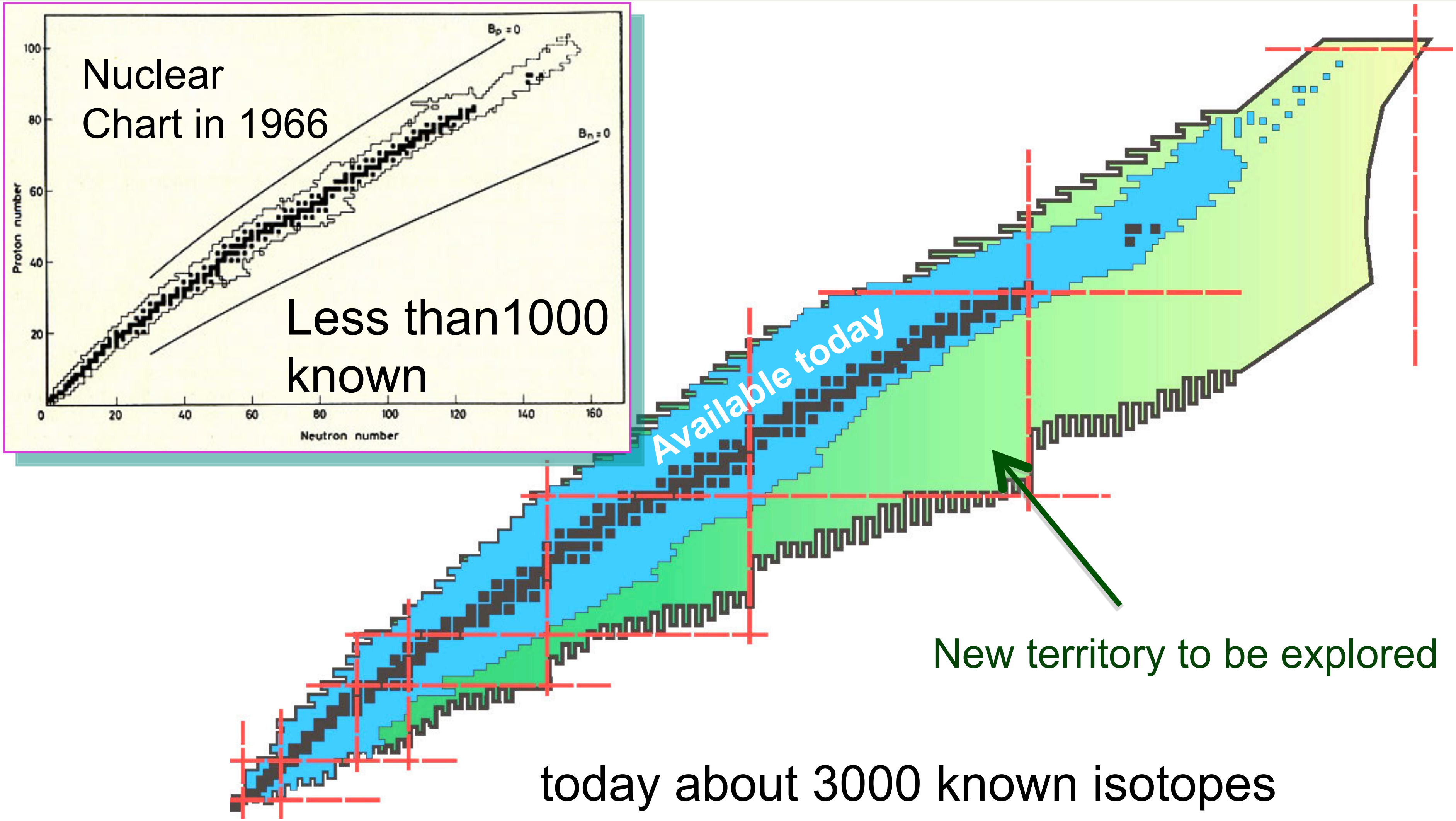
FRIB projected production rates



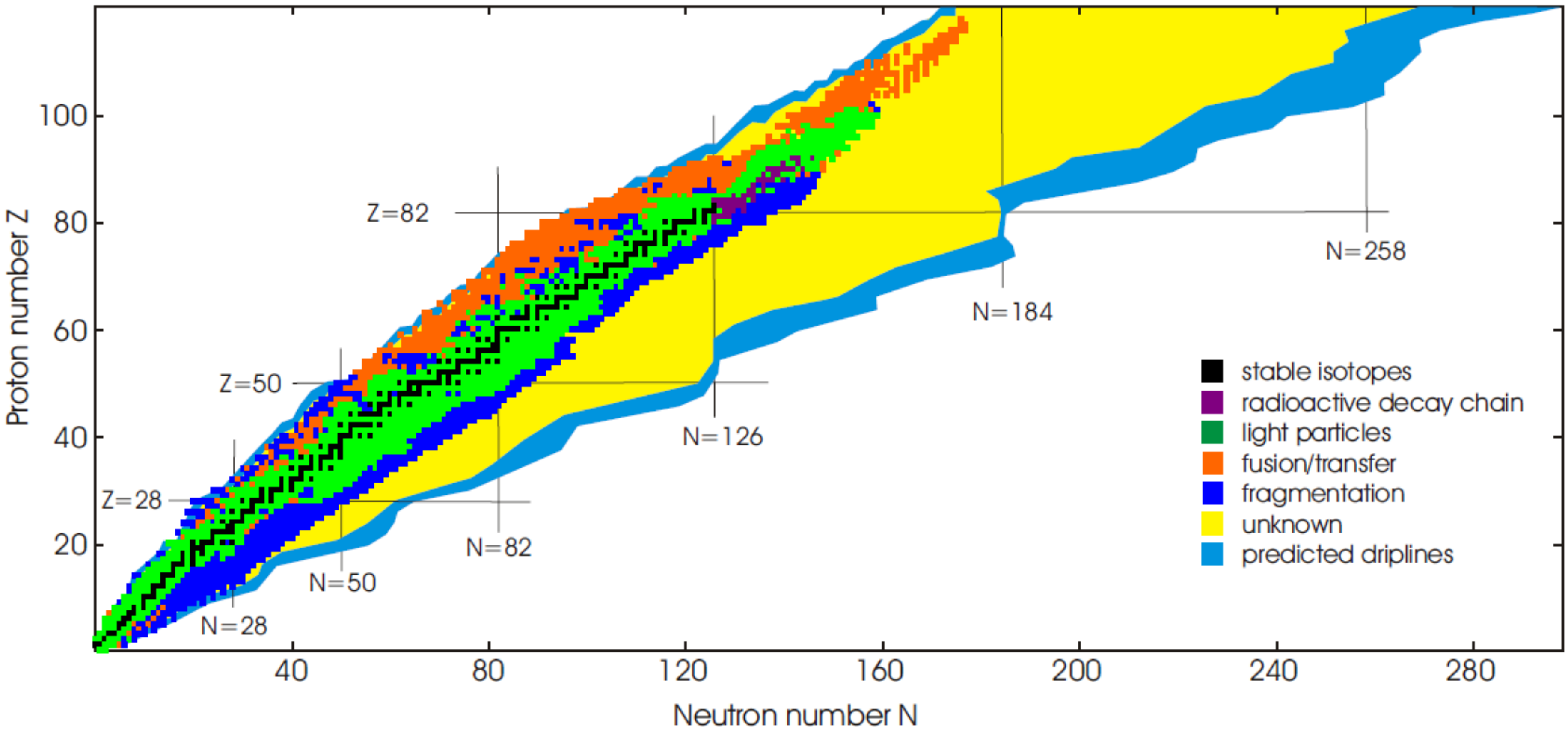
Blue 1 particle per day

O. Tarasov, T. Baumann

Discovery potential

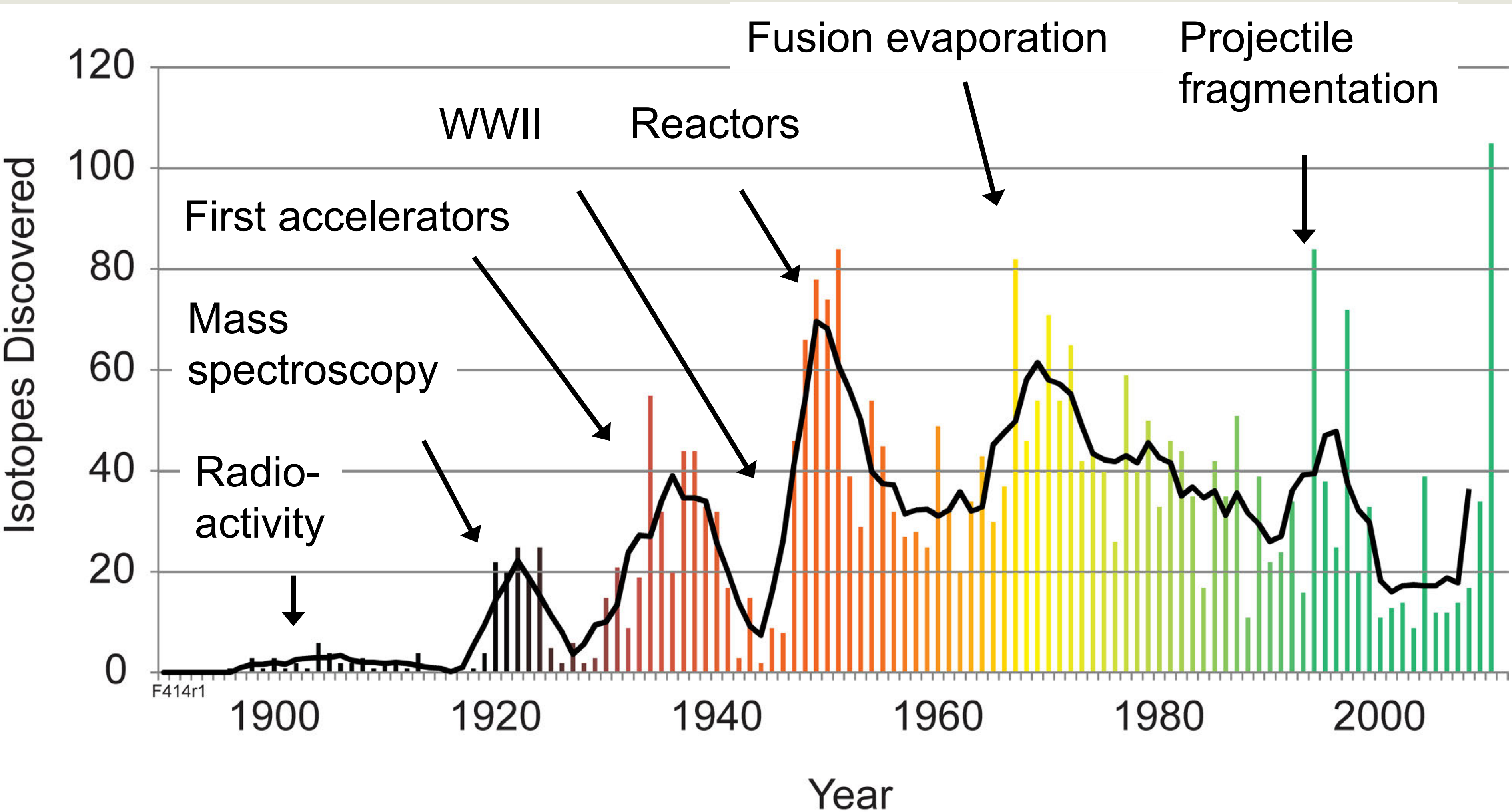


How many more nuclides are there?



7000 bound nuclide should exist (Erler *et al.*,Nature 486 (2012) 509)

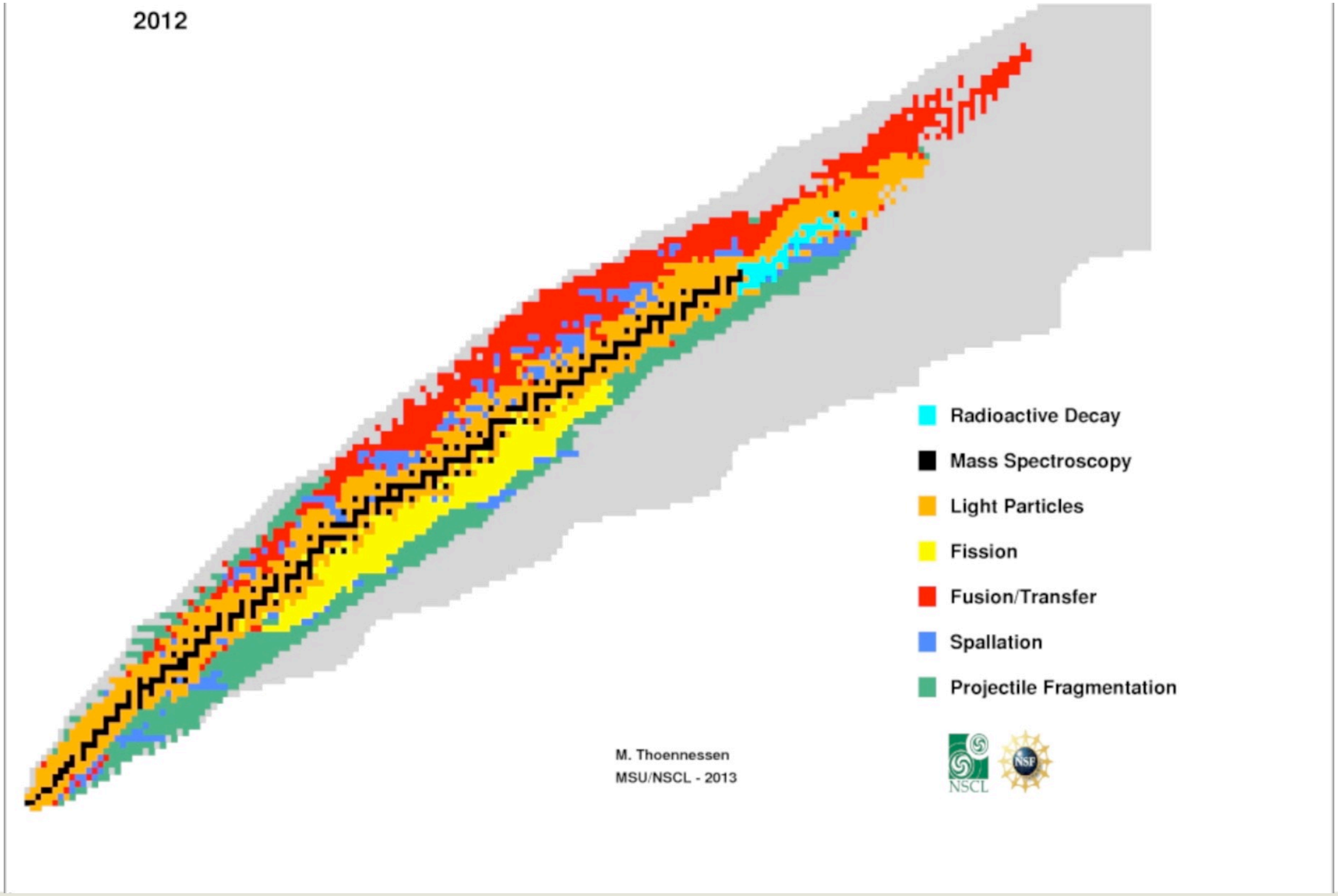
Discoveries are driven by new technologies



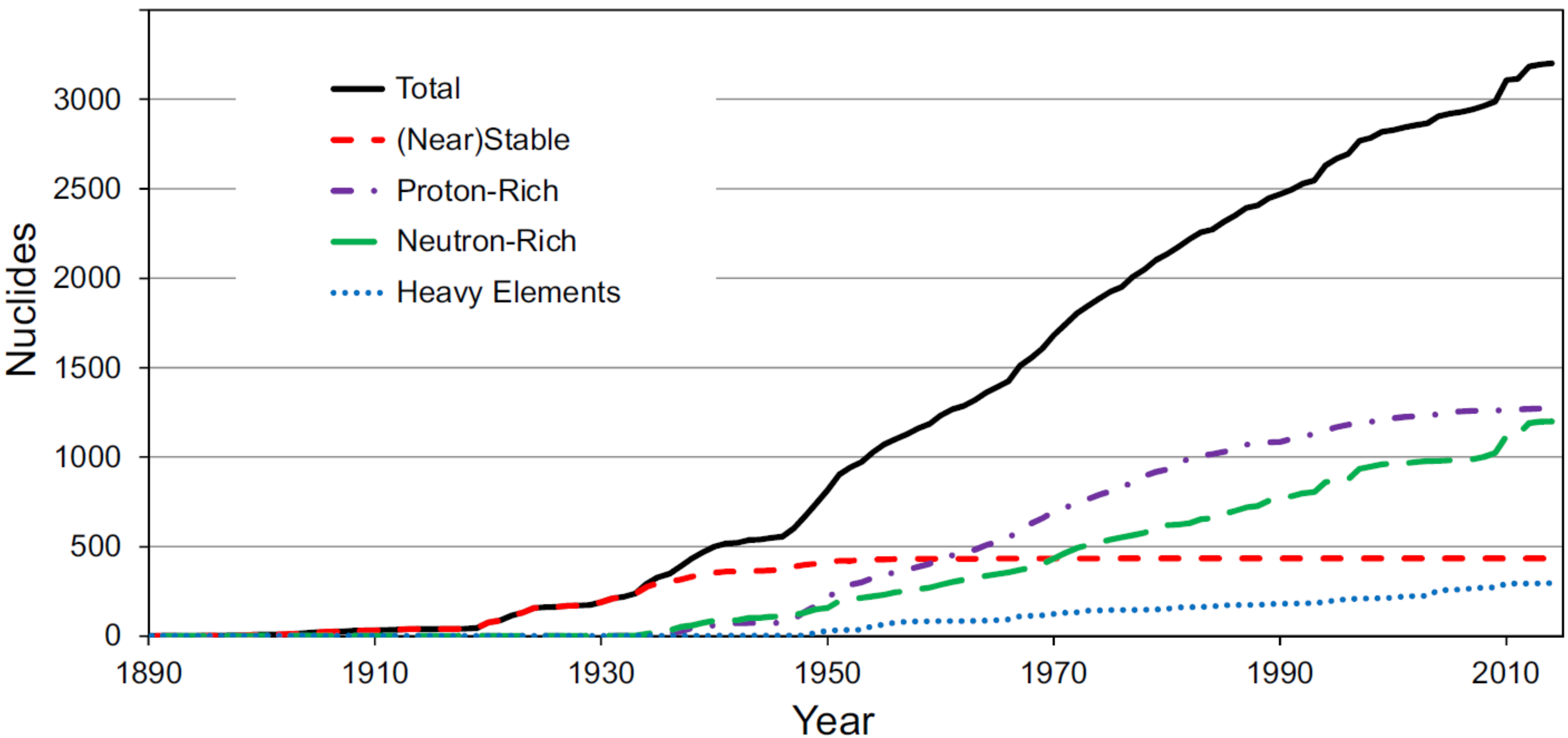
M. T. and B.M. Sherrill, Nature 473 (2011) 25

Timeline Movie

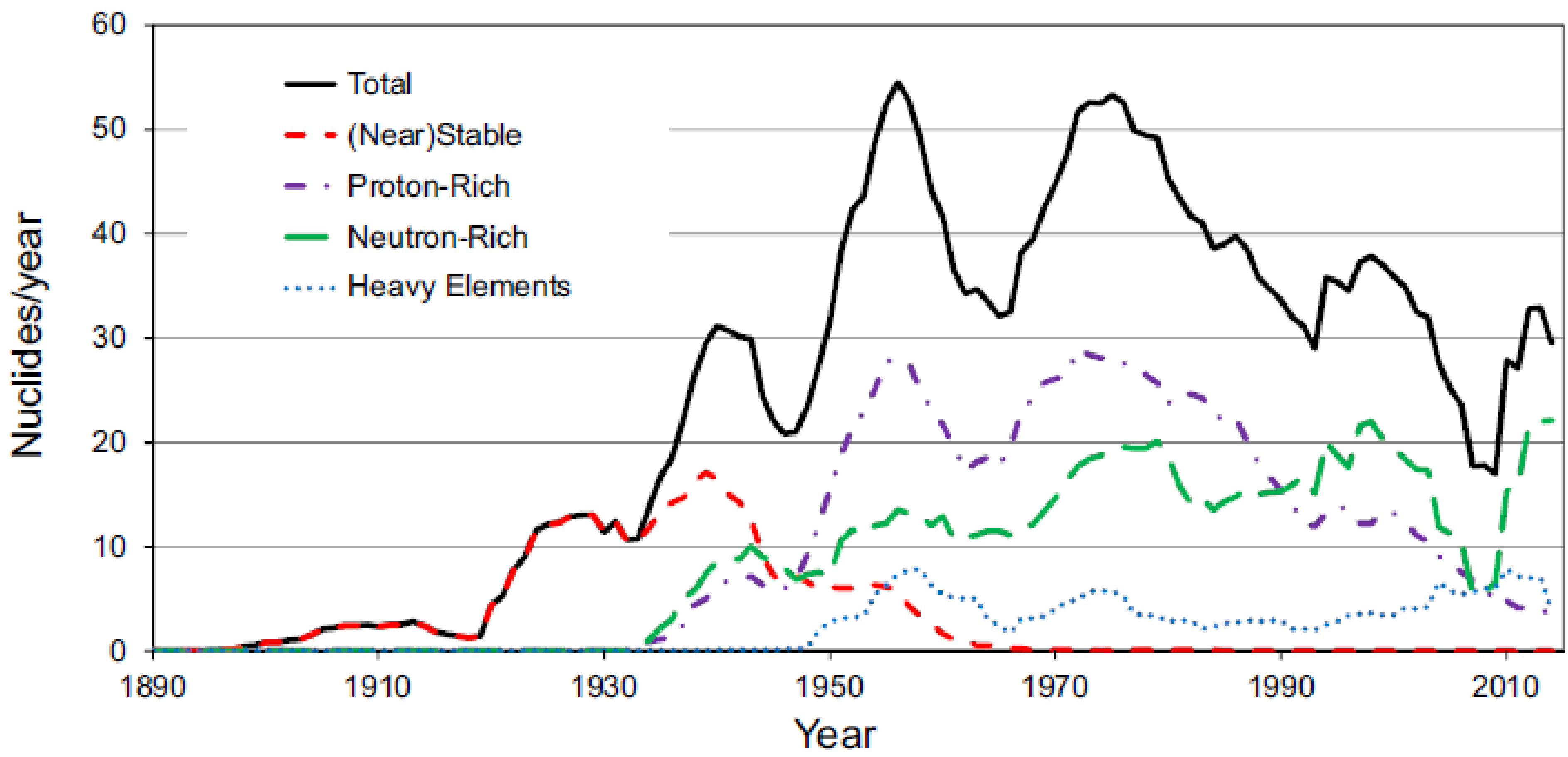
http://www.nscl.msu.edu/~thoennes/isotopes



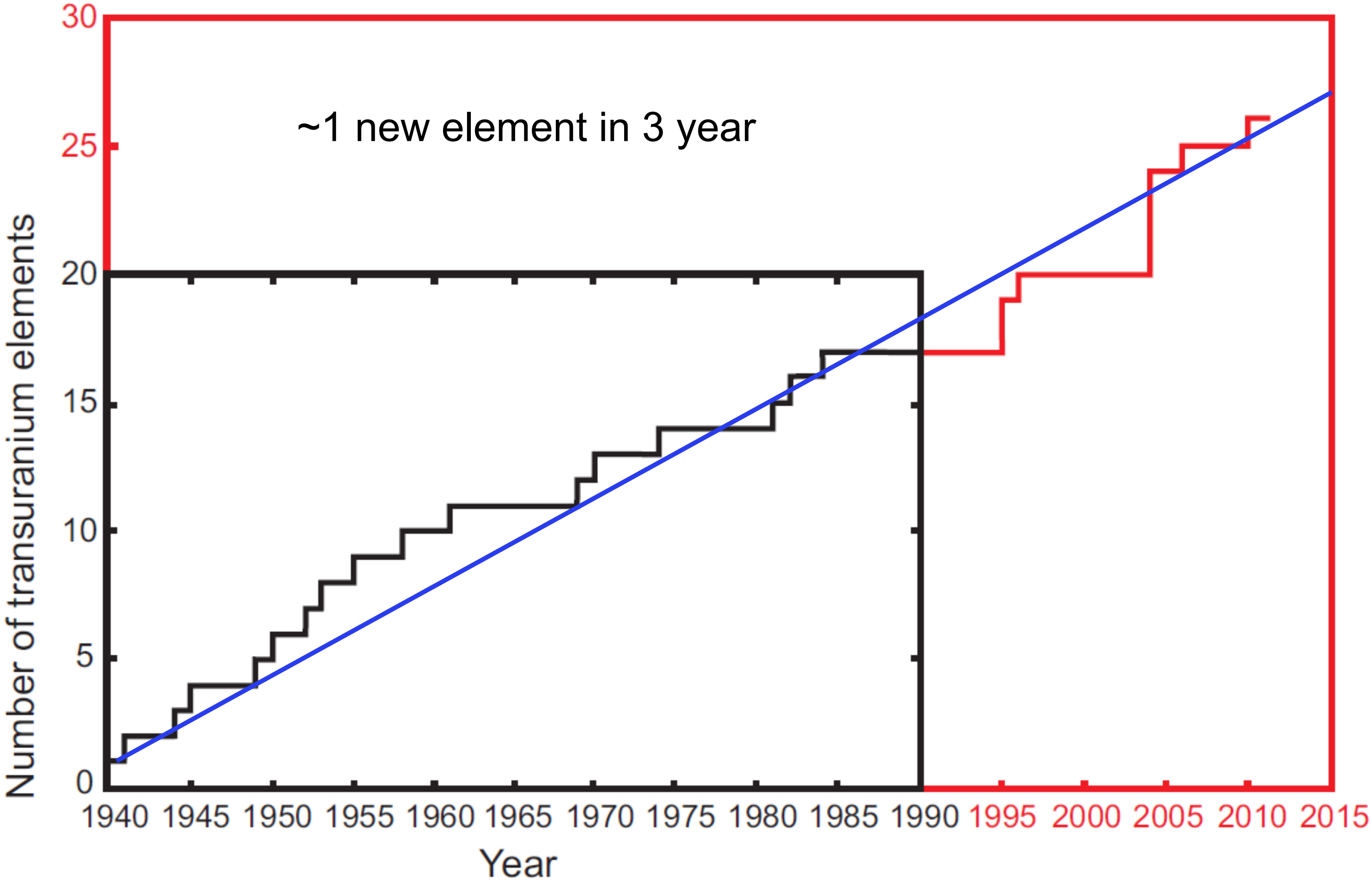
Known isotopes



Five-year running average



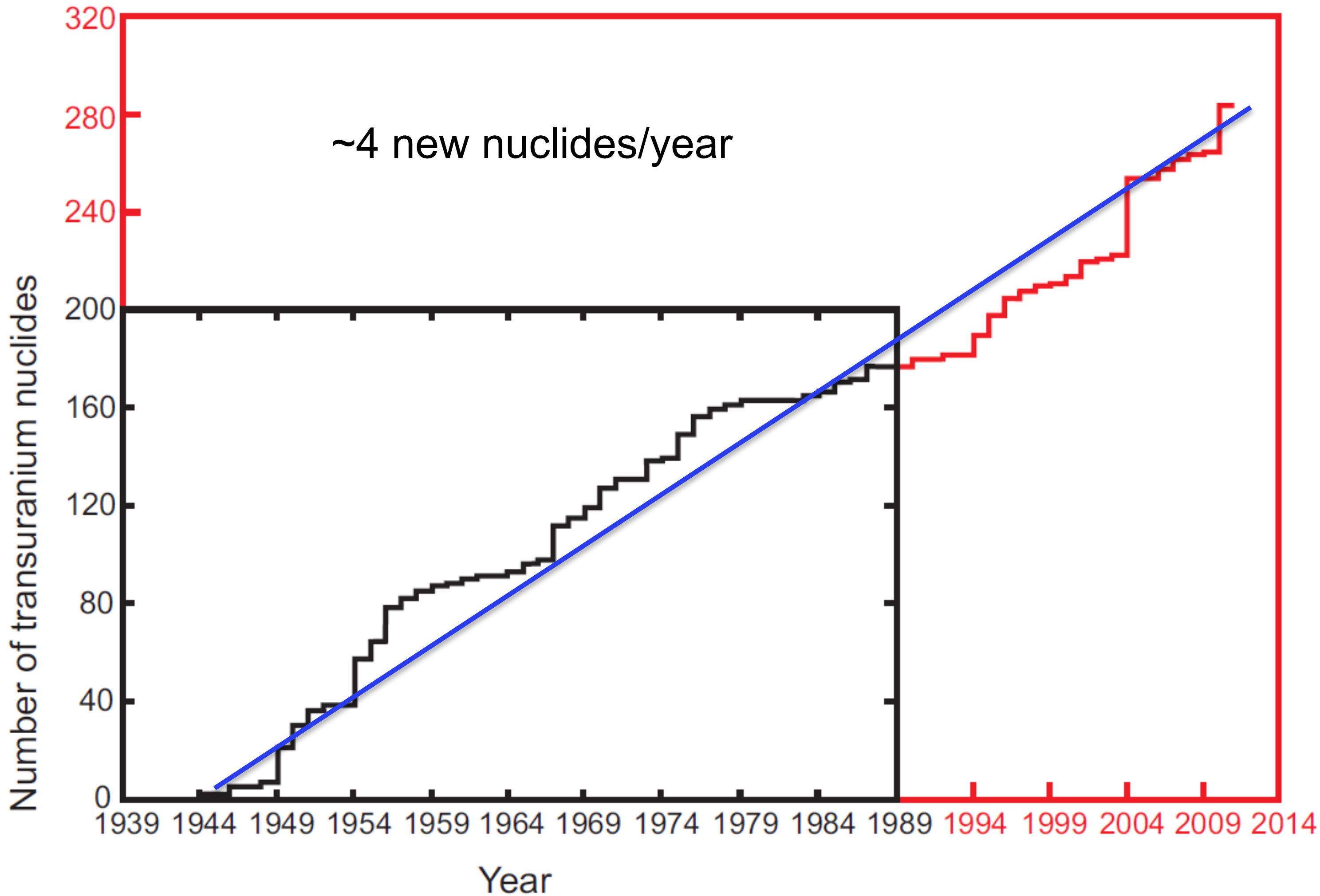
Discovery of superheavy elements



National Science Foundation
Michigan State University

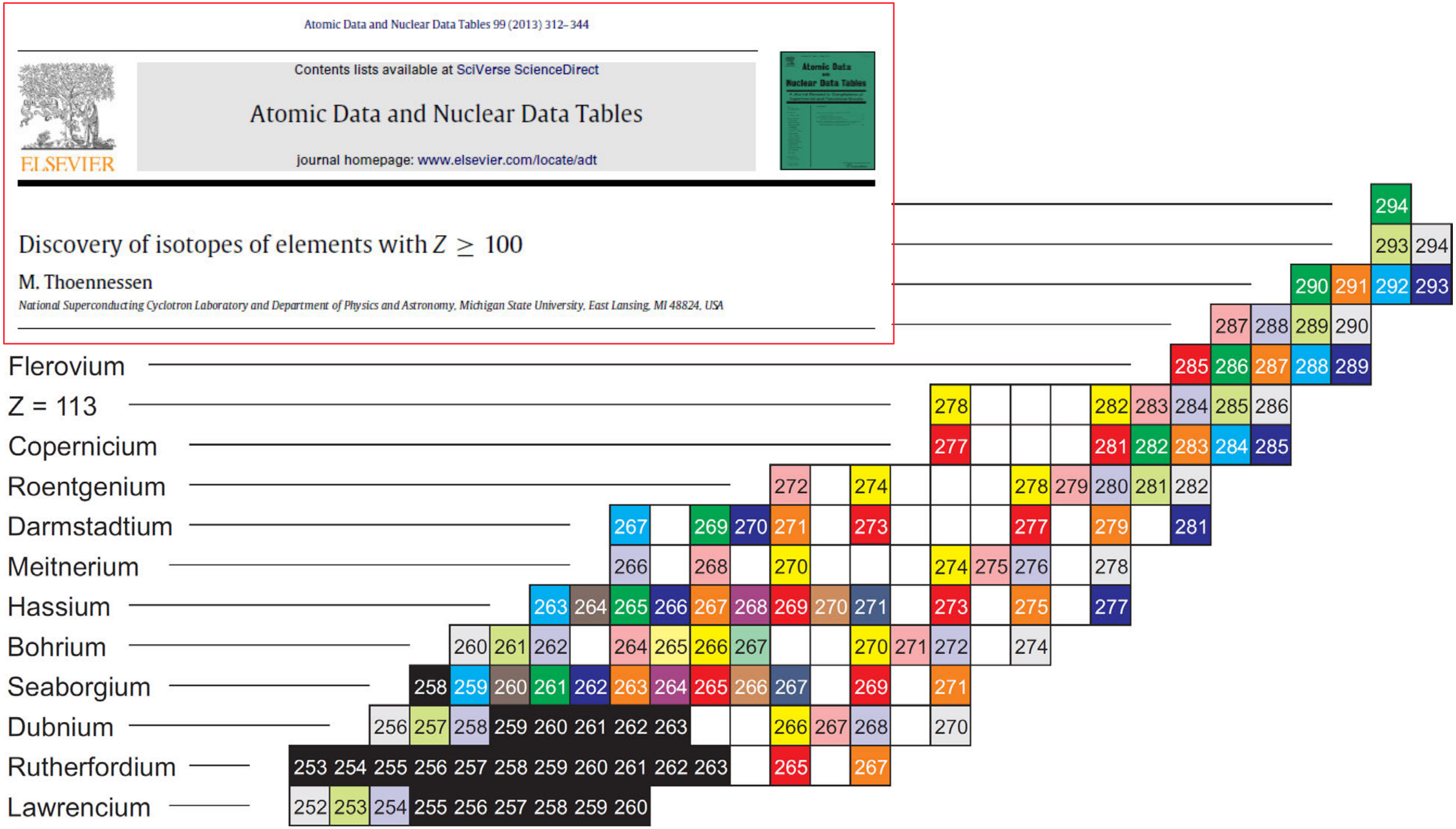
G. T. Seaborg and W. D. Loveland, “The elements beyond uranium", Wiley, New York, New York (1990)

Discovery of super heavy nuclides

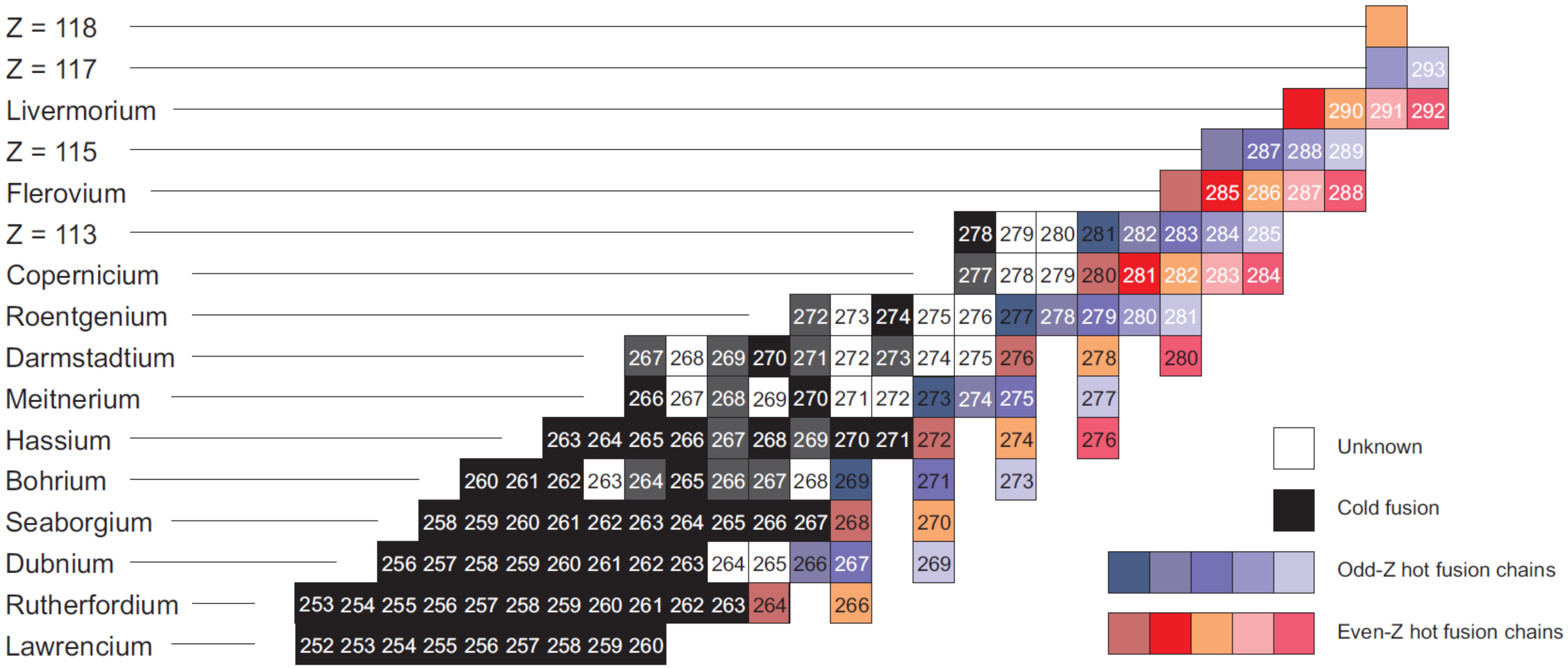


G. T. Seaborg and W. D. Loveland, “The elements beyond uranium", Wiley, New York, New York (1990)

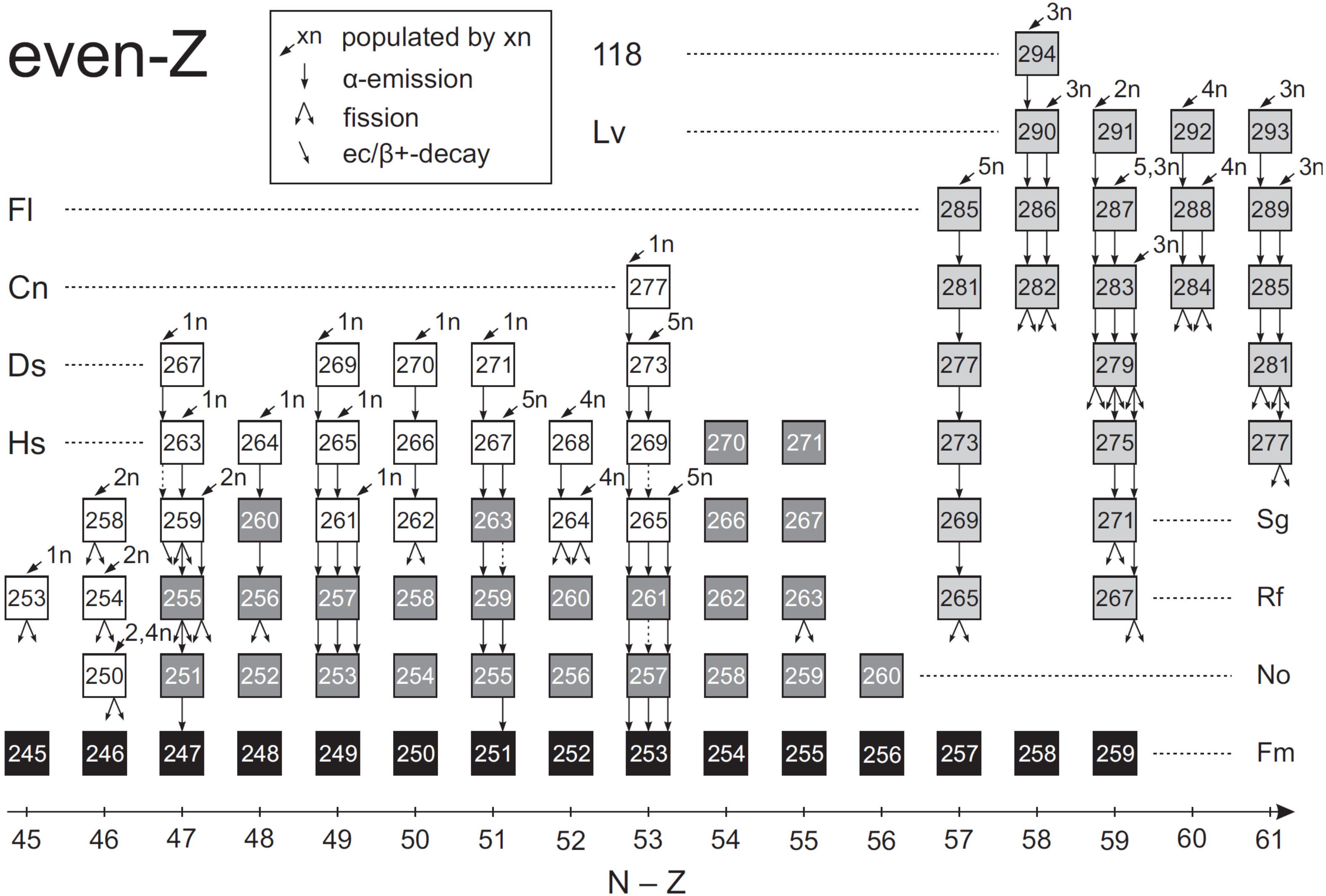
Isotope discovery project



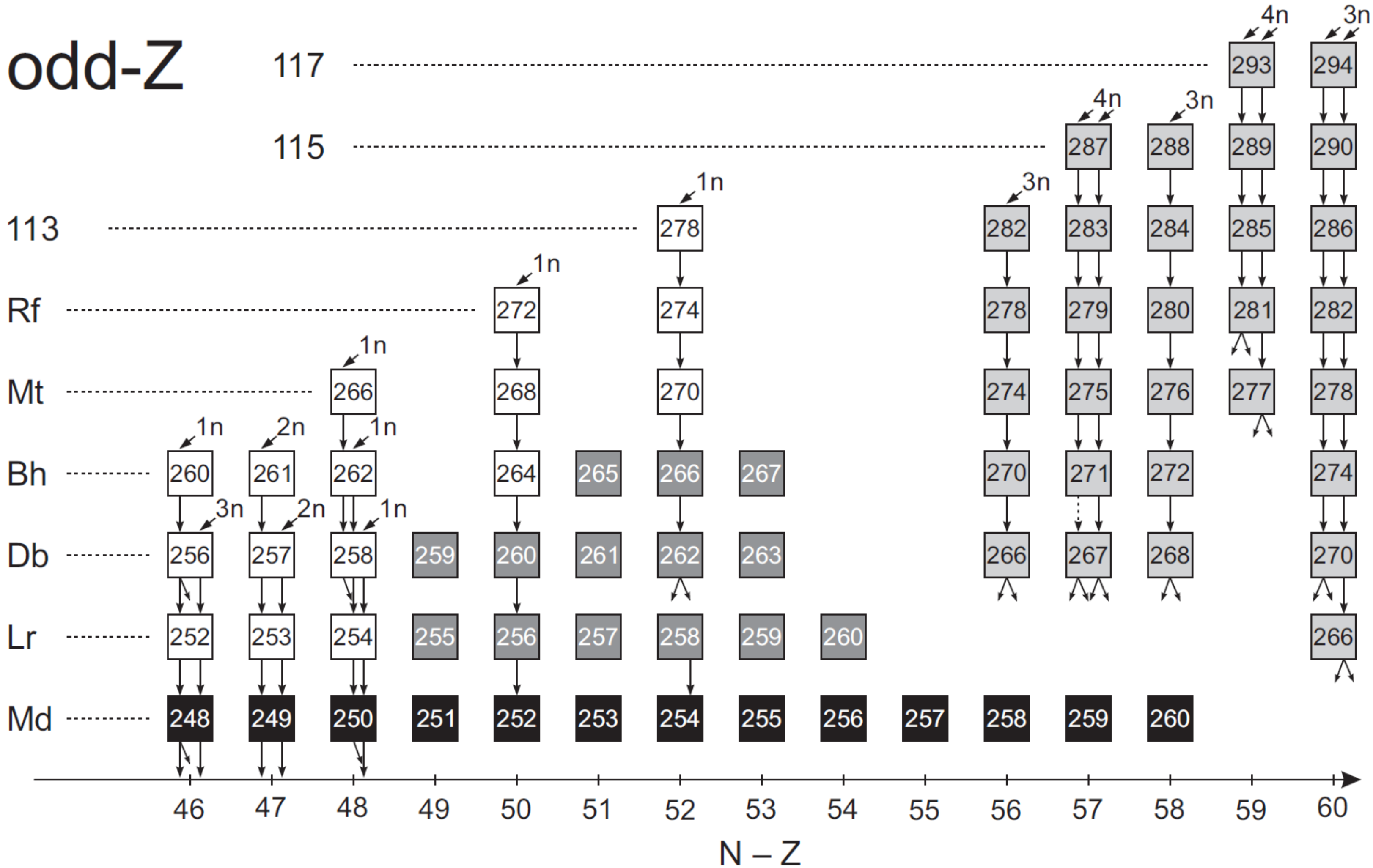
Connect hot and cold fusion results



Z versus N–Z

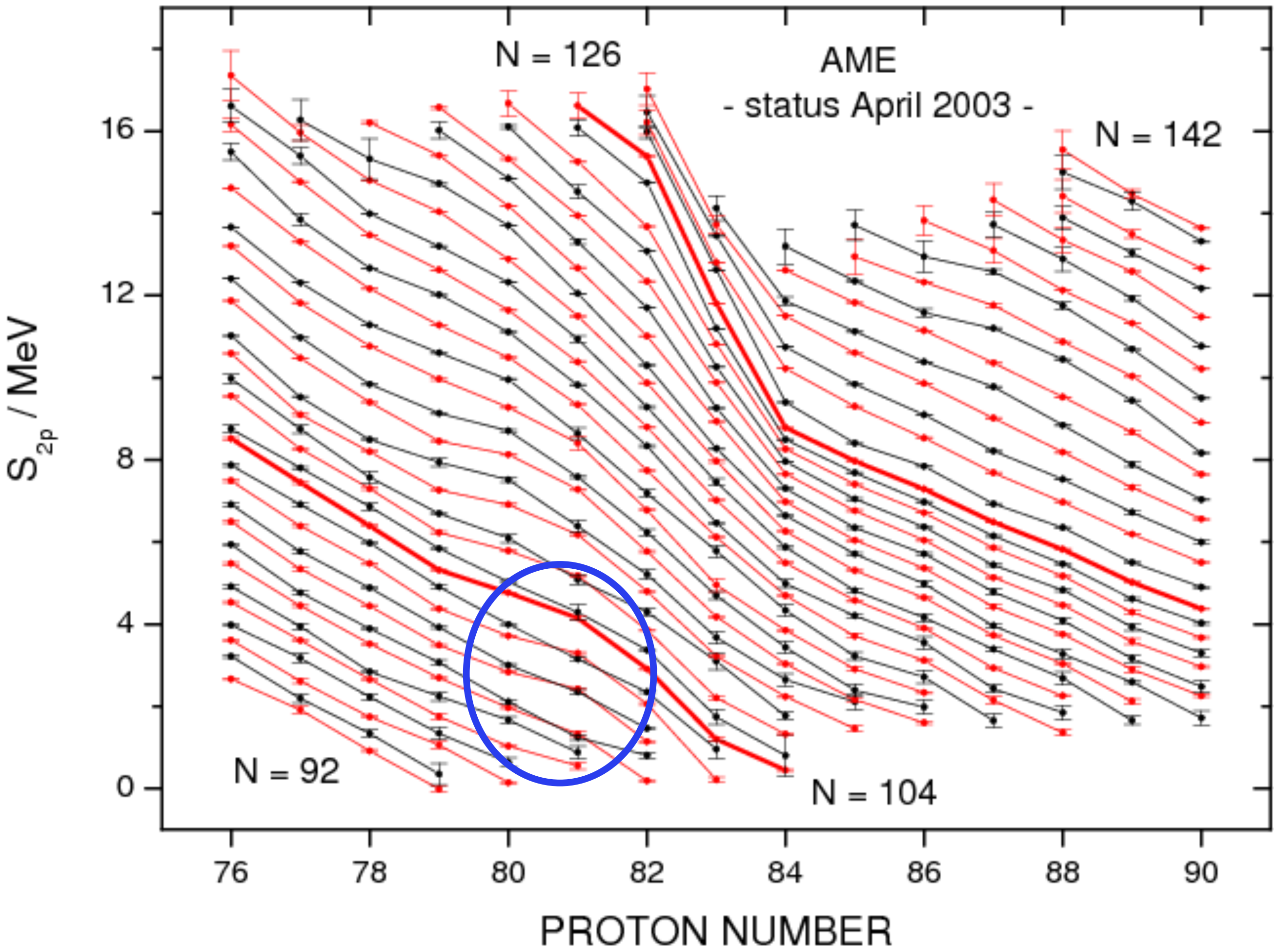

even-Z
xn populated by xn
α-emission
fission
ec/β+-decay
118
294
Lv
290 291 292 293
Fl
285 286 287 288 289
Cn
277 281 282 283 284 285
Ds
267 269 270 271 273 277 279 281
Hs
263 264 265 266 267 268 269 270 271 273 275 277
258 259 260 261 262 263 264 265 266 267 269 271
Sg
253 254 255 256 257 258 259 260 261 262 263 265 267
Rf
250 251 252 253 254 255 256 257 258 259 260
No
245 246 247 248 249 250 251 252 253 254 255 256 257 258 259
Fm
1n 2n 3n 4n 5n 5,3n 2,4n
45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61
N – Z

Z versus N–Z

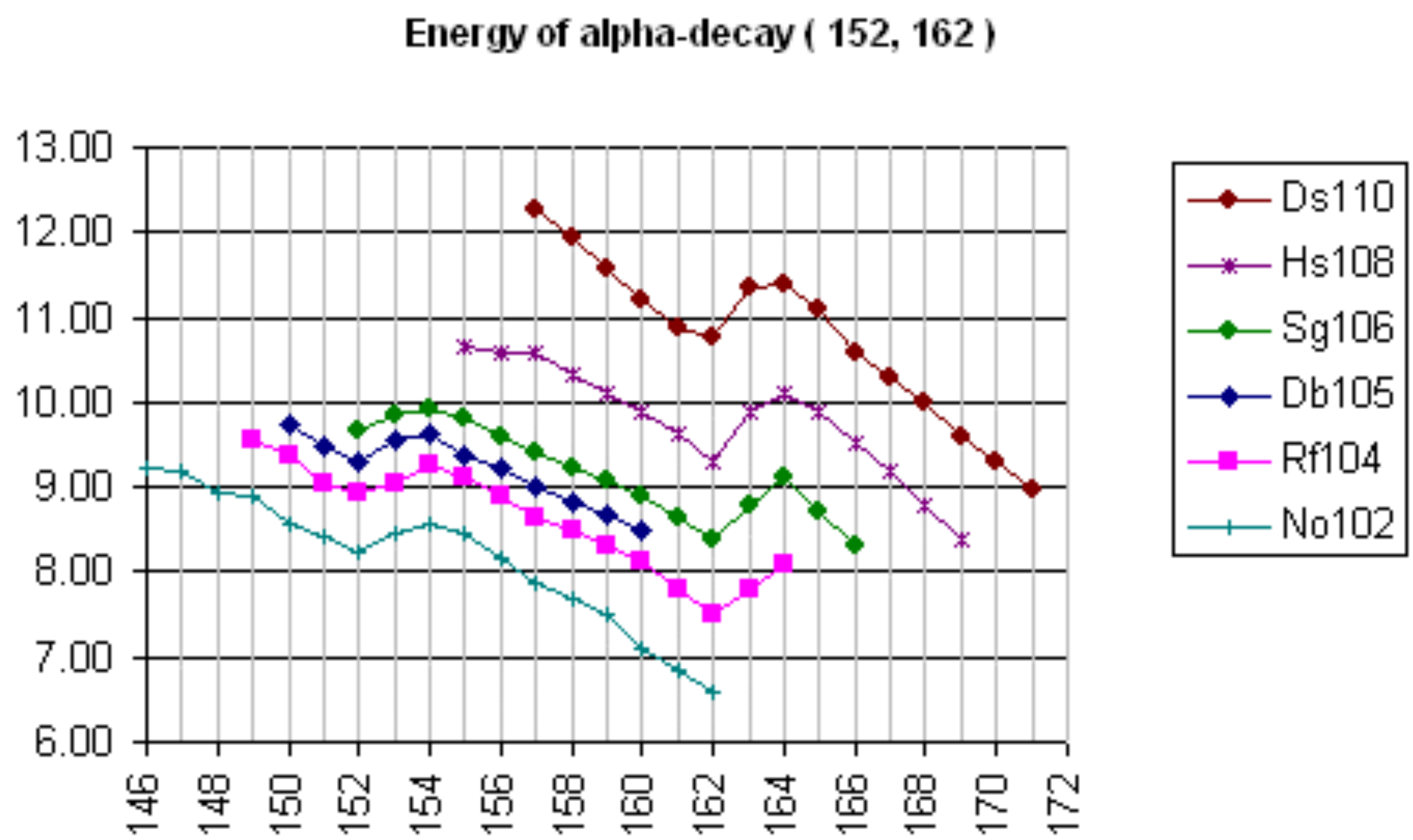


odd-Z
117
115
113
Rf
Mt
Bh
Db
Lr
Md
4n 3n
293 294
4n 3n
287 288 289 290
1n 3n
278 282 283 284 285 286
1n
272 274 278 279 280 281 282
1n
266 268 270 274 275 276 277 278
1n 2n 1n
260 261 262 264 265 266 267 270 271 272 274
3n 2n 1n
256 257 258 259 260 261 262 263 266 267 268 270
252 253 254 255 256 257 258 259 260 266
248 249 250 251 252 253 254 255 256 257 258 259 260
46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
N – Z

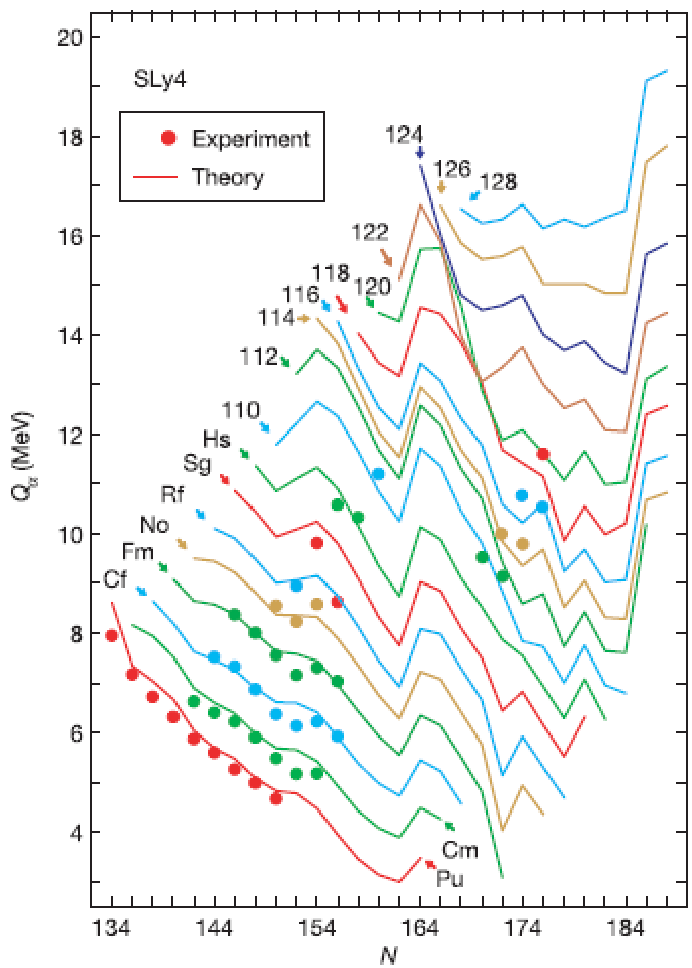
Trends and systematics: S_{2p}

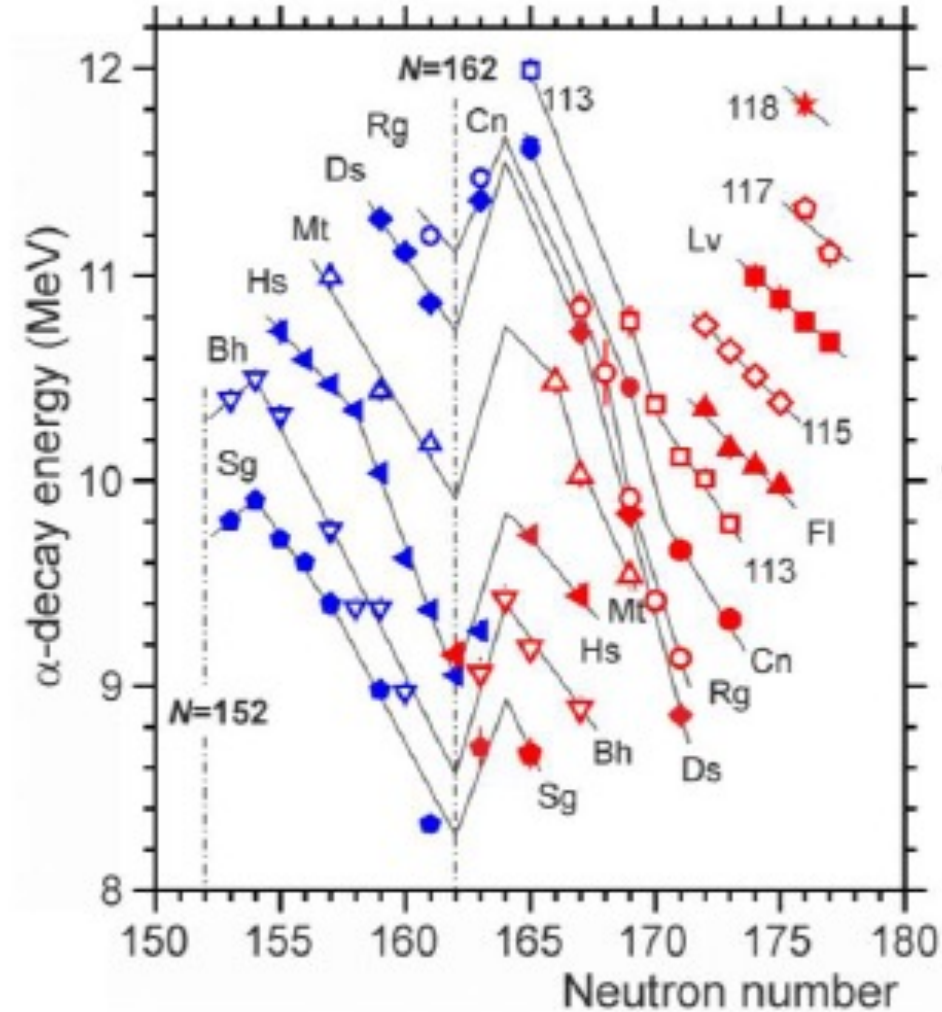


Trends and systematics: E_{alpha}



Superheavies: E_{alpha}

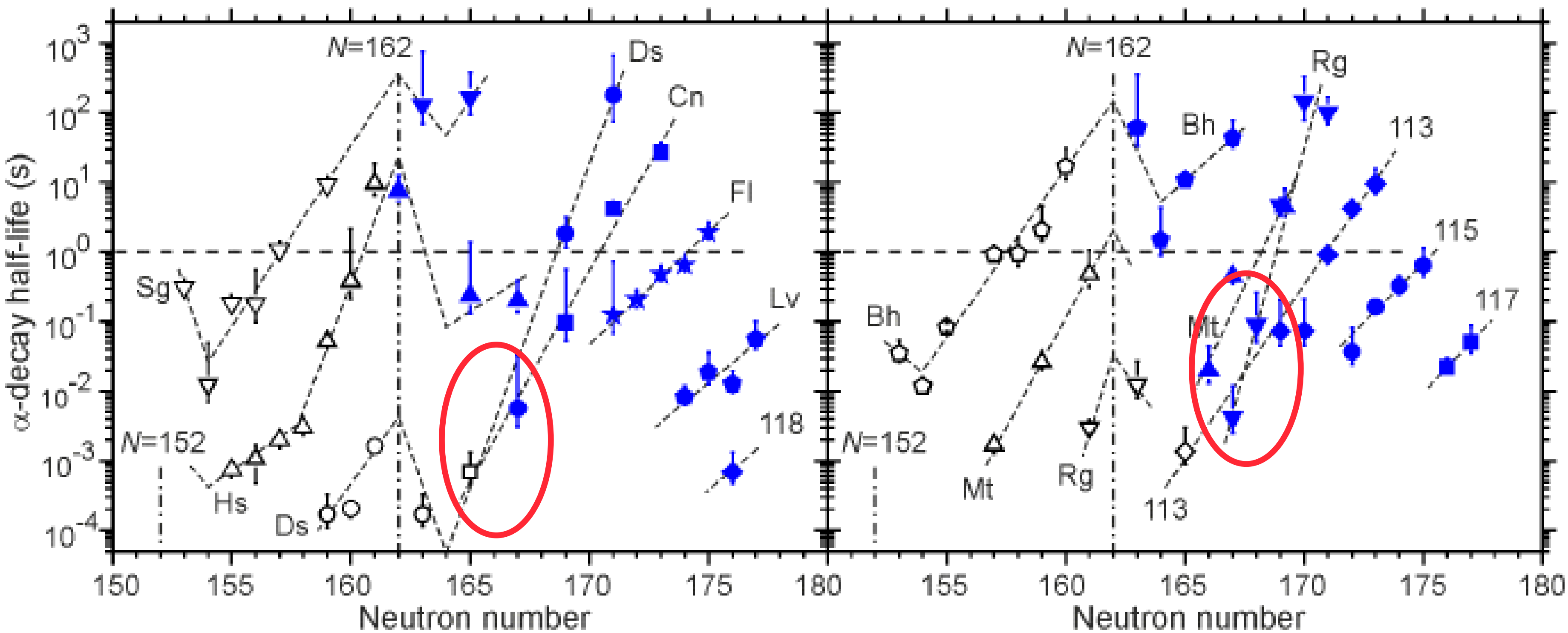




Cwiok, Heenen, Nazarewicz, Nature 433 (2005) 705

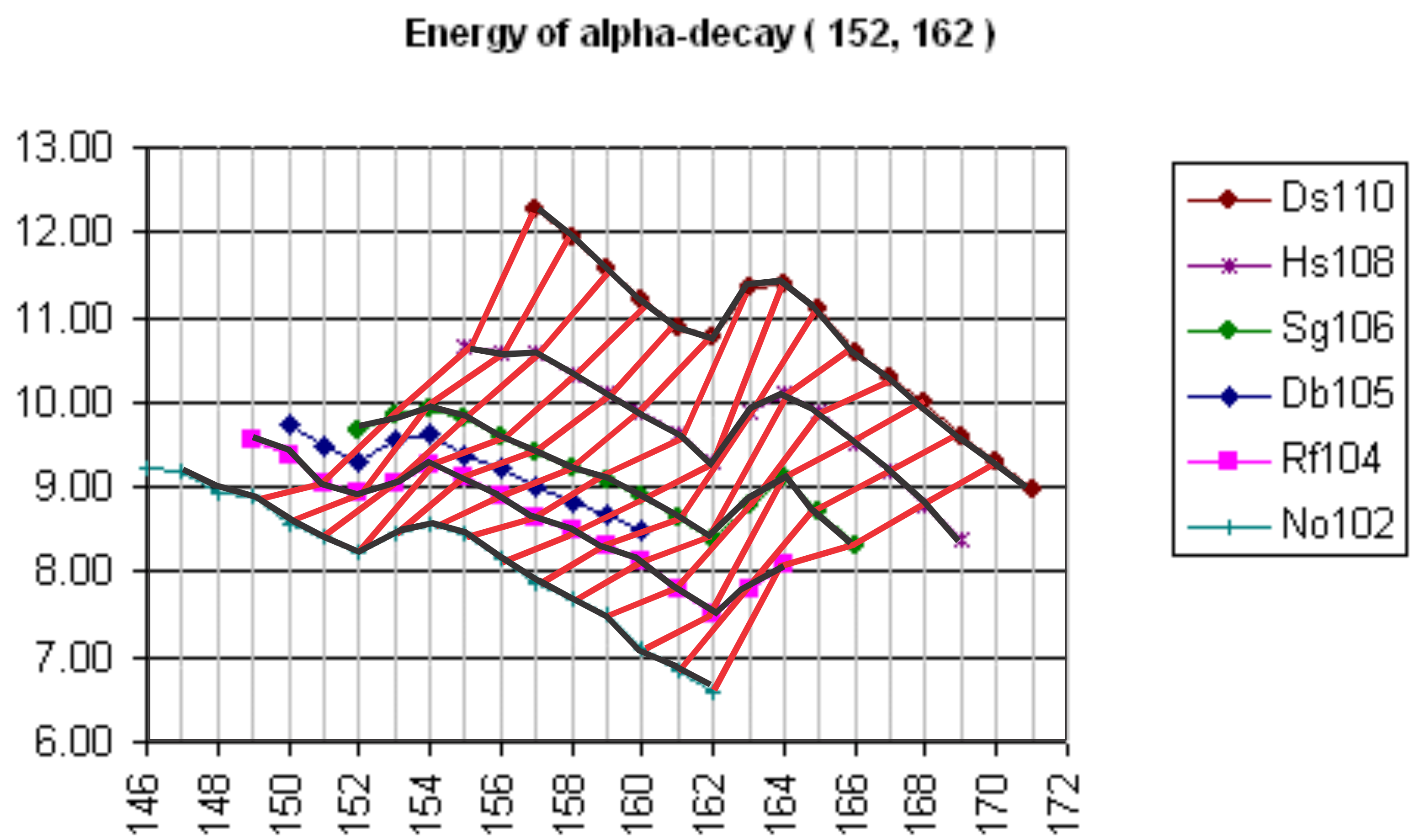
Utyonkov and Oganessian, Nucl. Phys. A

Superheavies: $T_{1/2}$

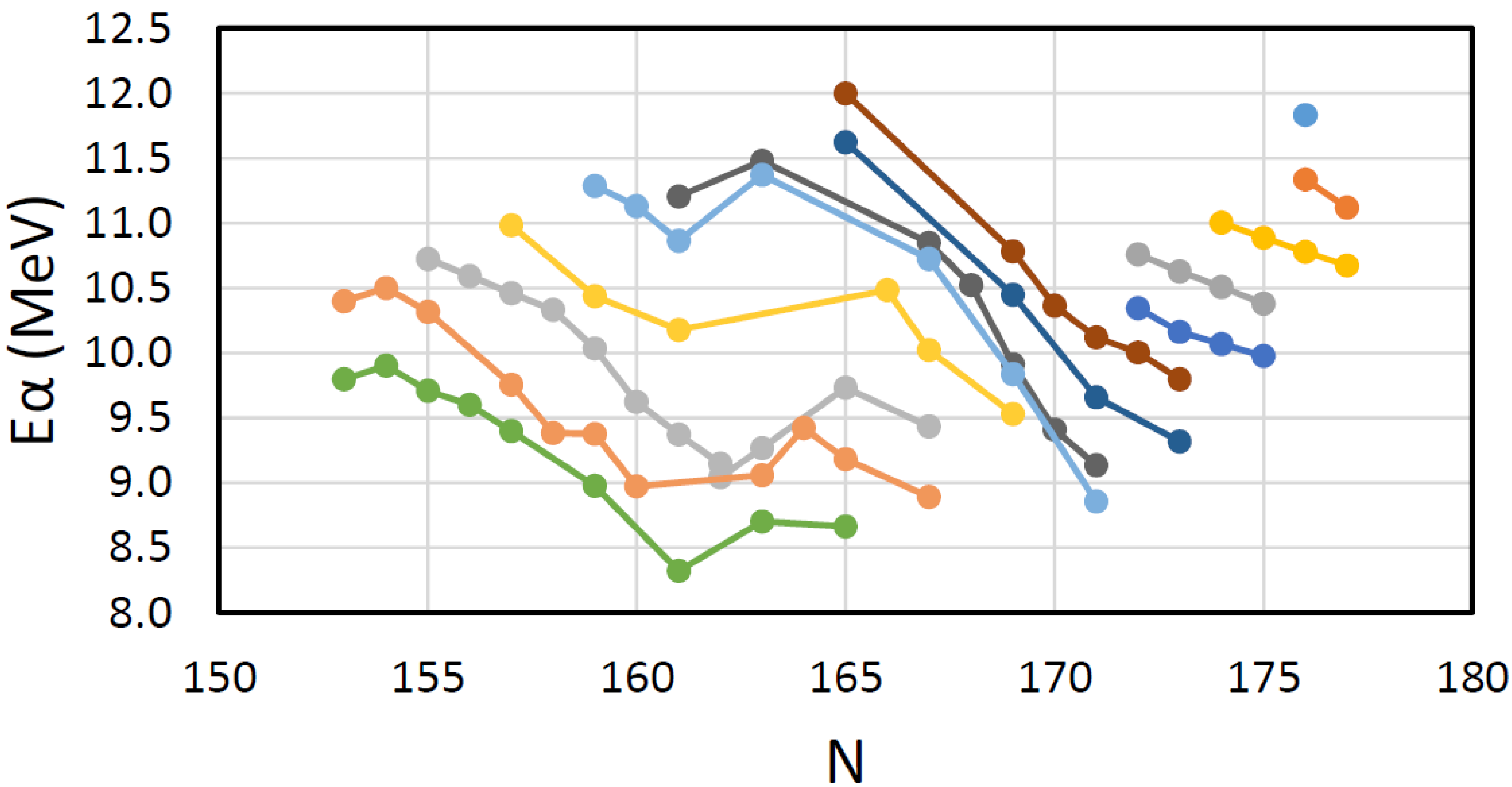


Utyonkov and Oganessian, Nucl. Phys. A

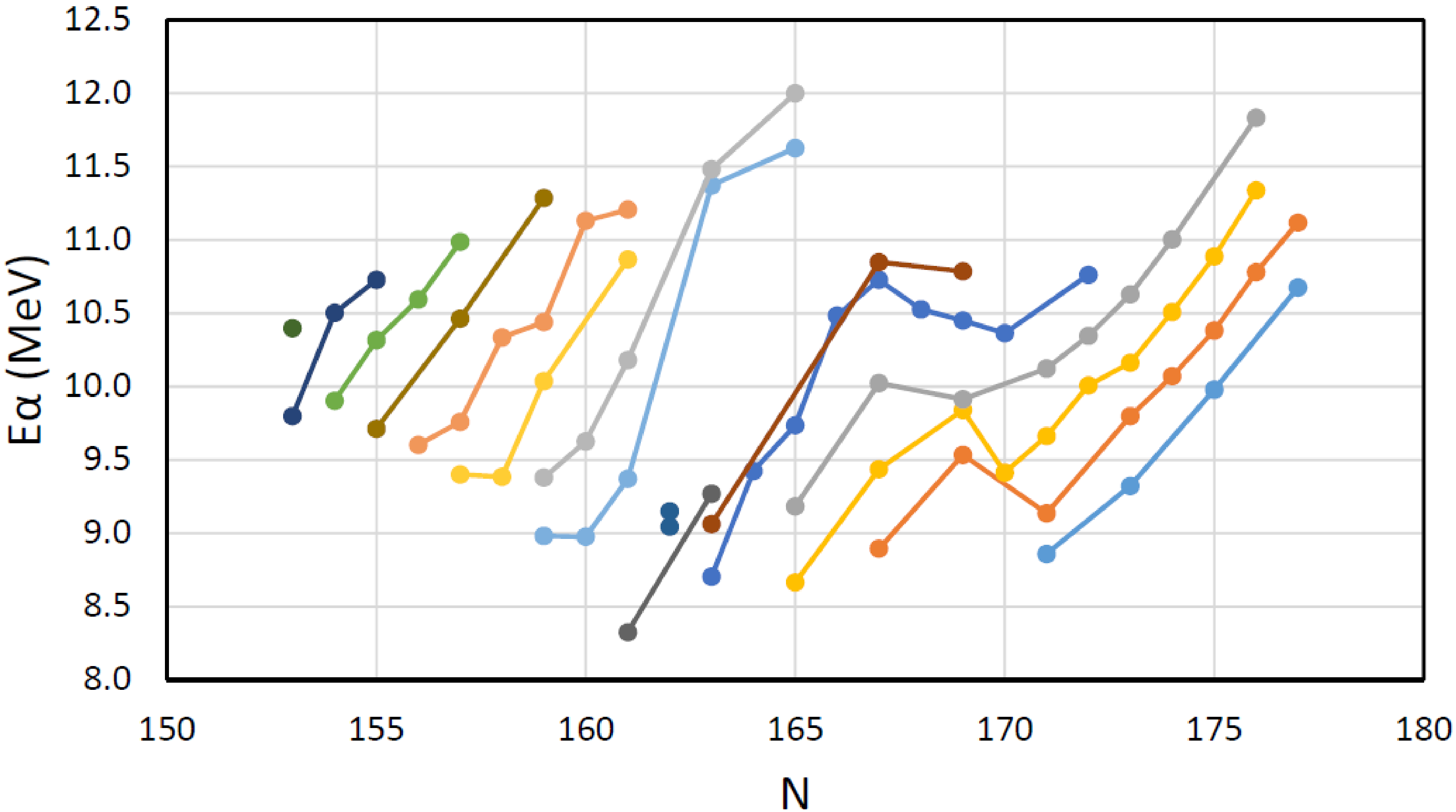
Trends and systematics: N–Z E_{alpha}



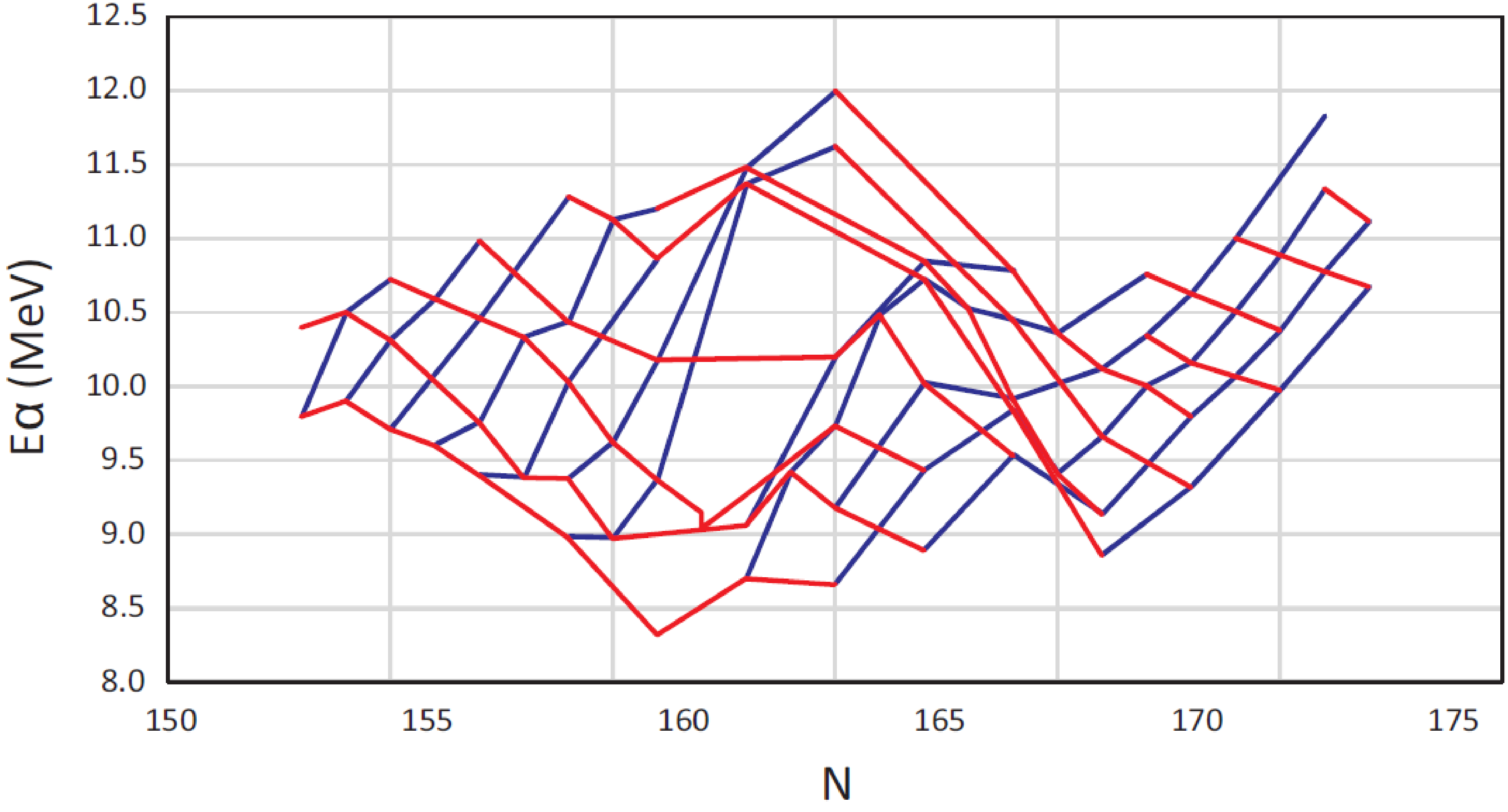
Superheavies lines of constant Z: E_{alpha}



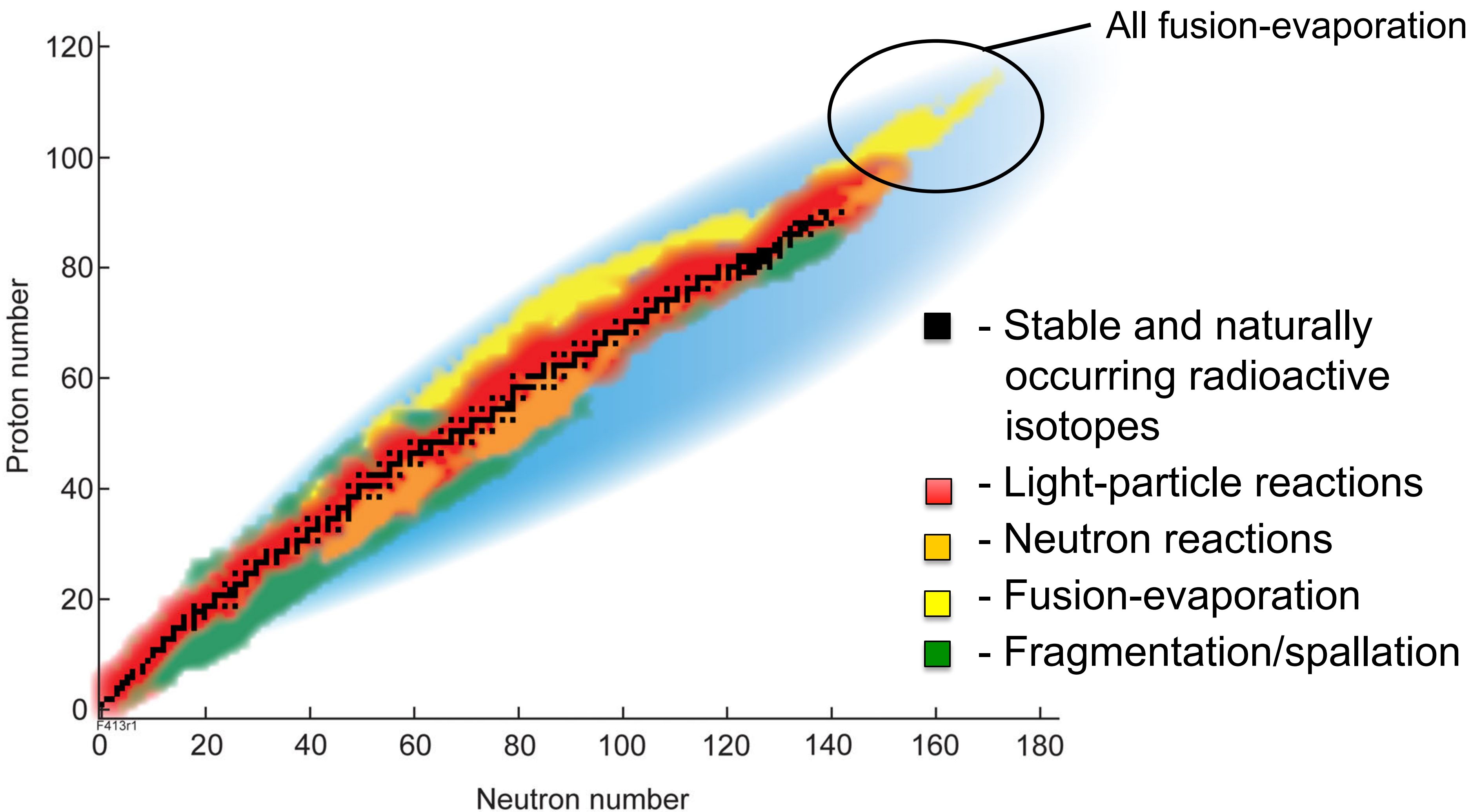
Superheavies lines of constant N–Z: E_{alpha}



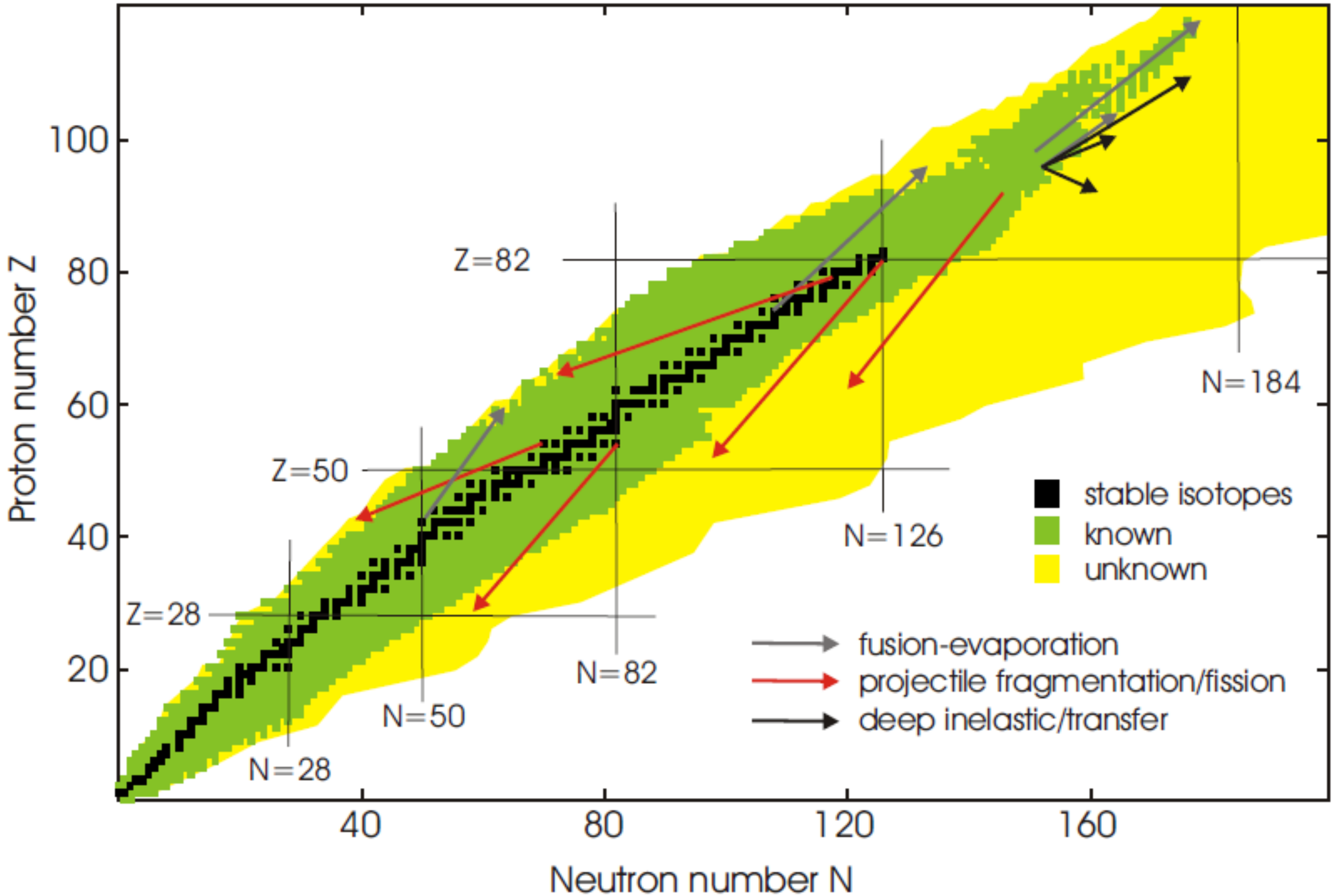
Lines of constant N–Z



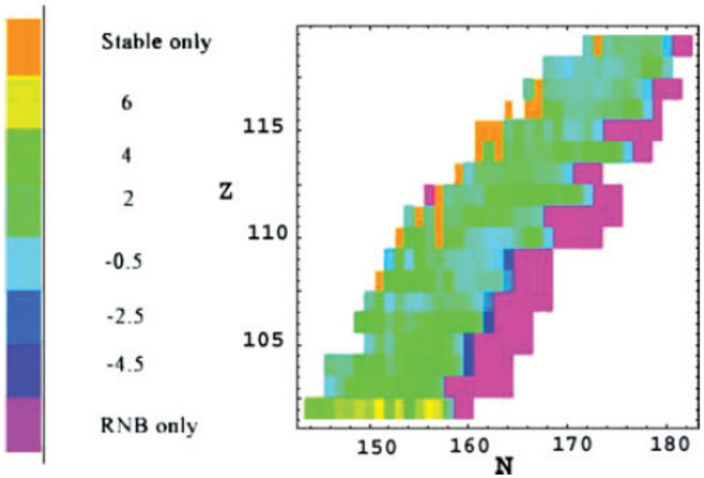
Production methods



How can new nuclides be discovered?

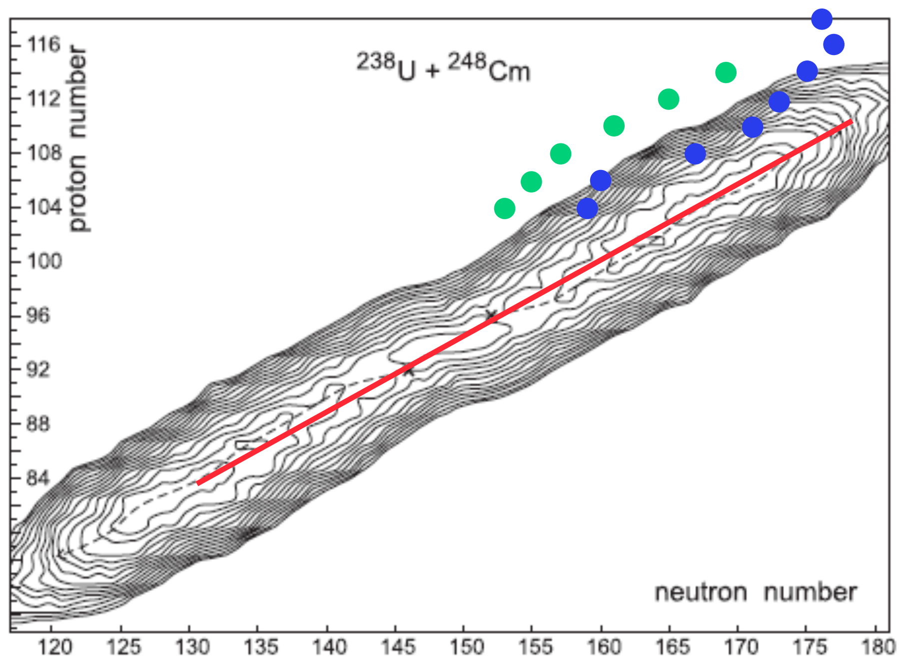


How produce new superheavy nuclides



fusion with radioactive beams

W. Loveland,
Phys. Rev. C 76 (2007) 014612



- cold fusion
- hot fusion
- multi-nucleon transfer

V. Zagrebaev and W. Greiner
Phys. Rev. C 78 (2008) 34610

Summary and outlook

- FRIB construction is on schedule:
  - Project completion June 2022
  - Early completion in December 2020
- FRIB will most likely not discover new elements
- But FRIB could reach neutron-rich isotopes of superheavy elements towards N =184
- 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