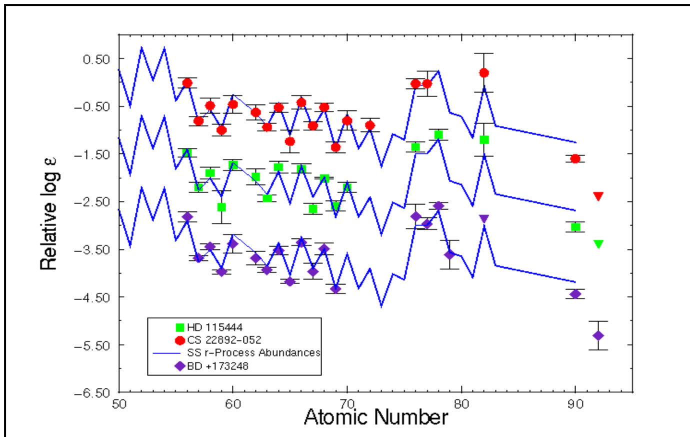
H. Schatz

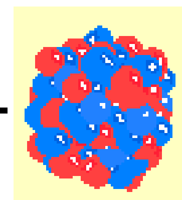
Nuclear physics in the r-process

New precision observations of r-process elements



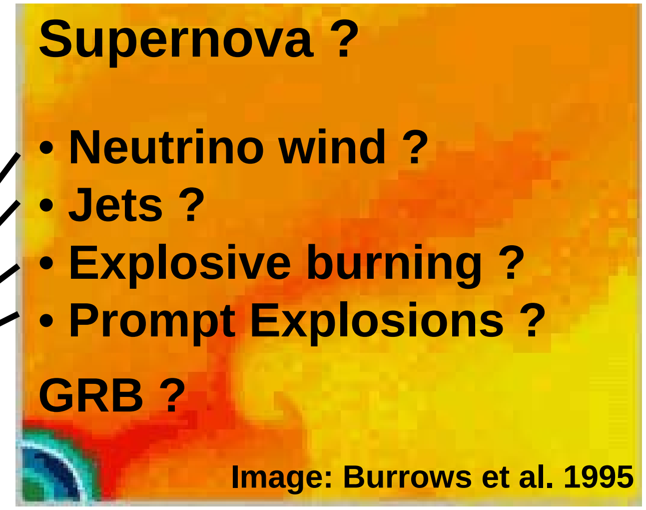
graph by J. Cowan

Nuclear Physics

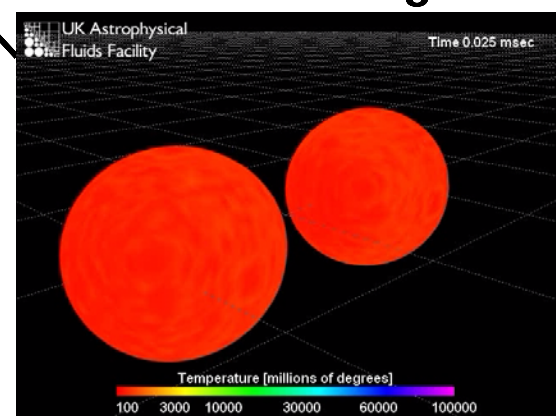


Missing link

r-process models



Neutron star mergers ?



Need nuclear physics:

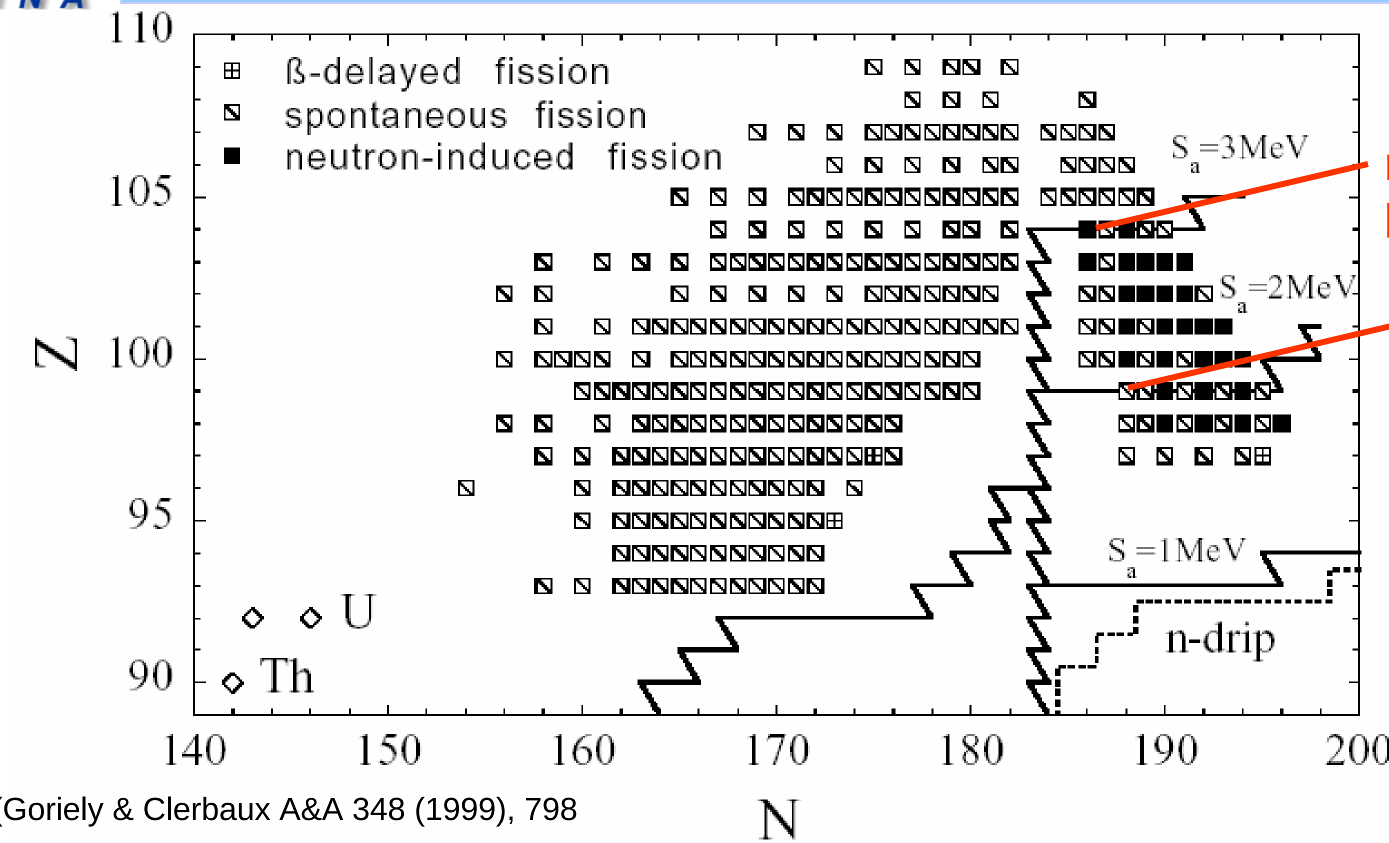
→ With abundance observations the only experimental constraint of r-process environment

→ Disentangle contributions from various s- and r-processes to observed abundances

→ Quantitative interpretation of abundance observations

Fill out in class:

The endpoint of the r-process

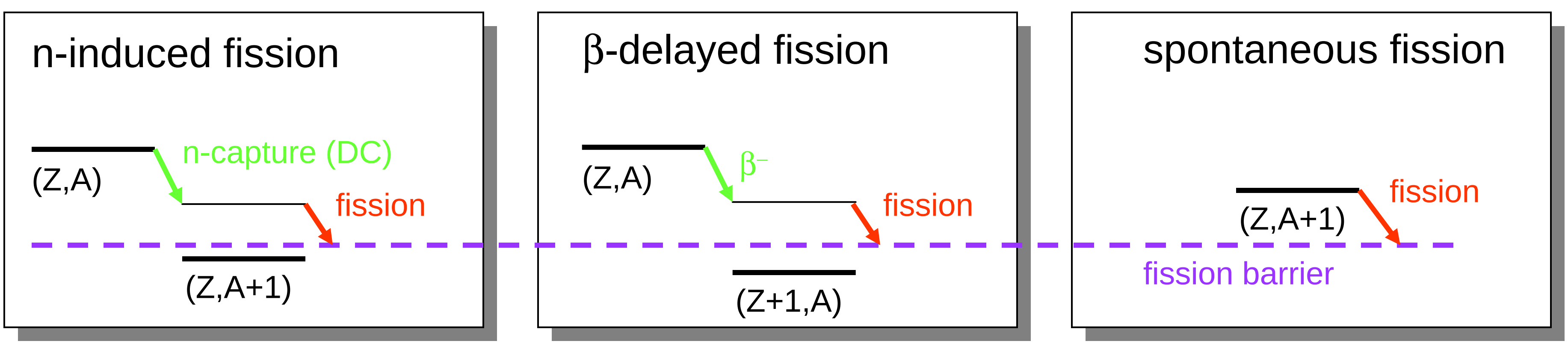


(Goriely & Clerbaux A&A 348 (1999), 798)

r-process ended by n-induced fission

or spontaneous fission

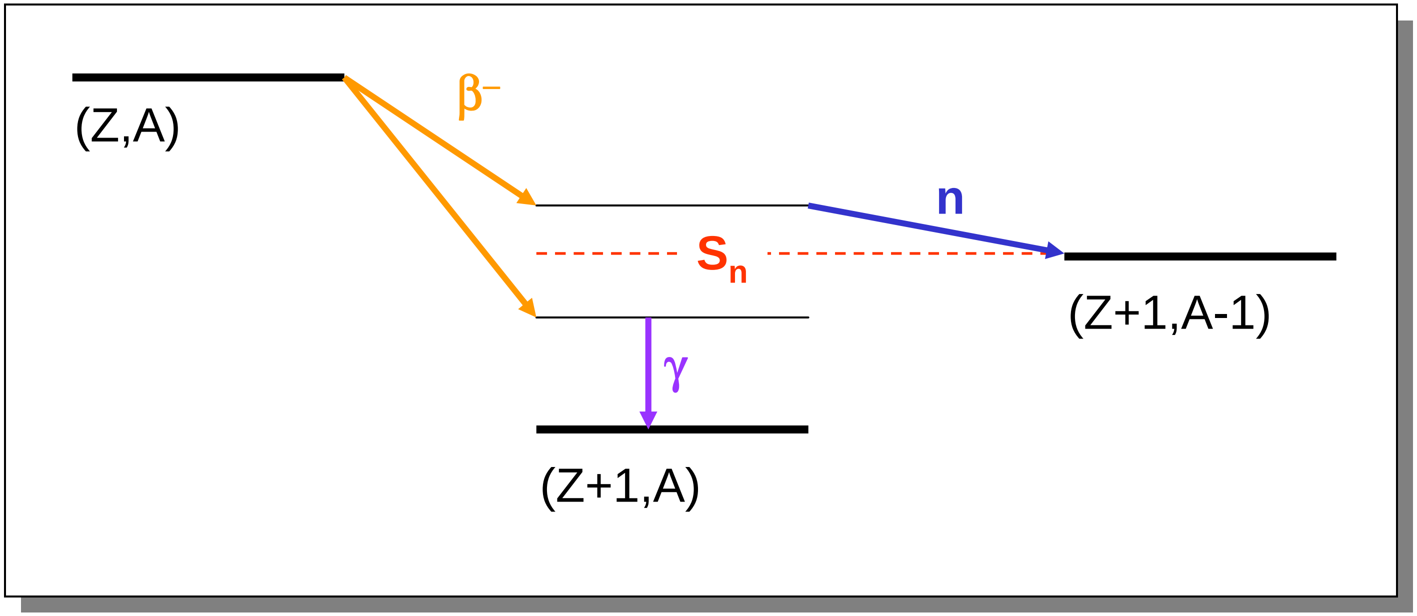
(different paths for different conditions)



Beta delayed neutron emission

Neutron rich nuclei can emit one or more neutrons during β-decay if **$S_n<Q_\beta$**

(the more neutron rich, the lower S_n and the higher Q_β)



If some fraction of decay goes above S_n in daughter nucleus then some fraction P_n of the decays will emit a neutron (in addition to e^- and ν)

(generally, neutron emission competes favorably with γ-decay - strong interaction !)

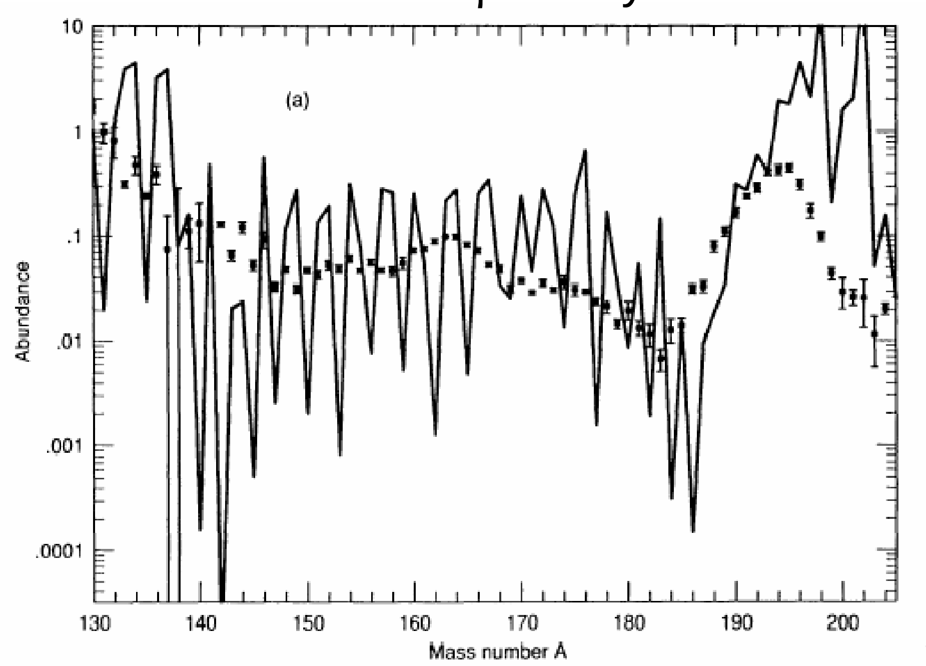
Importance of beta delayed neutron emission

Effects: **during r-process**: **none** as neutrons get recaptured quickly

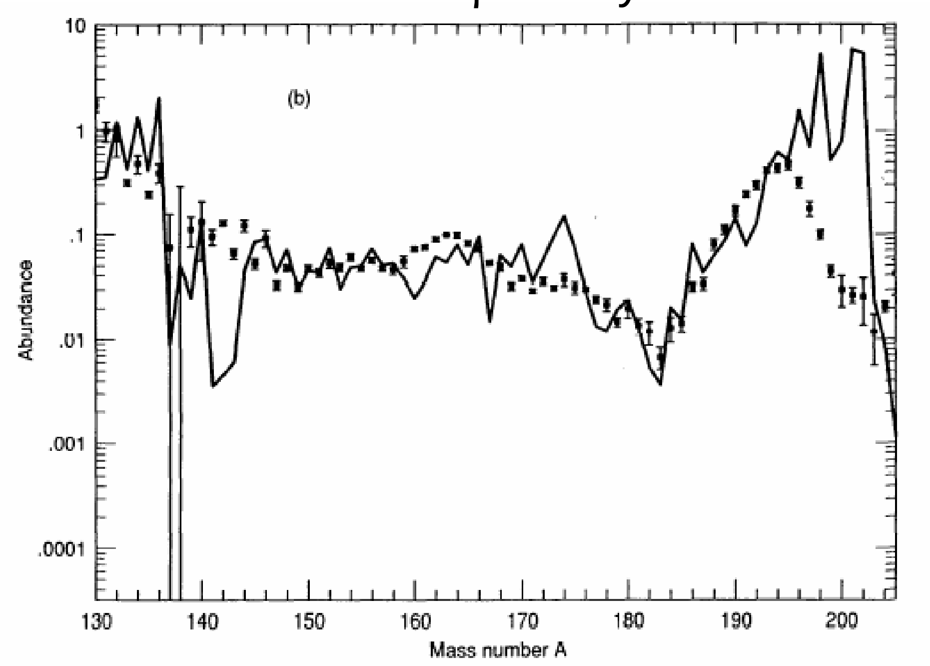
during freezeout
- **modification of final abundance**
- **late time neutron production (those get recaptured)**

Calculated r-process production of elements (Kratz et al. ApJ 403 (1993) 216):

before β-decay

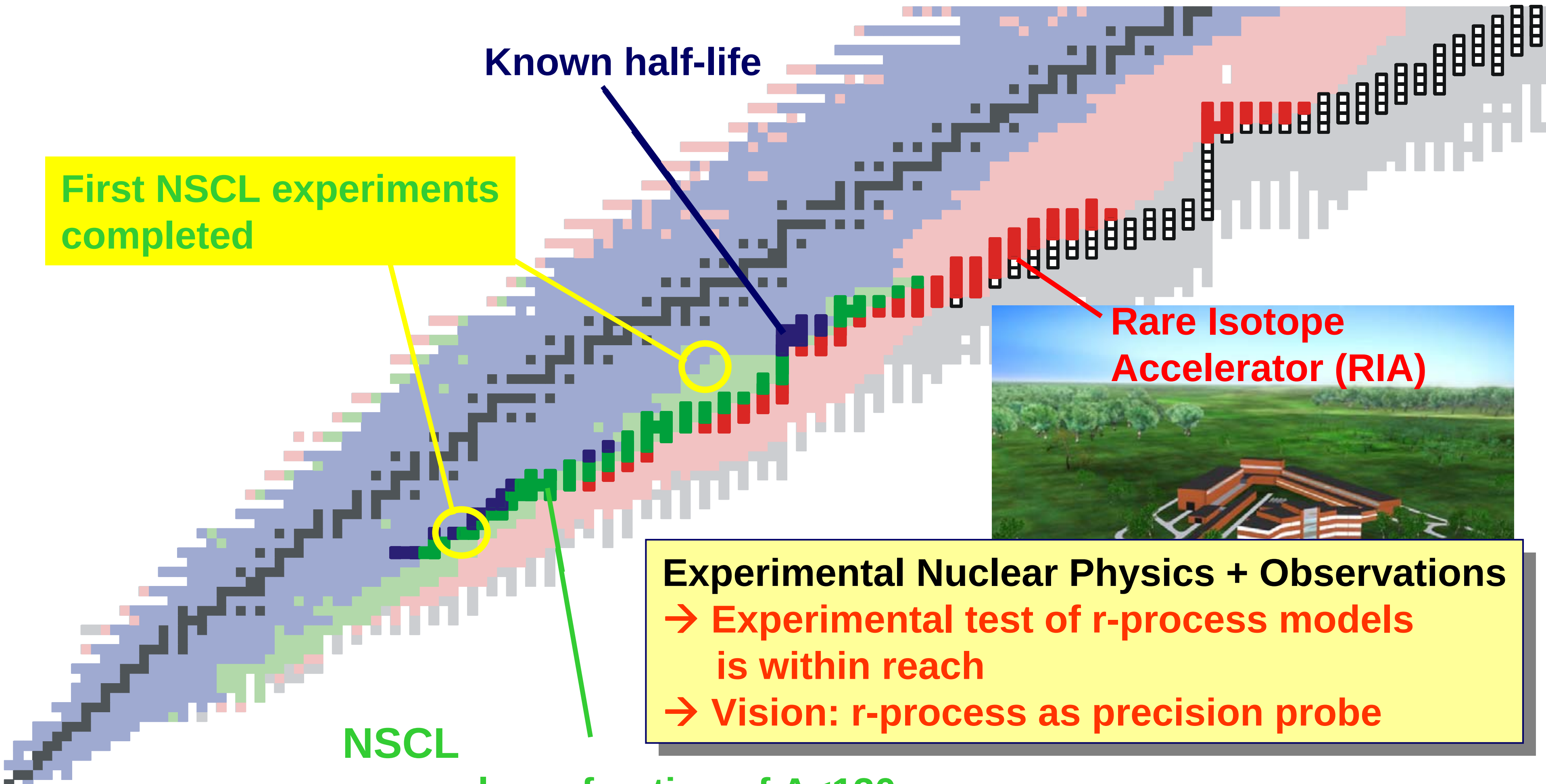


after β-decay



→ **smoothing effect from β-delayed n emission !**

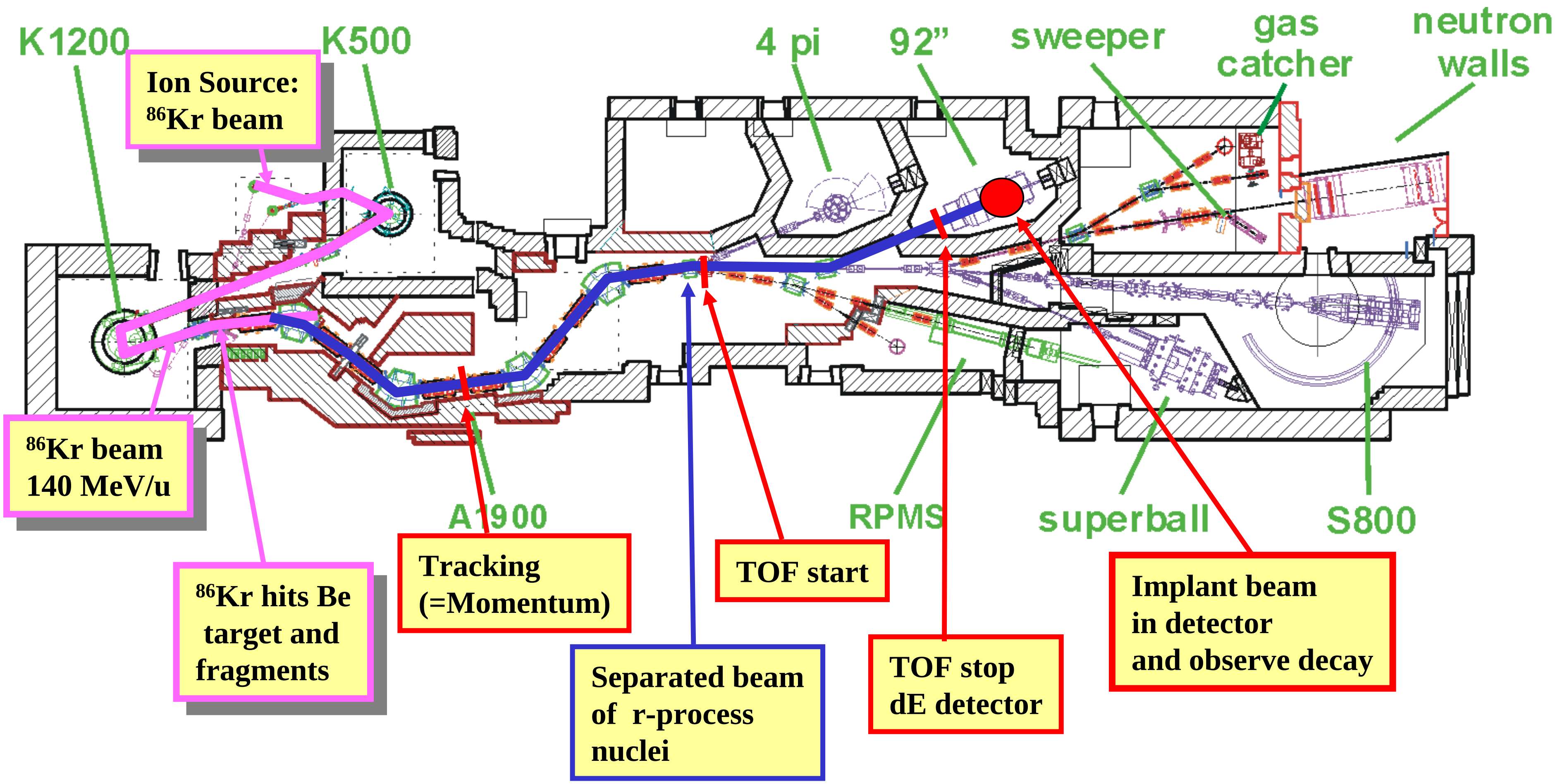
NSCL and future facilities reach



Experimental Nuclear Physics + Observations
→ Experimental test of r-process models is within reach
→ Vision: r-process as precision probe

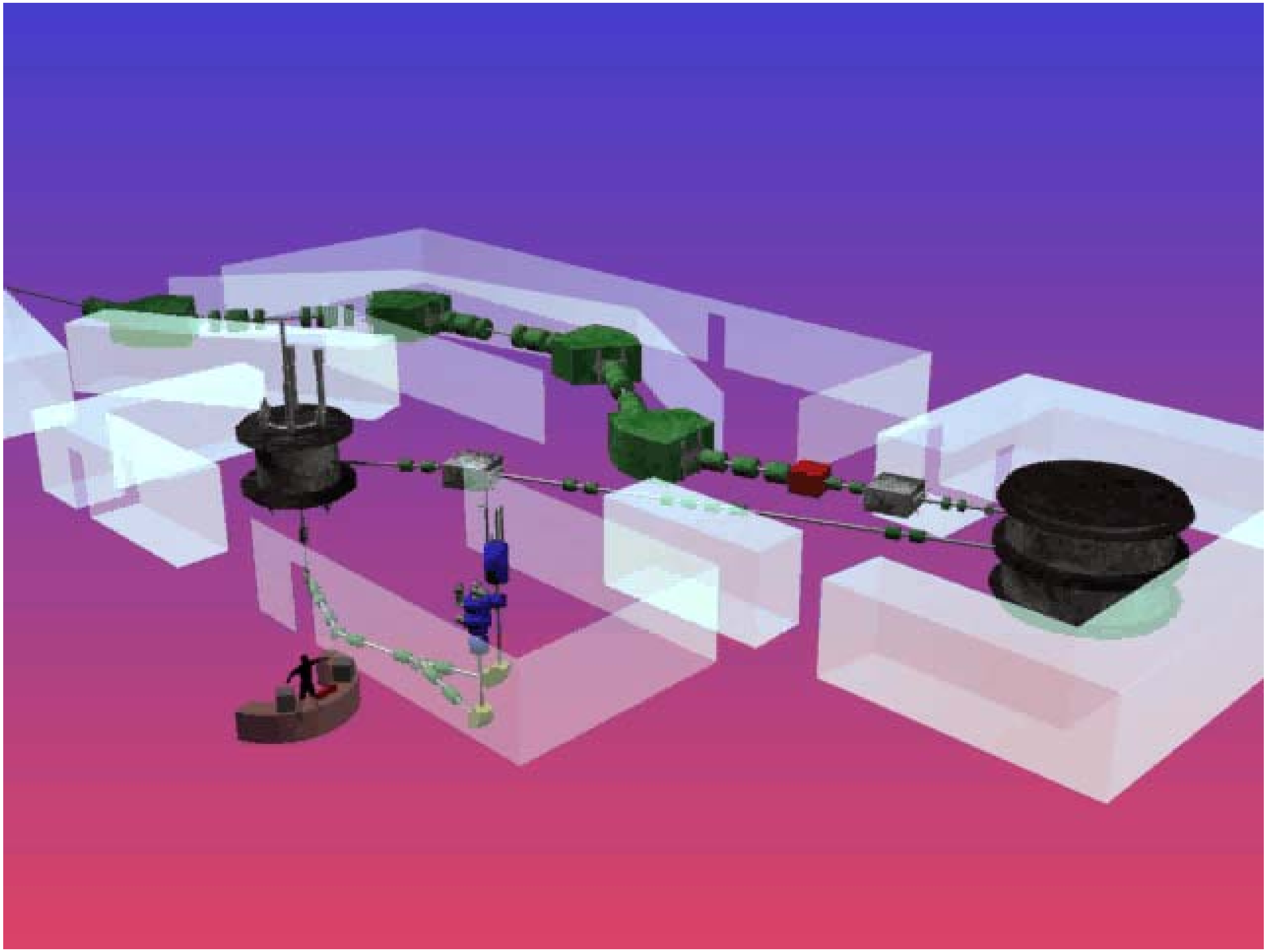
NSCL
covers large fraction of A<130 r-process
- big discrepancies among r-process models
- possibility of multiple r-processes

NSCL Coupled Cyclotrons at Michigan State University



Fast beam fragmentation facility – allows event by event particle identification

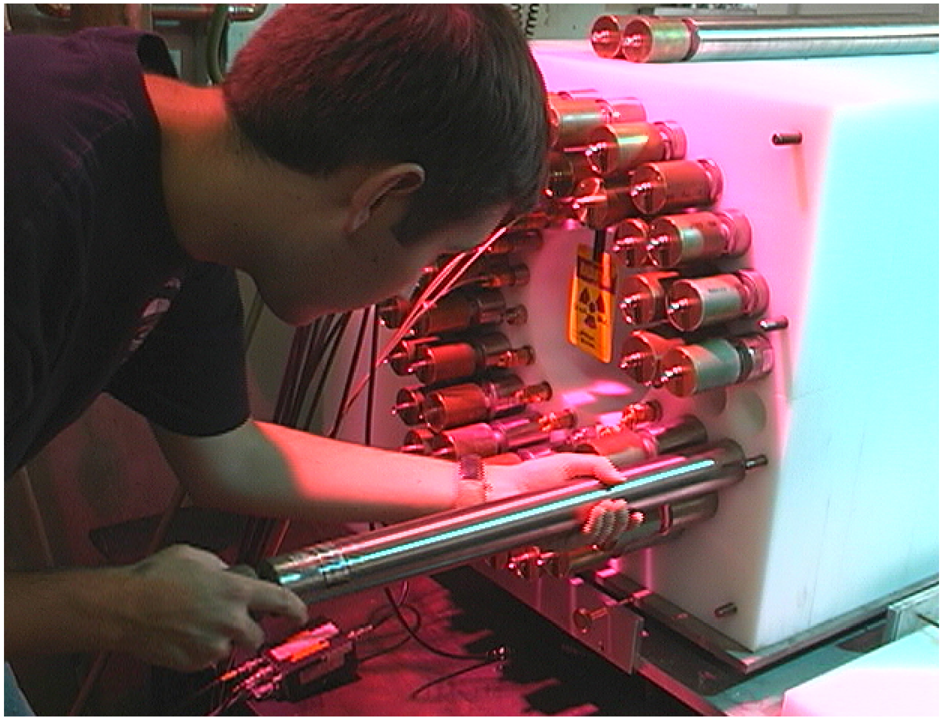
NSCL Coupled Cyclotron Facility



Installation of D4 steel, Jul/2000

H. Schatz

First experiment: r-process in the Ni region (Hosmer et al.)



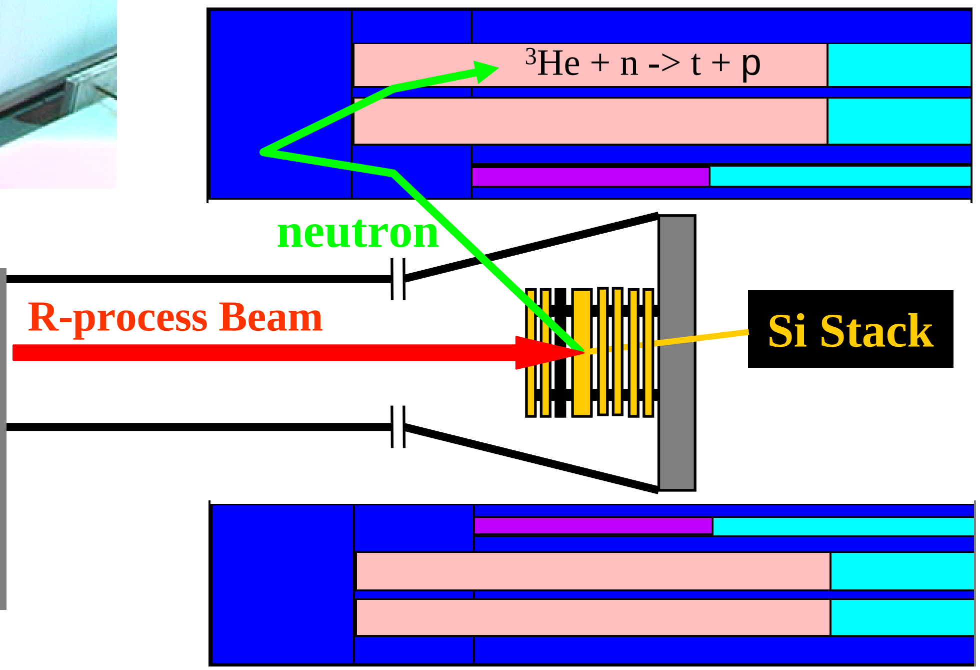
Measure:

- β-decay half-lives
- Branchings for β-delayed n-emission

Detect:

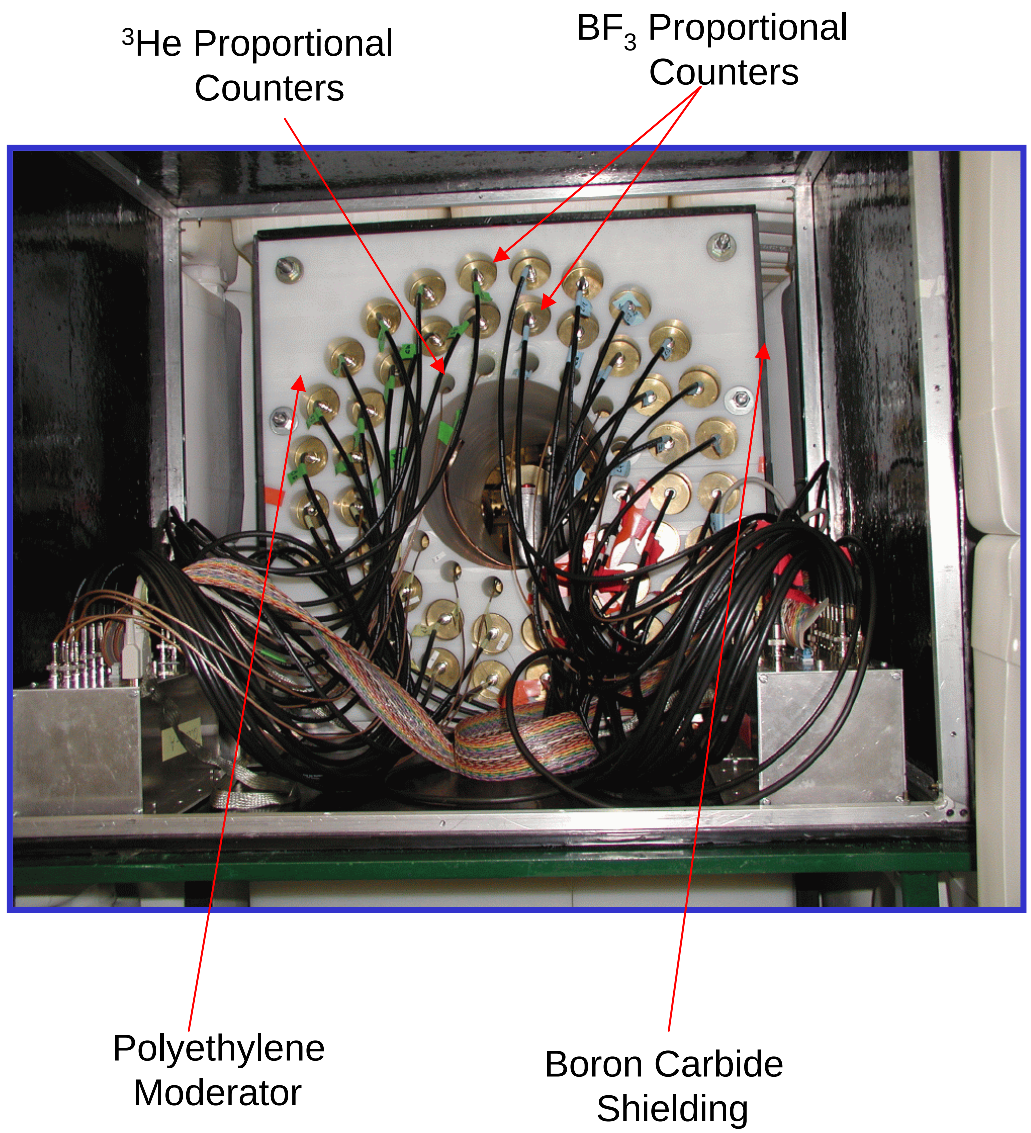
- Particle type (TOF, dE, p)
- Implantation time and location
- β-emission time and location
- Neutron-β coincidences

NSCL Neutron detector NERO



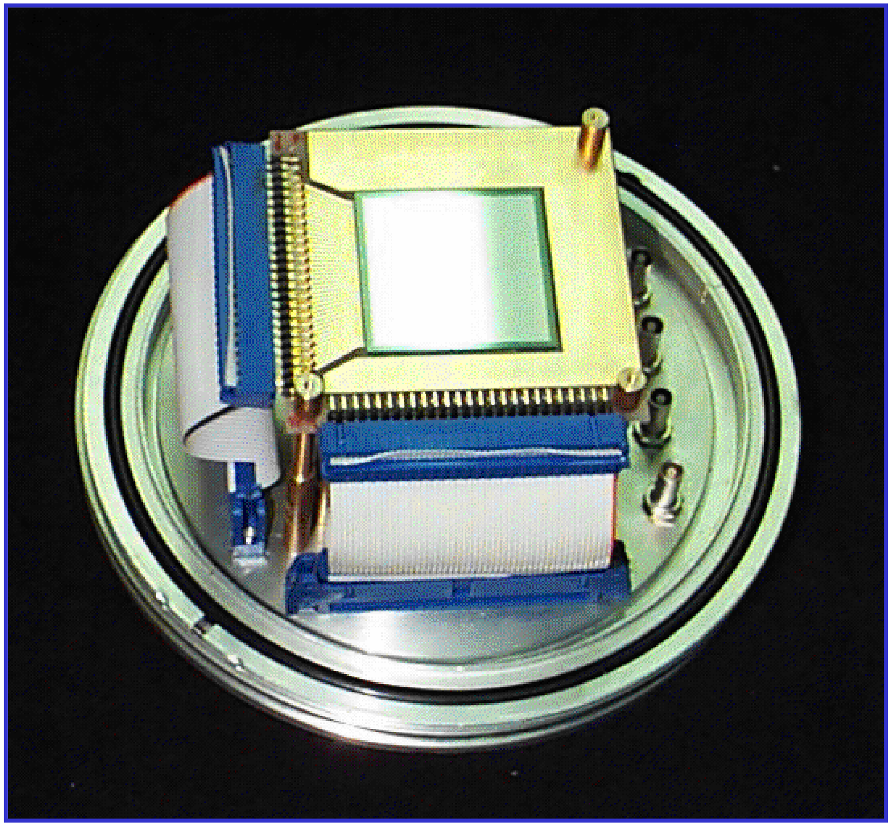
NERO – Neutron Emission Ratio Observer

Specifications:
- 60 counters total
  (16 ^{3}He , 44 BF_3)
- 60 cm x 60 cm x 80 cm polyethylene block
- Extensive exterior shielding
- 43% total neutron efficiency (MCNP)

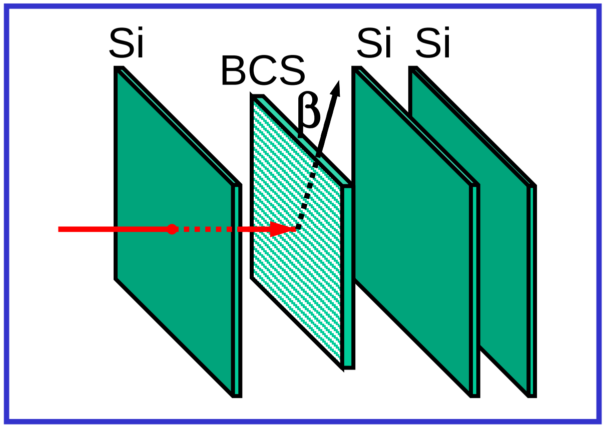


NSCL Beta Counting System

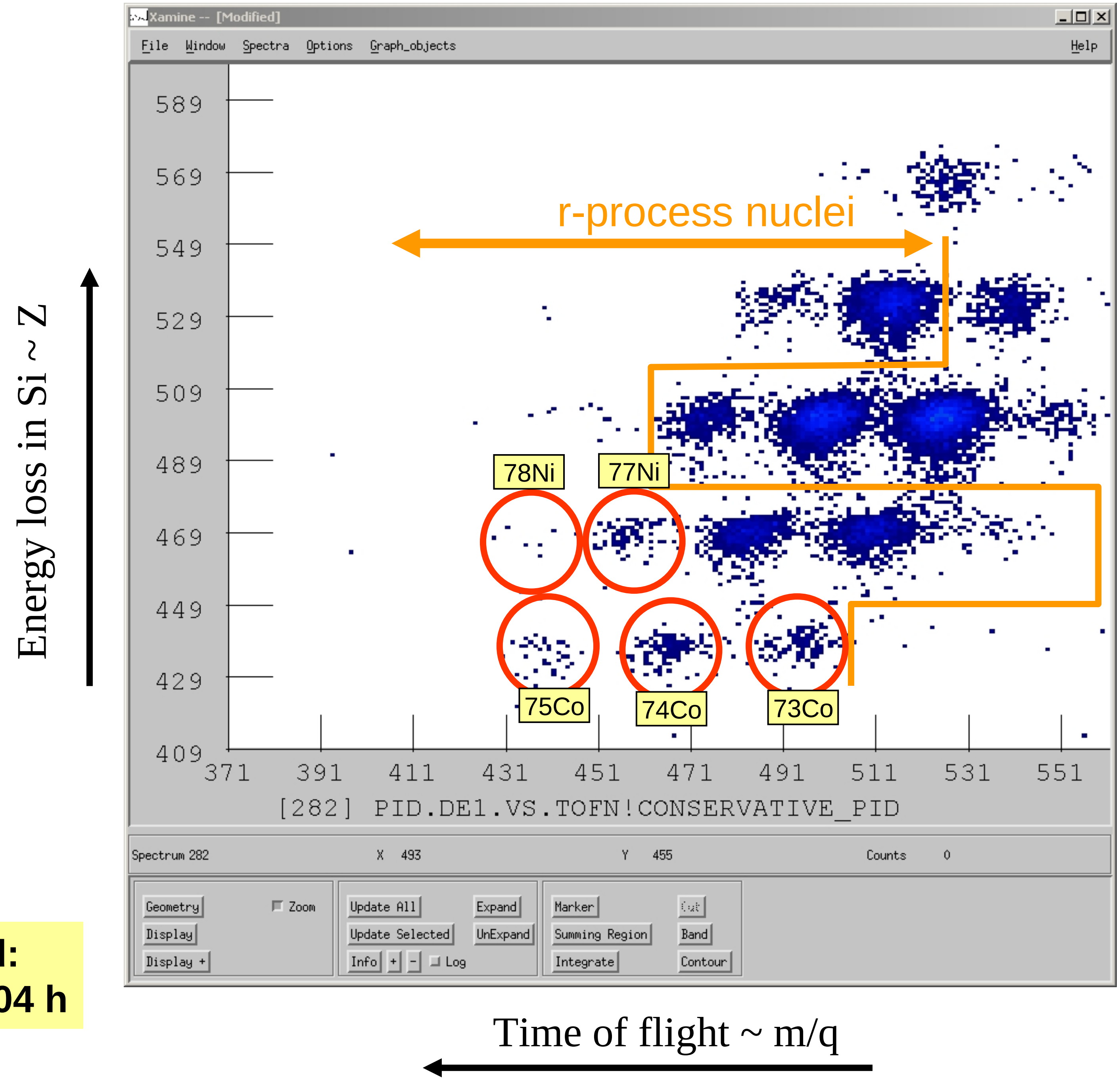
NSCL BCS – Beta Counting System



- 4 cm x 4 cm active area
- 1 mm thick
- 40-strip pitch in x and y dimensions ->1600 pixels

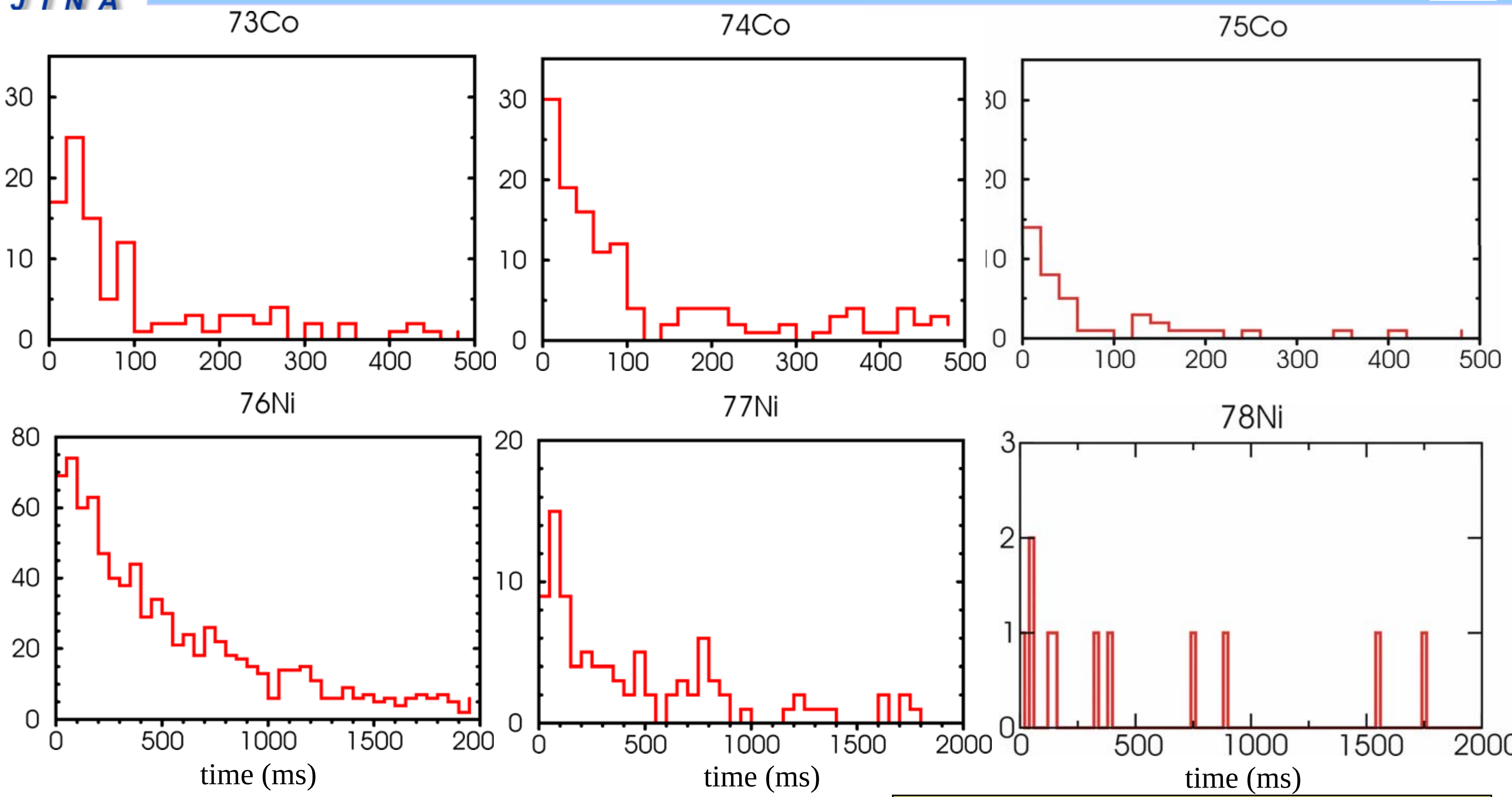


Particle Identification:



Total ^{78}Ni yield:
11 events in 104 h

Decay data

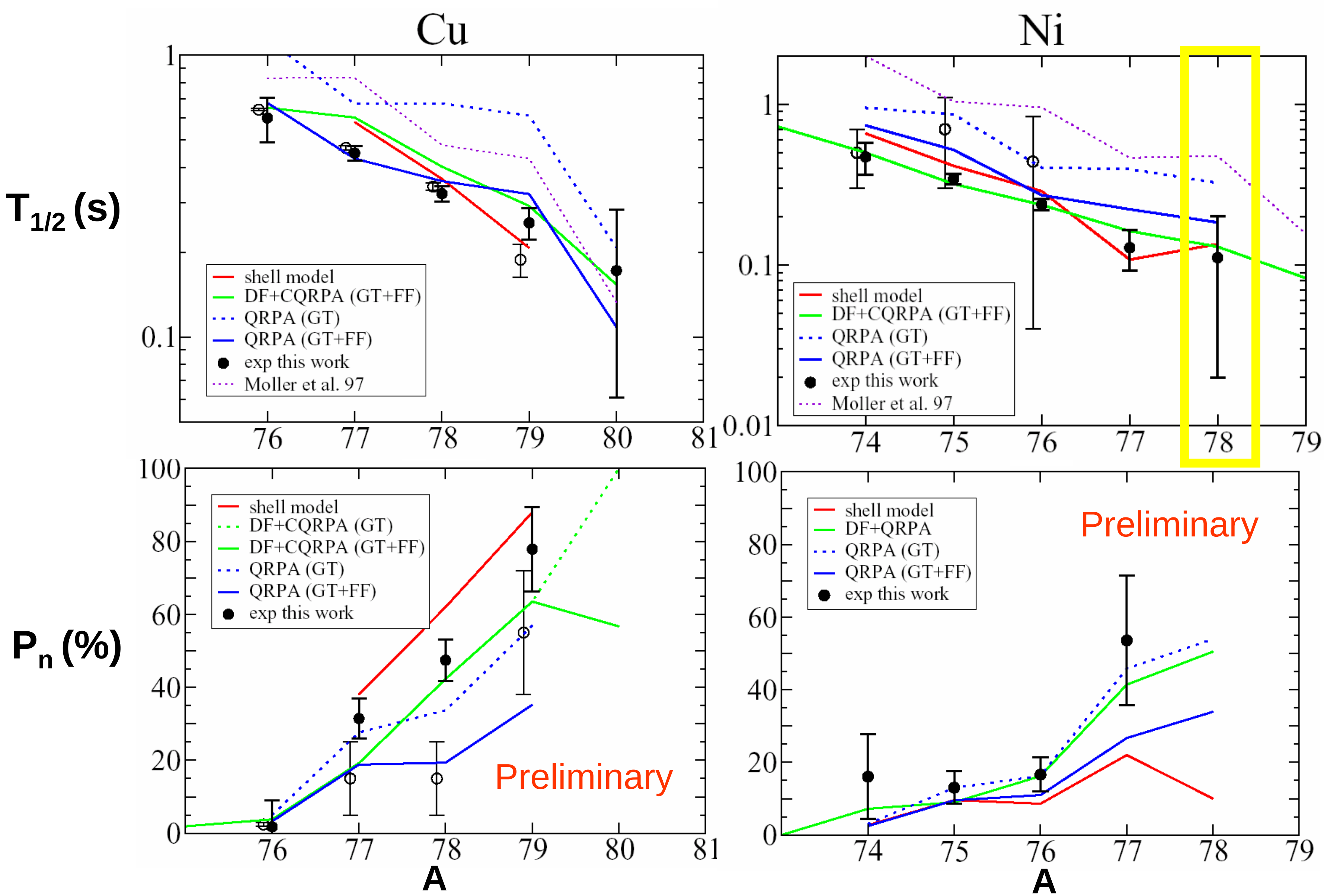


Fast radioactive beams:

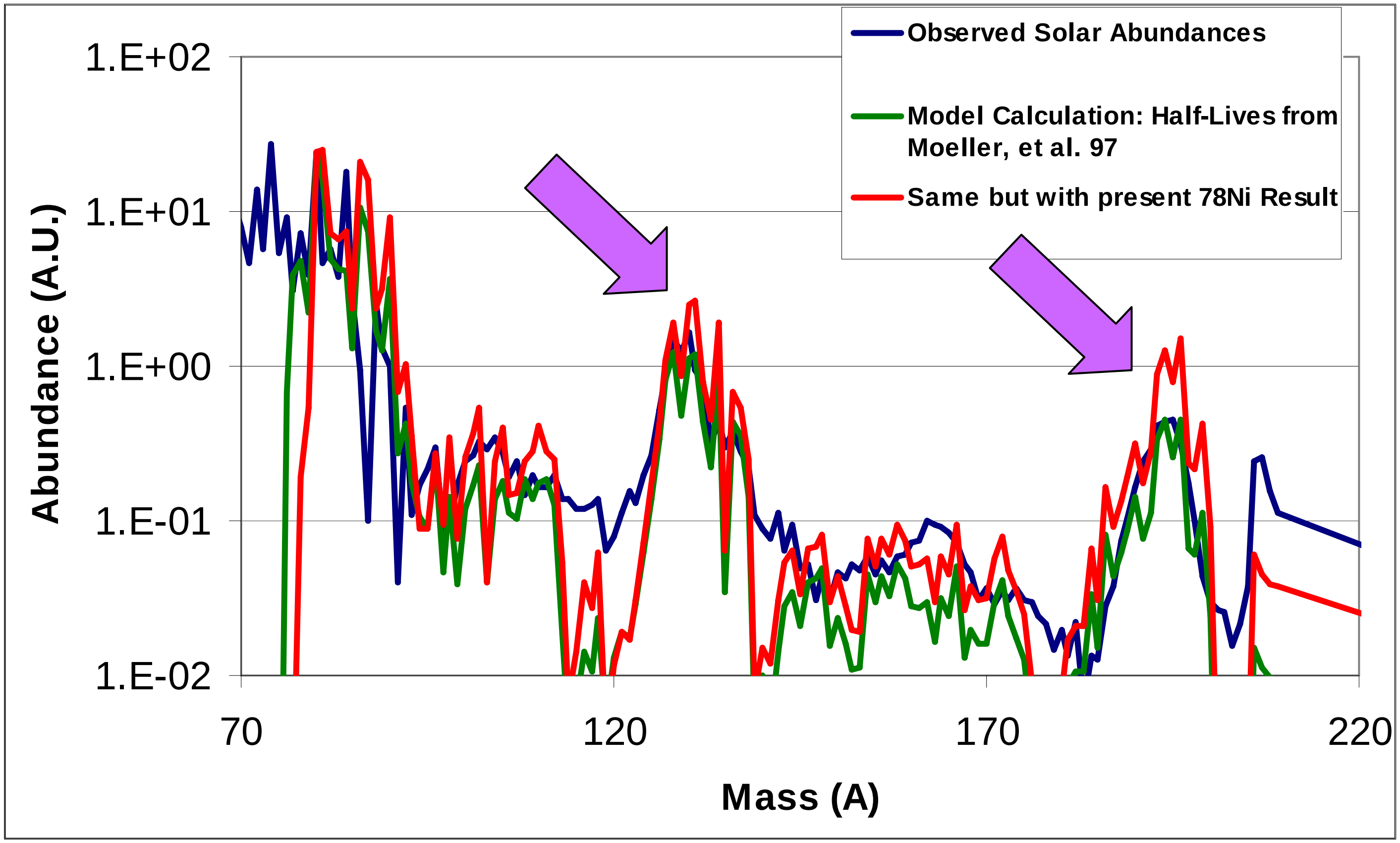
- No decay losses
- Rates as low as 1/day useful !
- Mixed beam experiments easy

Results (Hosmer et al. 2005)

DF+CQRPA Borzov et al. 2005, QRPA: Moller et al. 2003, Shell model: Lisetzky & Brown 2005



Impact of ^{78}Ni half-life on r-process models



→need to readjust r-process model parameters

→Can obtain Experimental constraints for r-process models from observations and solid nuclear physics

→ remainig discrepancies – nuclear physics ? Environment ? Neutrinos ? Need more data

78Ni Collaboration

MSU:
P. Hosmer
R.R.C. Clement
A. Estrade
P.F. Mantica
F. Montes
C. Morton
W.F. Mueller
E. Pellegrini
P. Santi
H. Schatz
M. Steiner
A. Stolz
B.E. Tomlin
M. Ouellette

Mainz:
O. Arndt
K.-L. Kratz
B. Pfeiffer

Pacific Northwest Natl. Lab.
P. Reeder

Notre Dame:
A. Aprahamian
A. Woehr

Maryland:
W.B. Walters

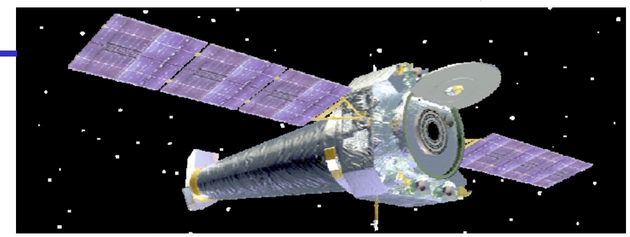
Joint Institute for Nuclear Astrophysics (JINA)

a NSF Physics Frontiers Center – **www.jinaweb.org**

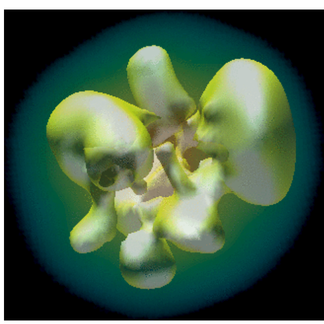
- **Identify and address the critical open questions and needs of the field**
- **Form an intellectual center for the field**
- **Overcome boundaries between astrophysics and nuclear physics and between theory and experiment**
- **Attract and educate young people**

Nuclear Physics Experiments

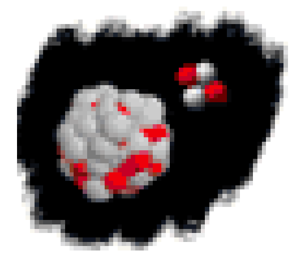
Astronomical Observations



Astrophysical Models



Nuclear Theory



JINA

Core institutions:
- **Notre Dame**
- **MSU**
- **U. of Chicago**

Associated:
- **ANL**
- **LANL**
- **U of Arizona**
- **UC Santa Barbara**
- **UC Santa Cruz**
- **VISTARS (Mainz,GSI)**

http://www.jinaweb.org

Summary

r-process problem one of the key issues in modern nuclear astrophysics

Great progress has been made in
- modeling the r-process (many possible sites !)
- in obtaining observational information
- in addressing the nuclear physics of extremely n-rich nuclei (experiments now away from shell closures possible !)

Further joint progress in astronomy and nuclear physics is needed (need progress in theory AND experimental/observational constraints)

→ Next generation observatories (and surveys, e.g. SEGUE)
→ Next generation rare isotope accelerator (RIA)

- **Need to build interdisciplinary culture to maximize science impact**
  - nuclear data need to be used in models
  - astrophysical signatures of nuclear processes need to be searched for
  - nuclear networks need to be used to interpret observations quantitatively

JINA @ http://www.jinaweb.org is an important step