Rare Isotope (Heavy Ion) Accelerators

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Talk Outline

- What are the drivers for rare isotope studies?
- Examples of reach into isotope space and reasons.
- Examples of planned facilities worldwide.
- Where does SRF fit into these new projects?
- What advances in technology and capability would enhance these future facilities?

Thanks!

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- SRF Workshop PC

★ DESY: Swaantje Mette, Katrin Lando

- ANL: Jerry Nolen, Hermann Grunder, Ken Shepard, Petr Ostoumov
- GSI Upgrade: Norbert, Hans Geissel
- MSU: Michael Thoennessen, Brad Sherrill, Konrad Gelbke, Richard York, Georg Bollen, Terry Grimm, Walter Hartung
- SPIRAL II: Alban Mosnier.
- TRIUMF: Paul Schmor, Bob Laxdal, Roger Poirier.

Why the Interest in Rare Isotopes?

Determine important properties of several thousand isotopes previously unavailable experimentally.

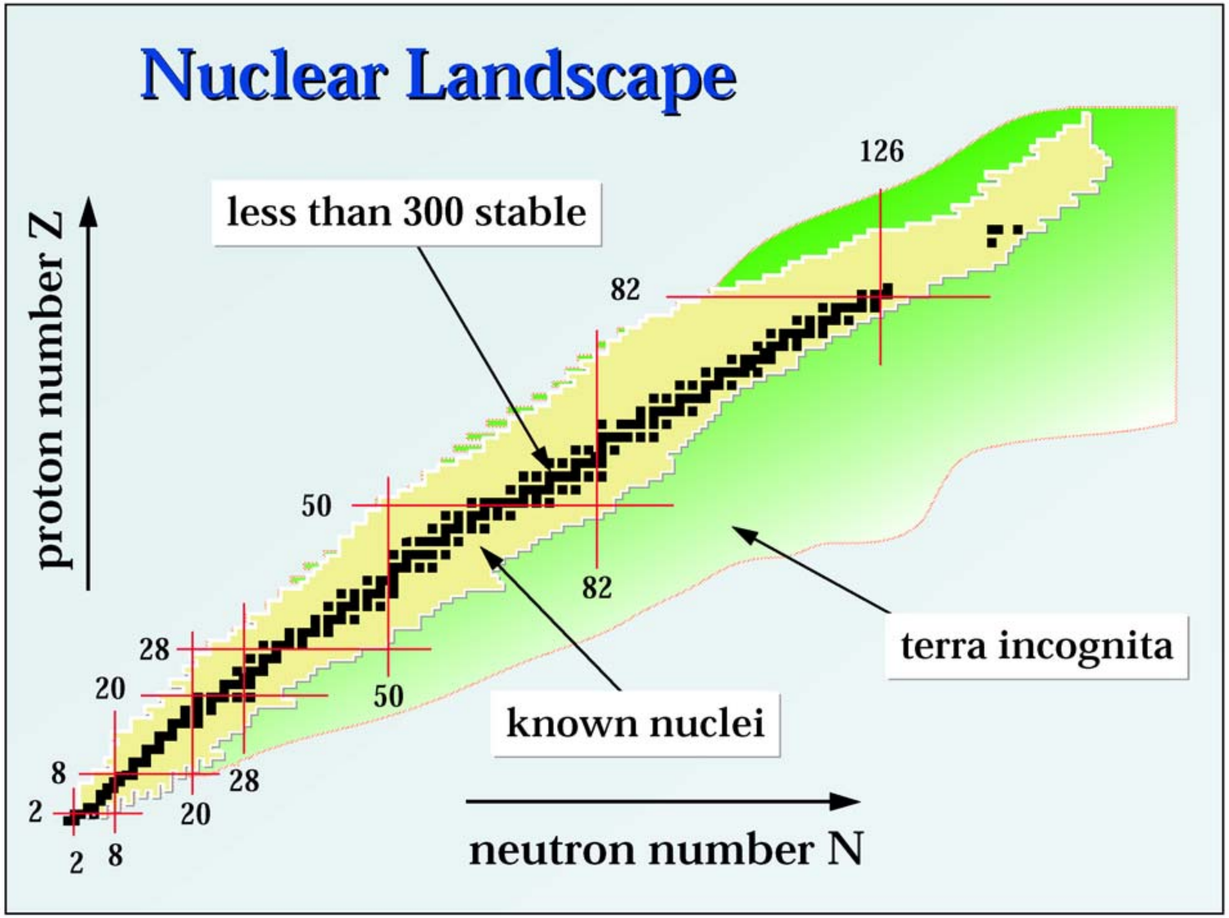
Solve fundamental problems of science (major challenges and mysteries of the universe):

- ★ **Origin of elements heavier than iron!**
- ★ **Stellar evolution theories need good data!**

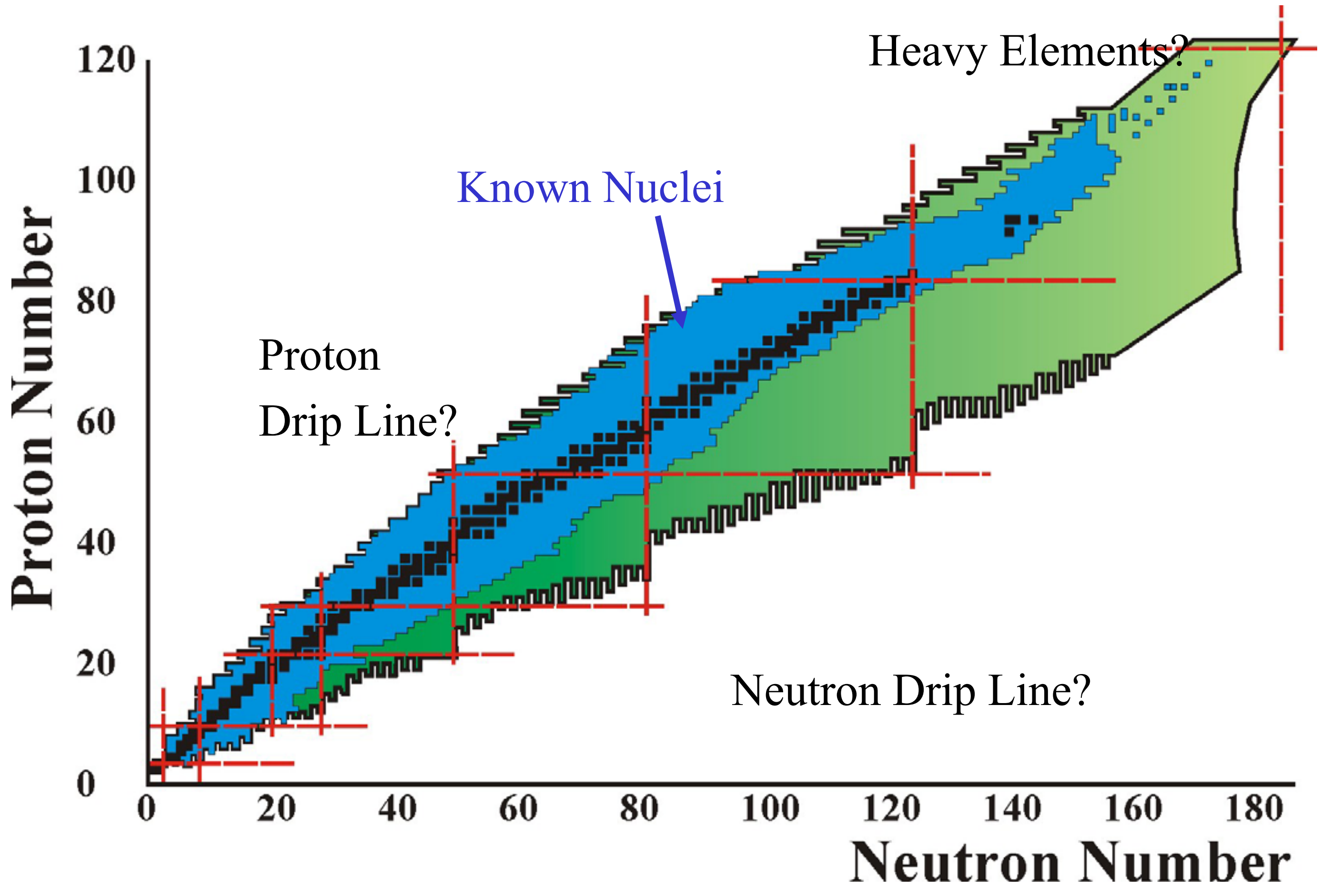
  (Chemical evolution of universe)

- **Nuclear properties (especially for large n/p ratios) and resultant feedback to nuclear theory. Nucleonic matter.**
- **Reaction cross-sections and other data to support thermonuclear studies. (Stars are complex hydrodynamical systems under extreme conditions.)**

Nuclear Landscape



The Chart of the Nuclides



The Origin of the Elements

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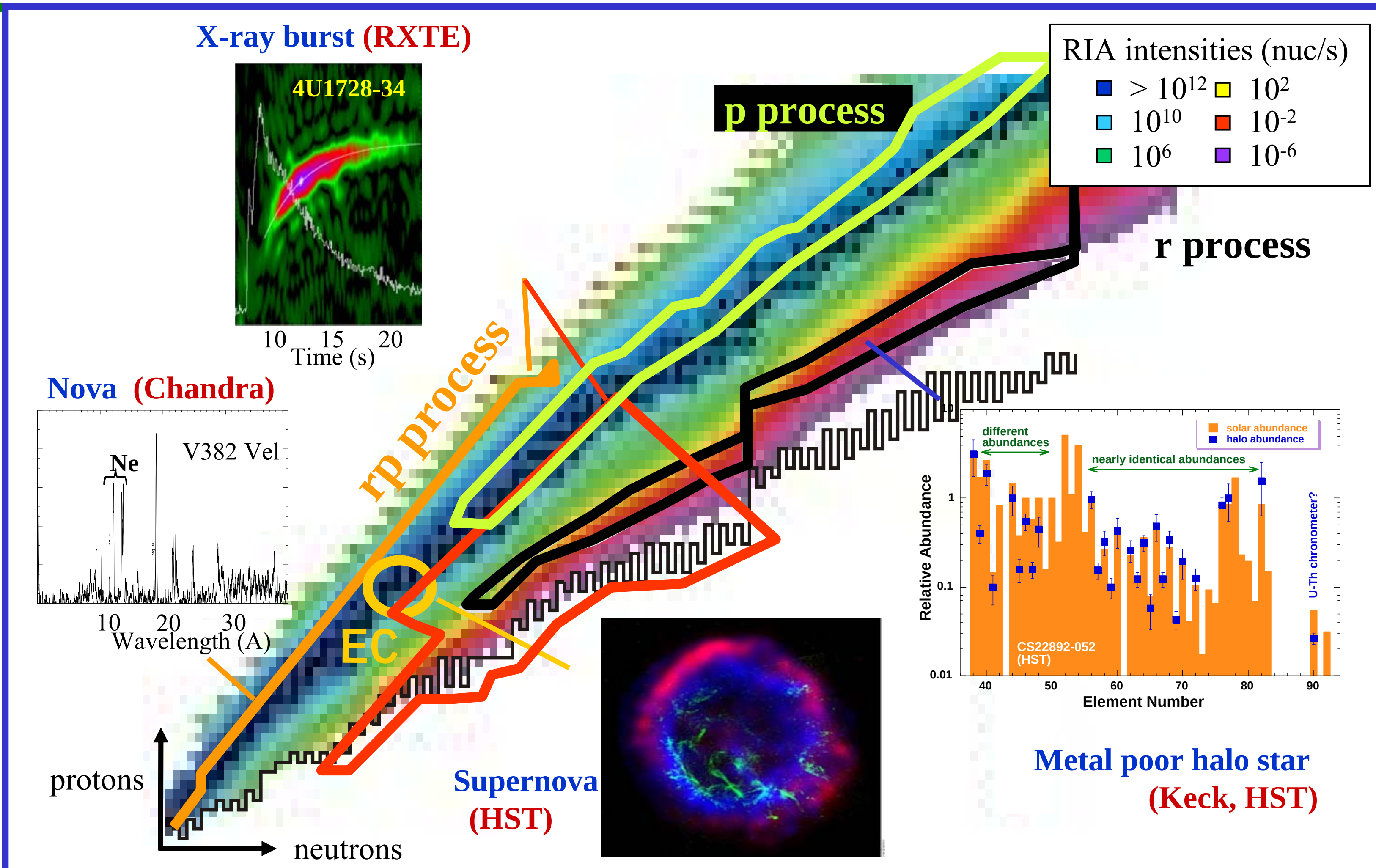

NASA: Timeline of the Universe

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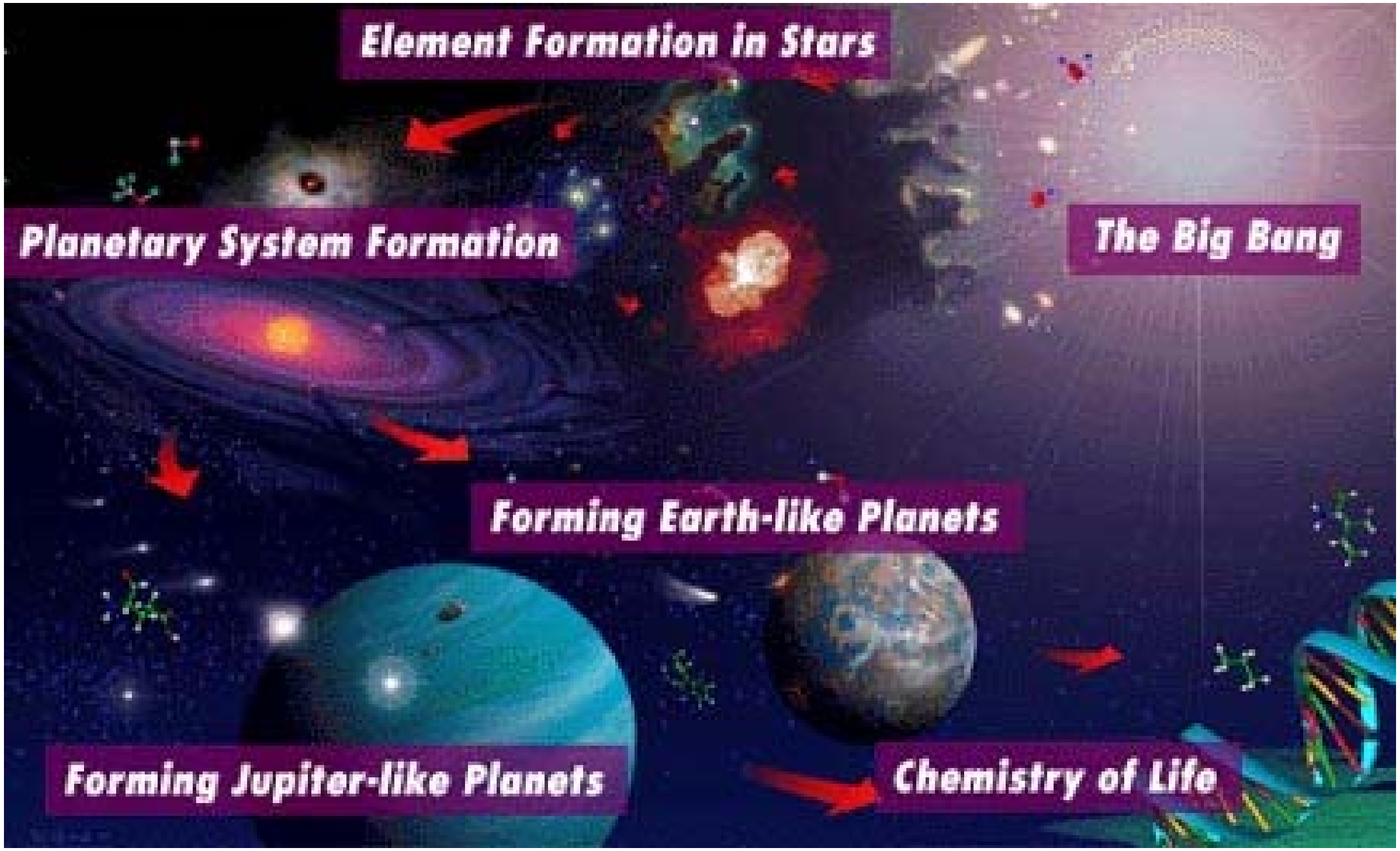
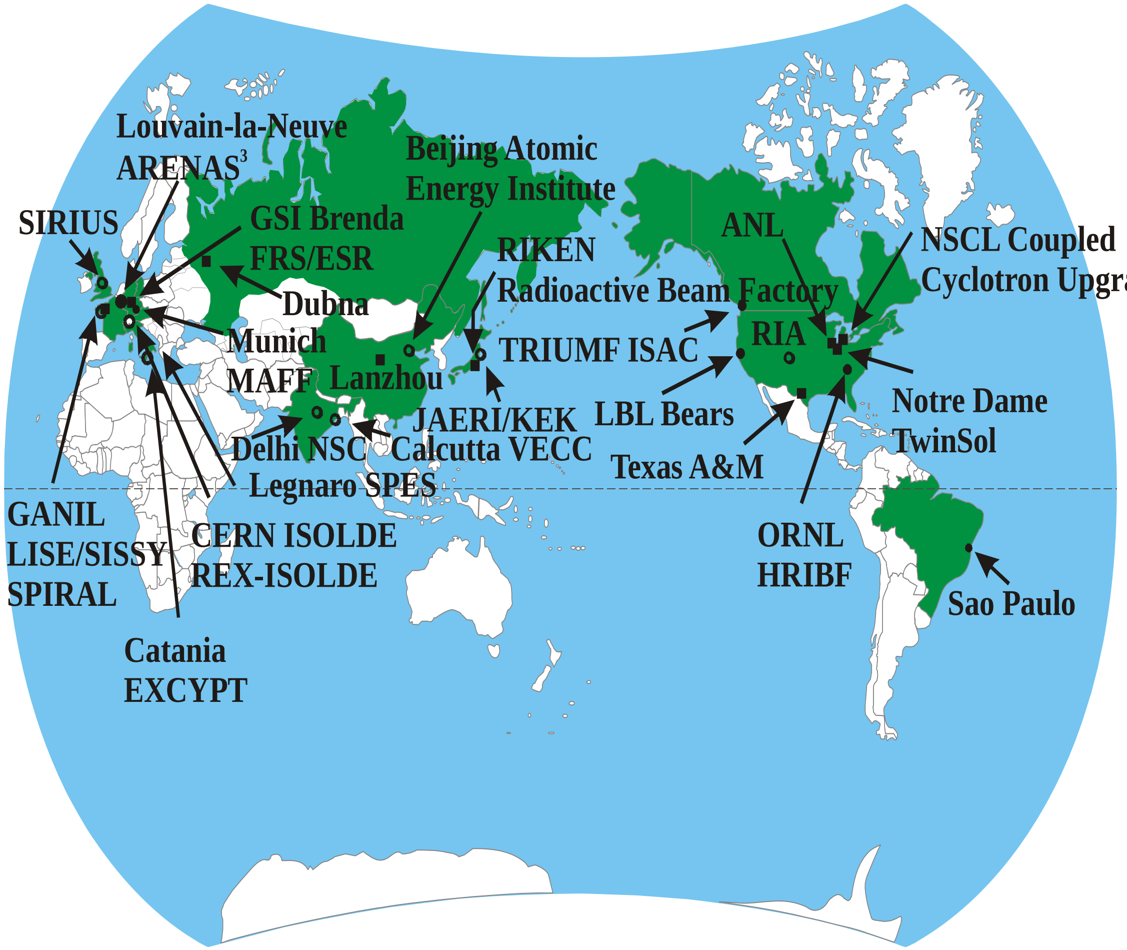


World Wide Effort in RIB Science



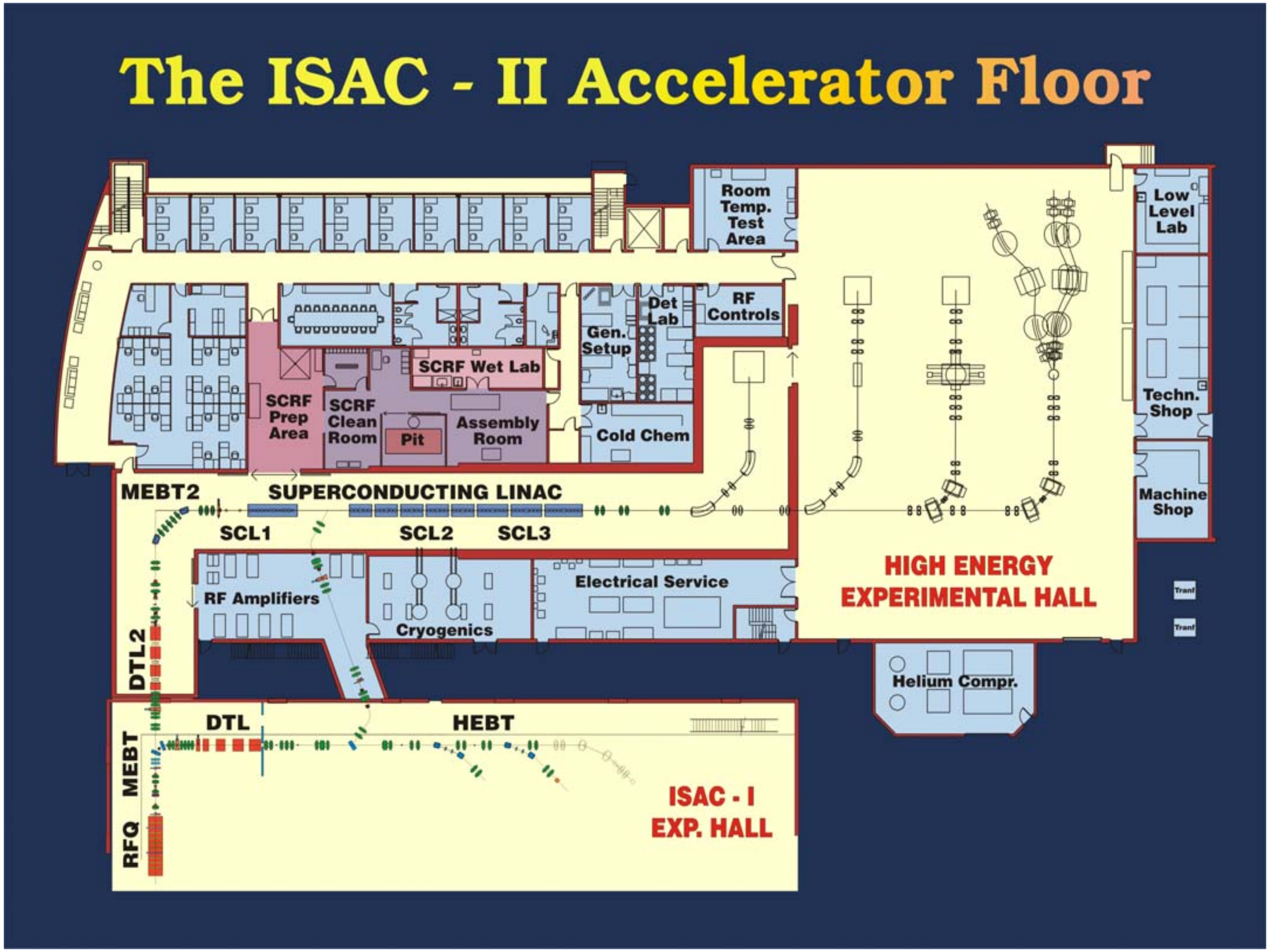
A Few New Planned Facilities – Impact SRF?

★ ISOL – Isotope Separation On Line

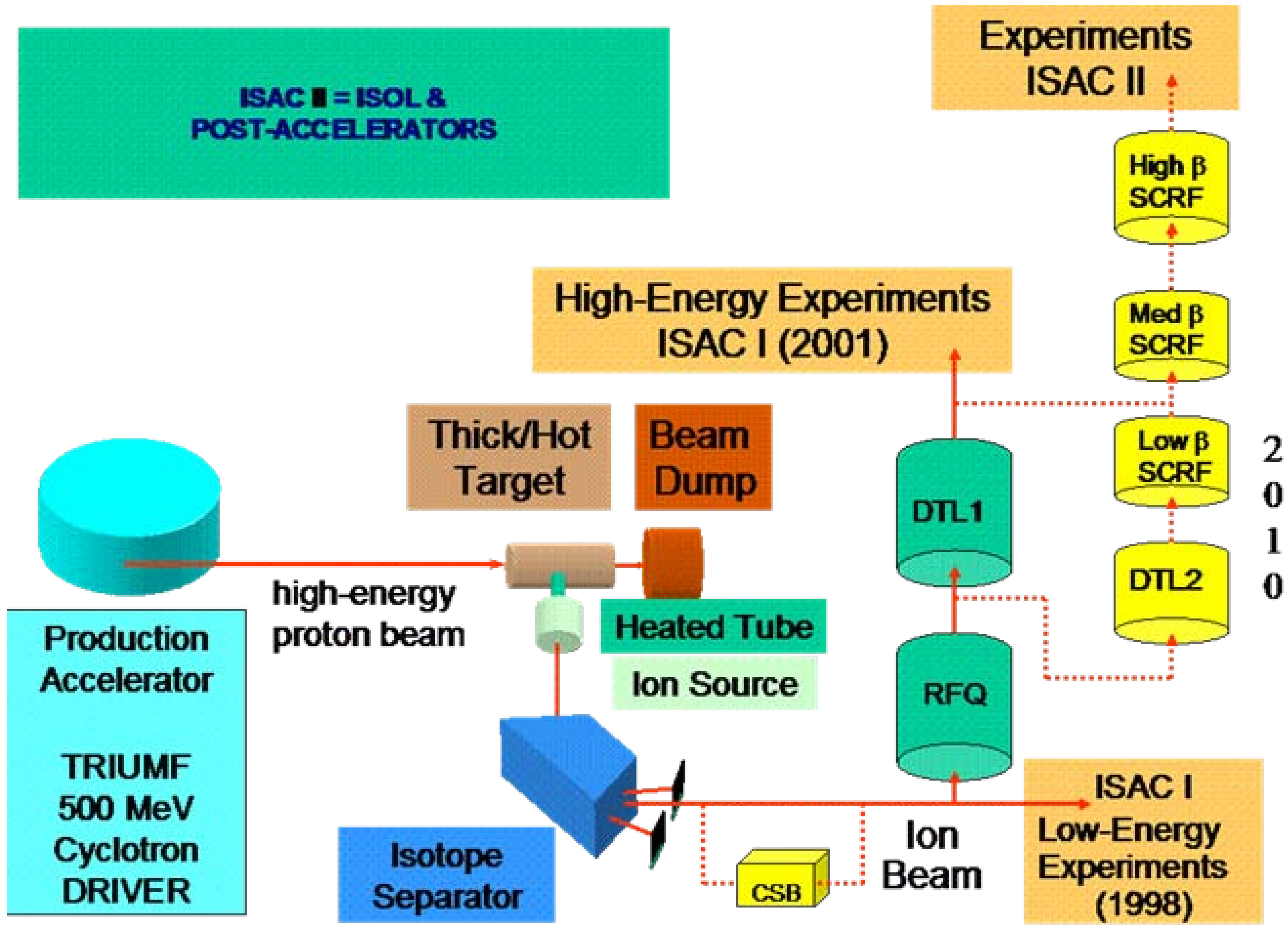
★ In Flight

- **ISAC II (Canada)**
- **RIKEN RIBF (Japan)**
- **GSI Upgrade (Germany)**
- **GANIL SPIRAL II (France)**
- **RIA (US)**

ISAC-II (TRIUMF Canada)



ISAC II Layout



TRIUMF Beam Line Layout

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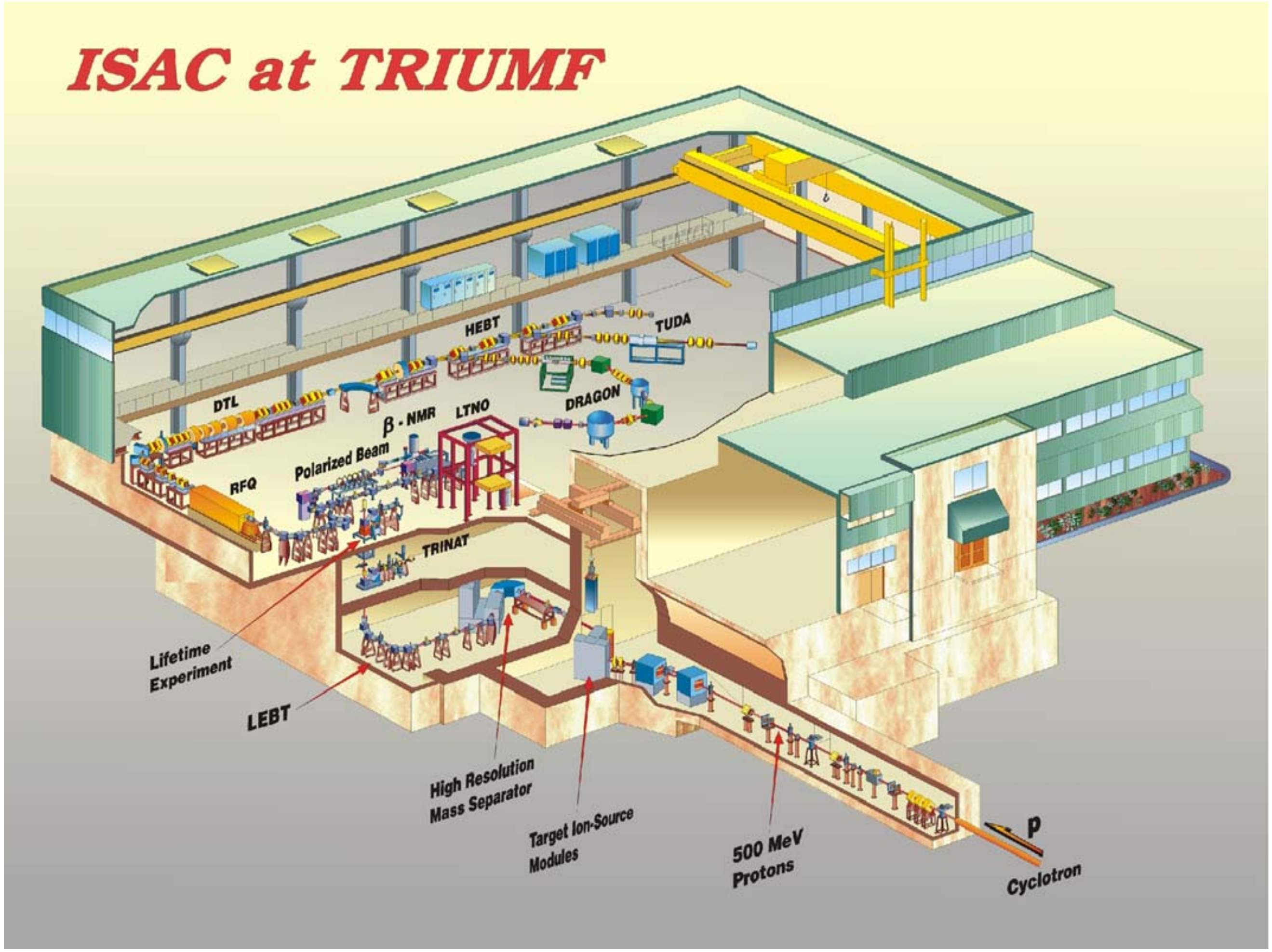

ISAC-II Summary

- Building is now being occupied
- SCRF development ongoing in rented space
  - Move to new lab in Sept.
- Phoenix ECRIS source being installed on test stand
  - One year of commissioning planned
- High Beta Cavity design initiated
- 20 Medium β Cavities in fabrication
  - Four production cavities delivered
  - Balance delivered in Aug. 2003
- Prototype cryomodule in fabrication and detailed design
  - First cold test by end of 2003
- Five medium β and two high β solenoids ordered
- Refrigerator contract to be awarded this month
  - phase I – 500W

TRIUMF SRF

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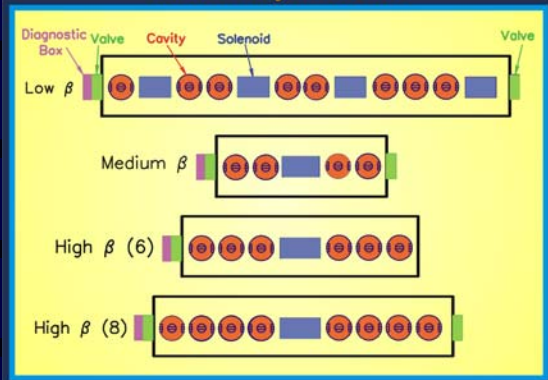
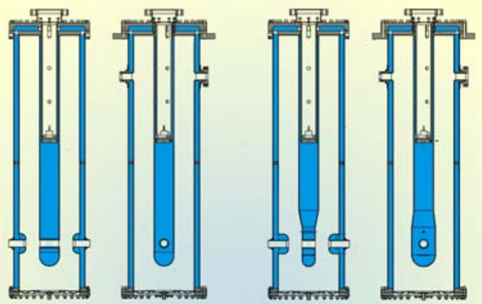
ISAC-II SC Linac



Section	β_0 (%)	f_{RF} (MHz)	No.	E_a (MV/m)
Low β	4.2	70.7	8	5
Med β	**5.7**	**106**	**8**	**6**
	7.1	**106**	**12**	**6**
High β	10.4	141	20	6

Medium Beta Cavities



(a) Nominal (β=7.1%) (b) Flat (β=5.7%)

freq=106.08MHz

$E_p/E_a \simeq 5$

$H_p/E_a \simeq 100$ G/(MV/m)

$U/E_a \simeq 0.09 J/(MV/m)^2$

$\Gamma \simeq 19\Omega$

RIBF (RIKEN Japan)

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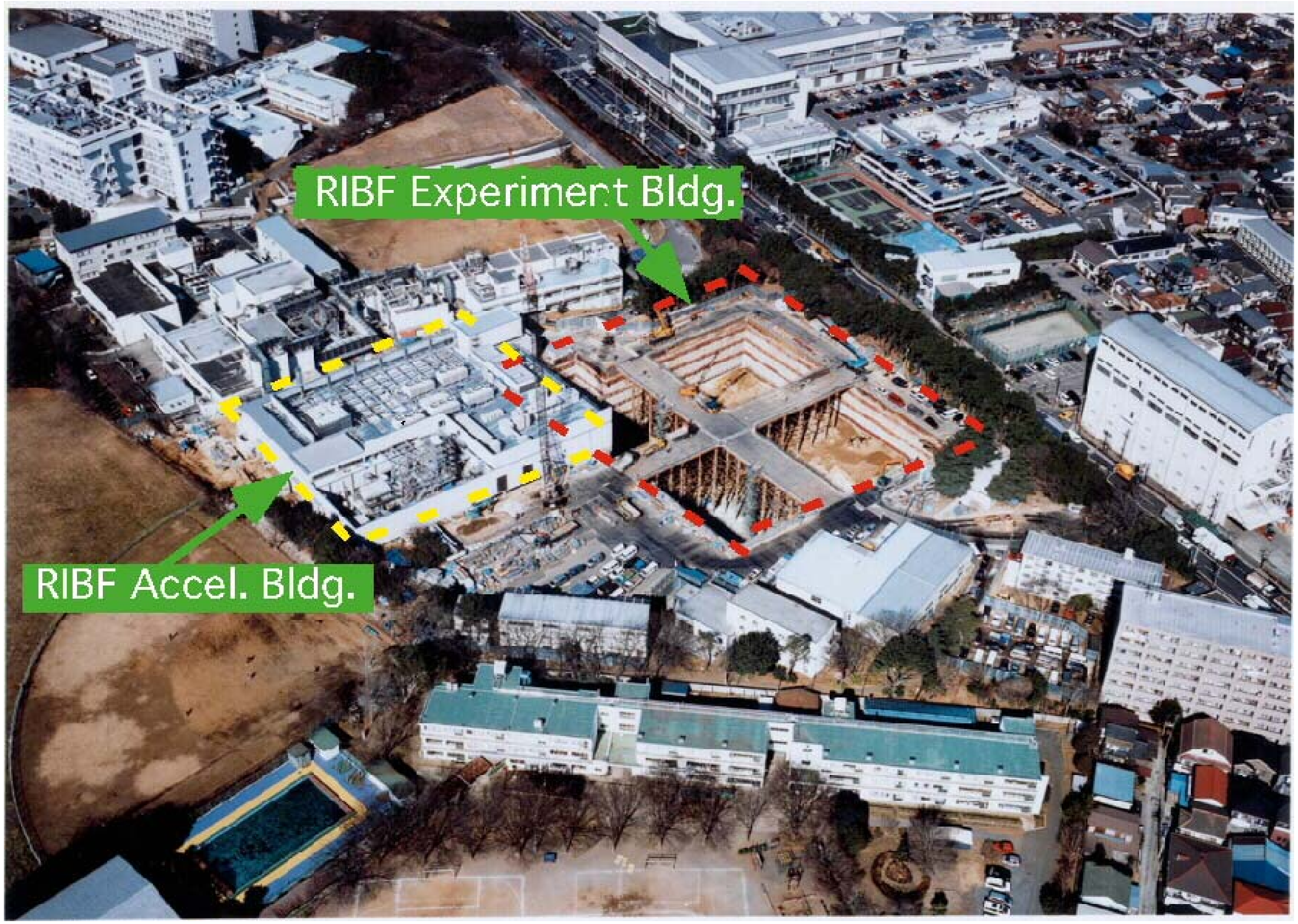
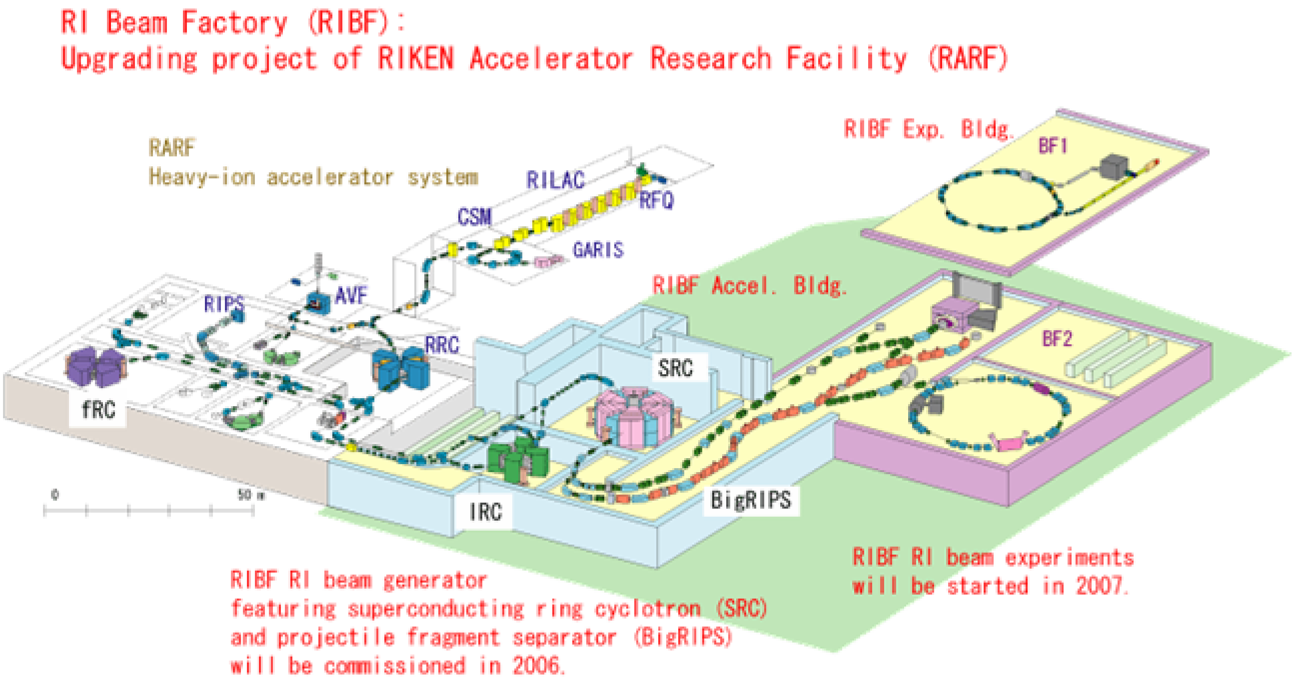


2003 February Progress picture

RIKEN RIBF



- **Rare Isotope Beam Facility**
  - **RRC Ring Cyclotron**
  - **IRC (K980)**
  - **SRC (K2500)**
  - **BigRIPS**
- **400 MeV/u light**
- **350 MeV/u heavy**

RIBF Production Rates

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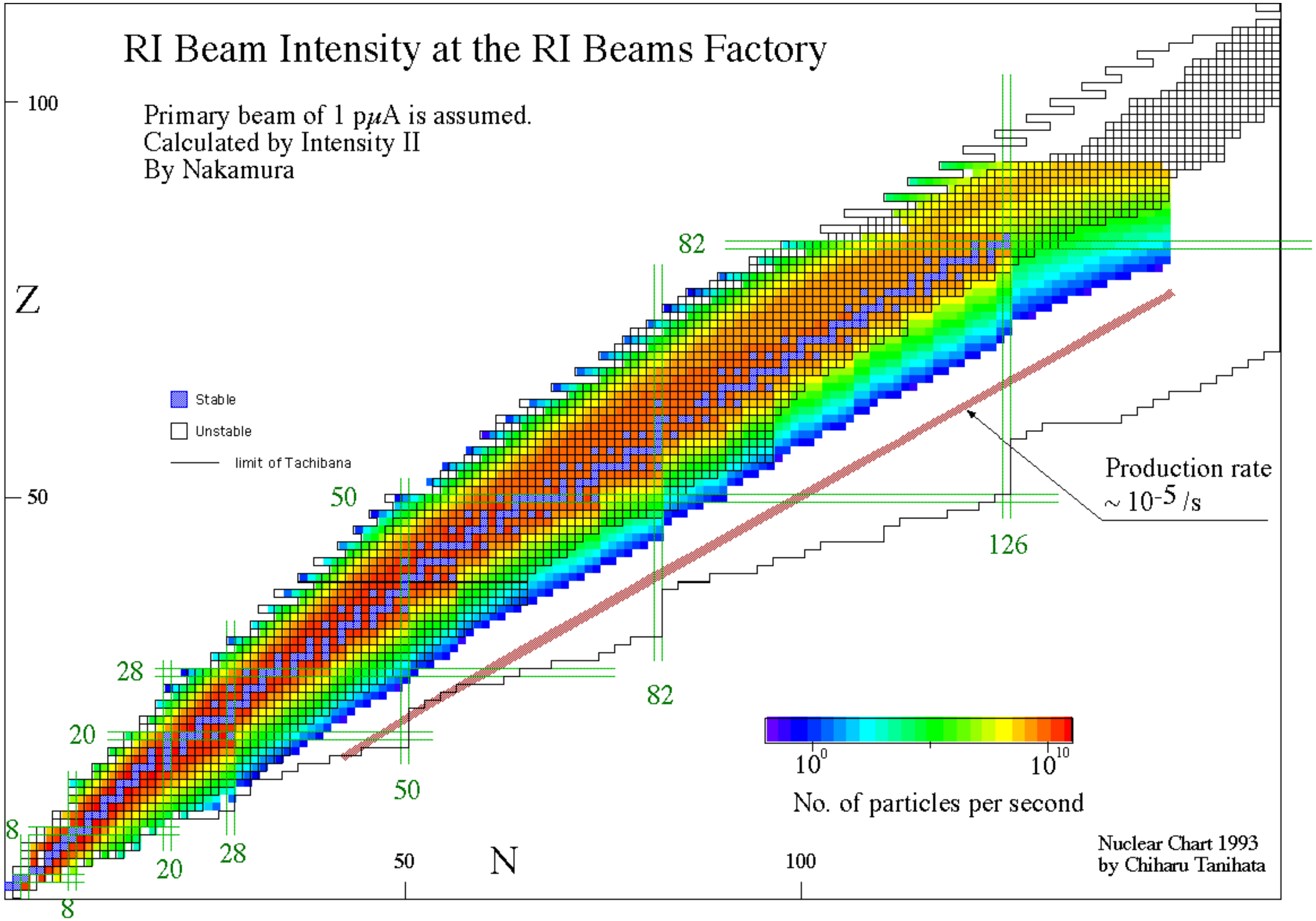
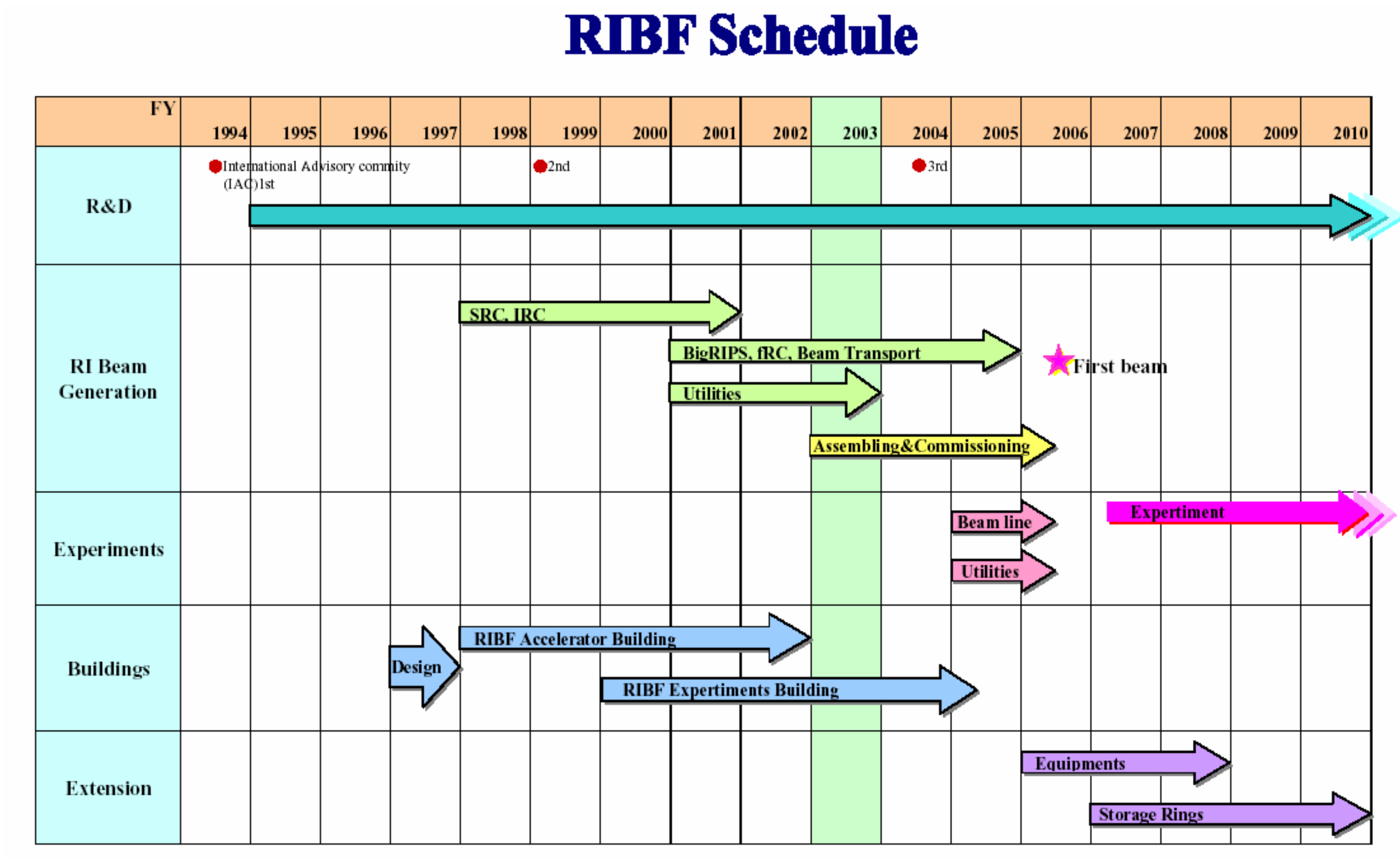
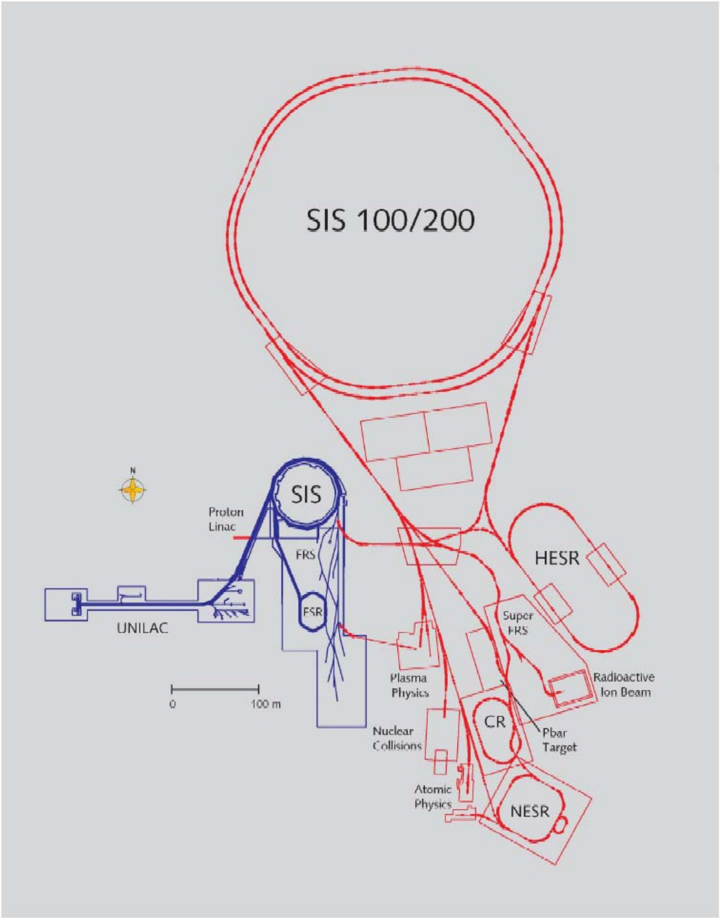


RIBF Schedule



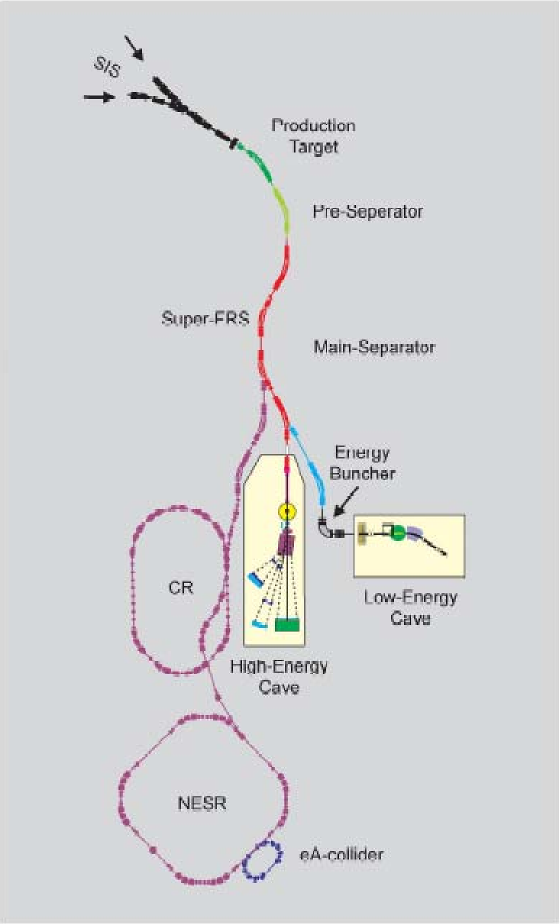
GSI Upgrade (Germany)

- **International Accelerator Facility – to 1.5GeV/u**
  - **Blue – existing facility**
    - **UNILAC**
      - **UNIversal Linear ACcelerator**
    - **SIS 18 (Tm)**
      - **Heavy (Schwer) Ion Synchrotron**
    - **FRS**
    - **ESR**
  - **Red – upgrade to facility**
    - **SIS 100 (SC) 1100 m cir.**
    - **SIS 200 (SC)**
    - **HESR**
    - **CR**
    - **NESR**
    - **Super-FRS**

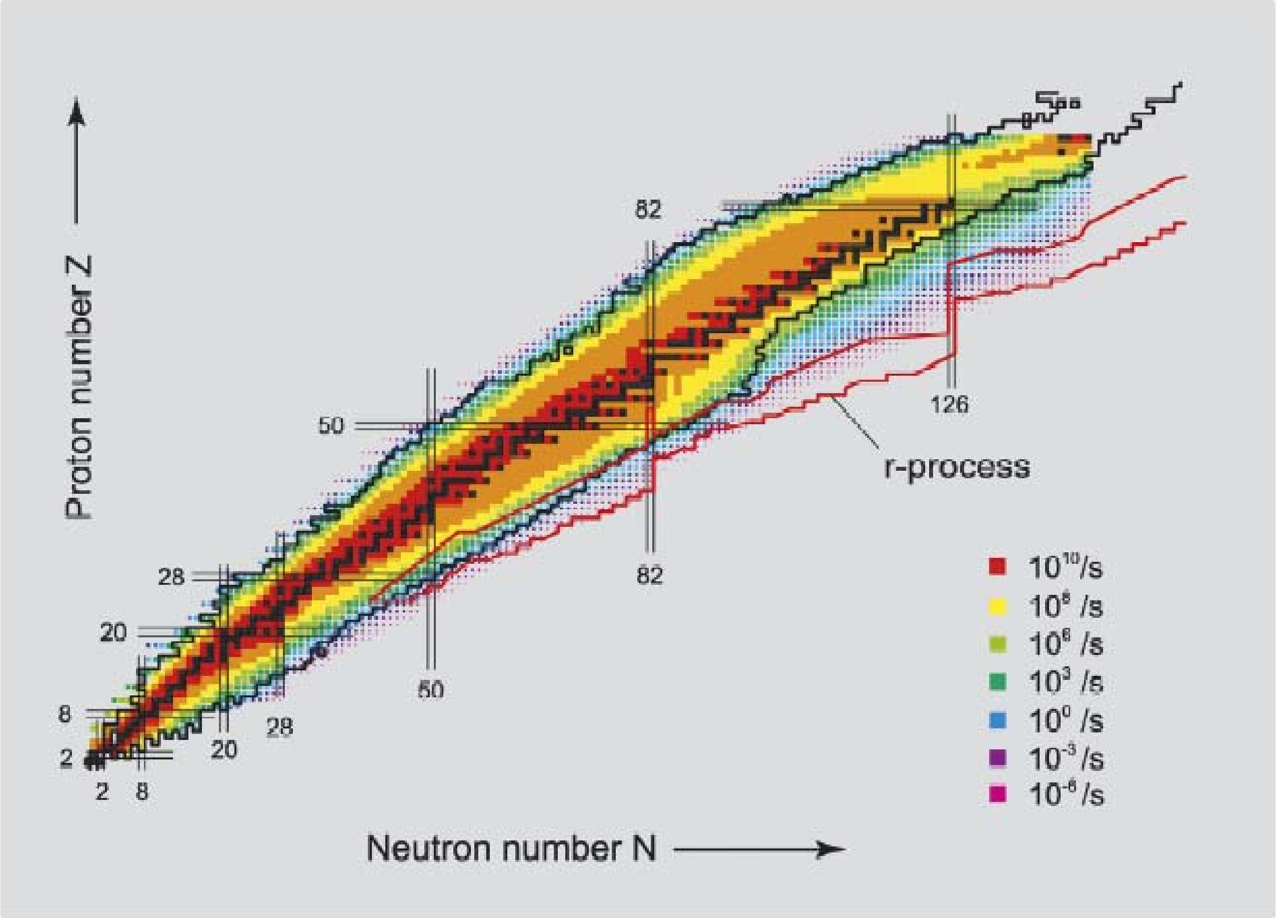


GSI Rare Isotope Facility

- **Schematic of proposed rare isotope beam facility:**
  - **Super-FRS**
  - **Collector Ring**
  - **New Exp. Storage Ring**
  - **e-A Collider**
- **High and Low Energy Experimental Areas**



GSI Production Rates



- **Pulsed facility**
- **High energy reach**
- **Factor of 100 less "PR" than RIA (ranges from 5 for heavy and >1000 for light)**

Rationale for Astrophysics
Part of GSI Upgrade

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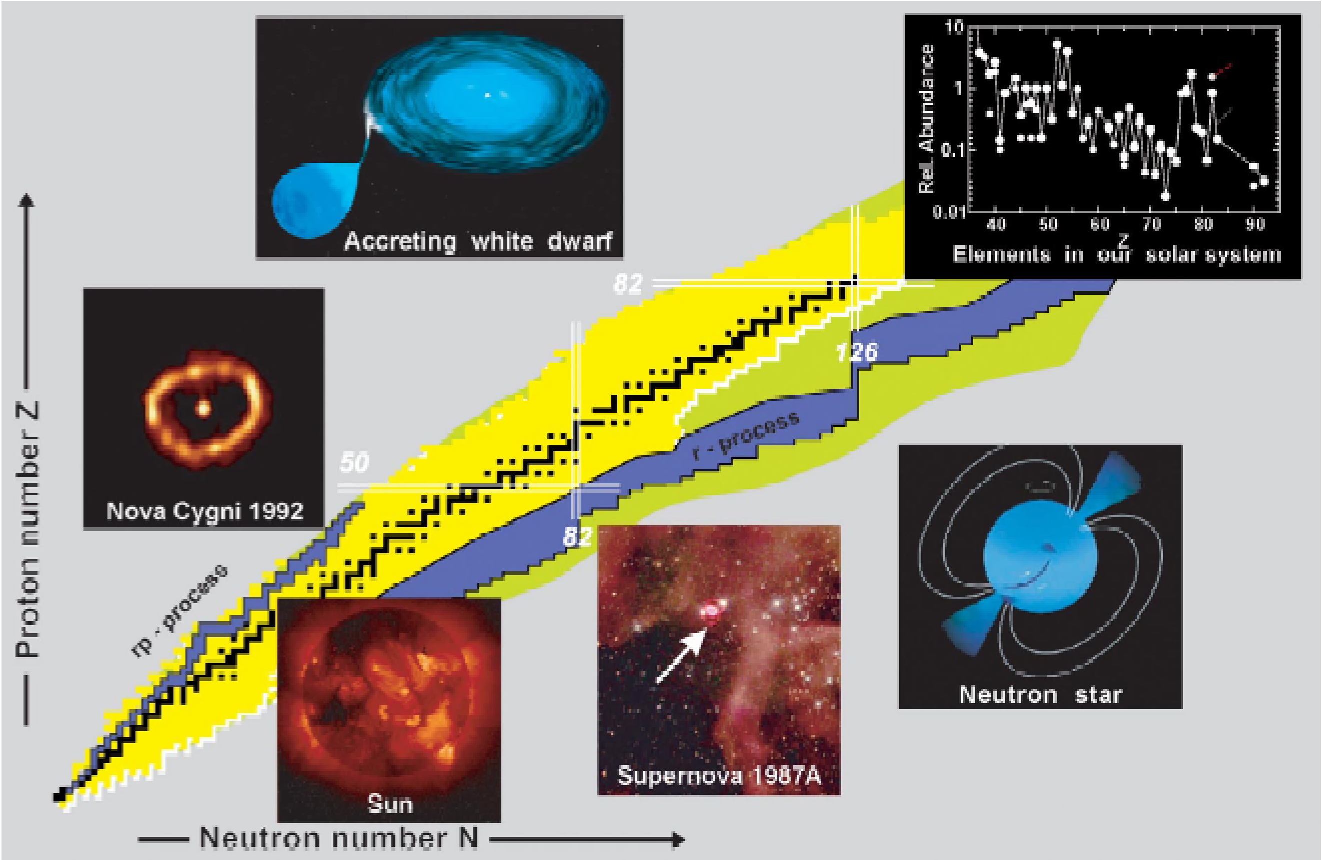


GANIL (France)

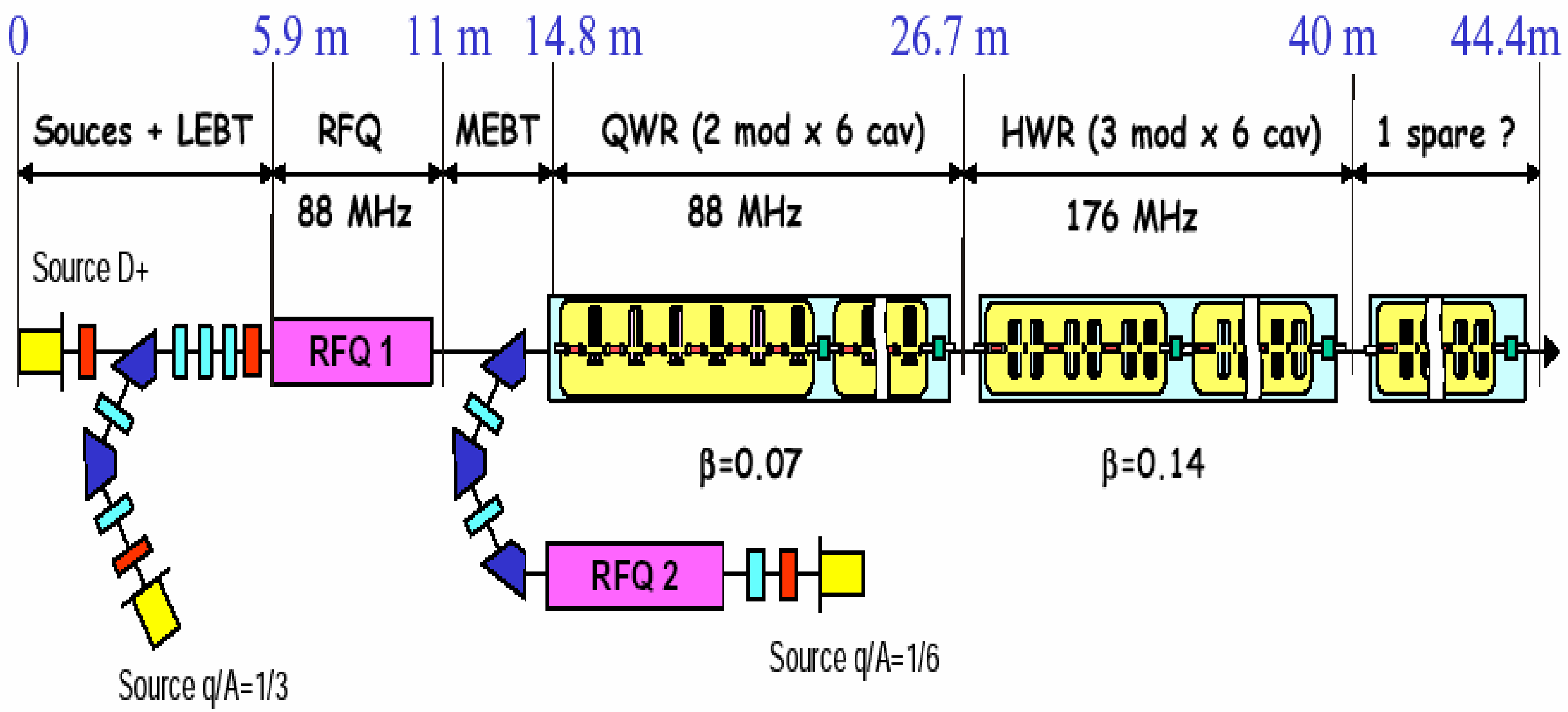
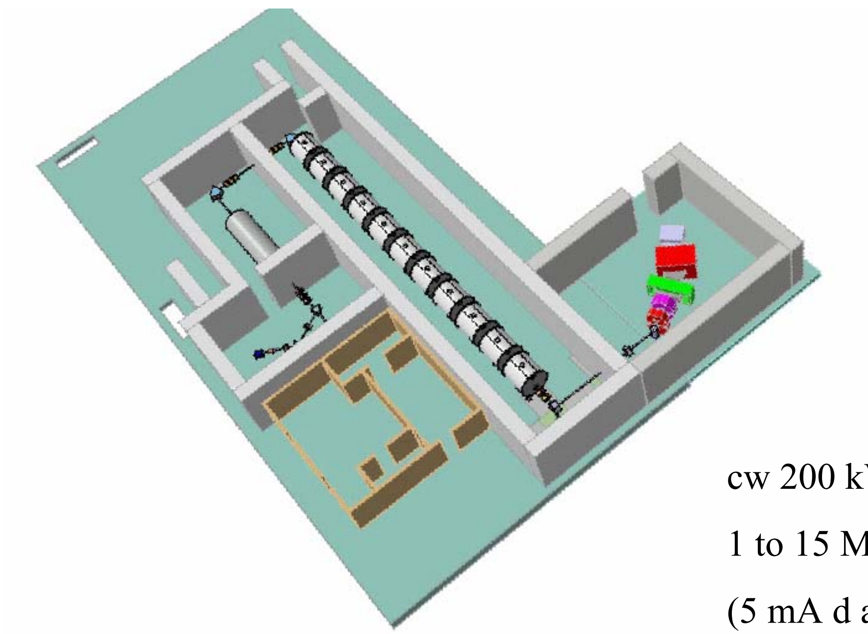
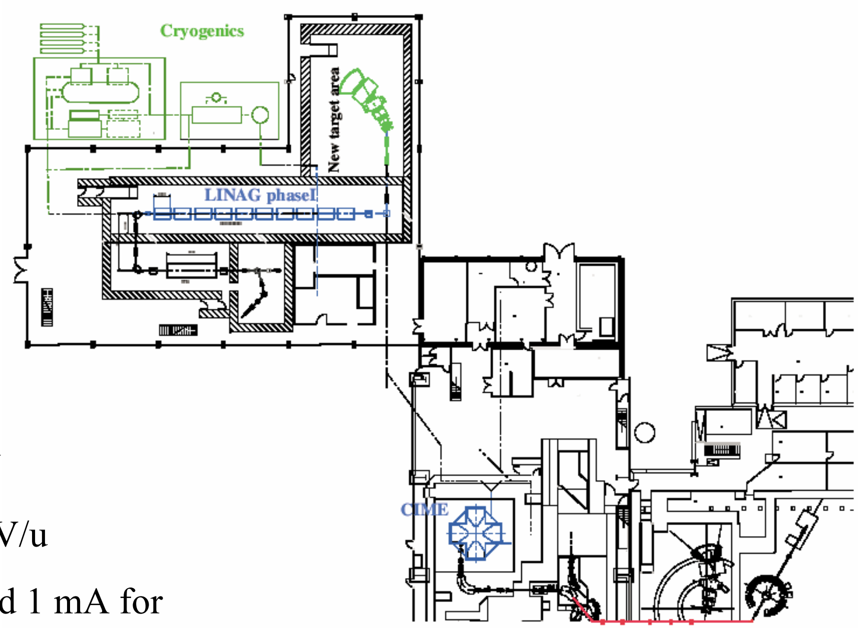


Figure 1 : Architecture of the SPIRAL 2 Linac

SPIRAL II





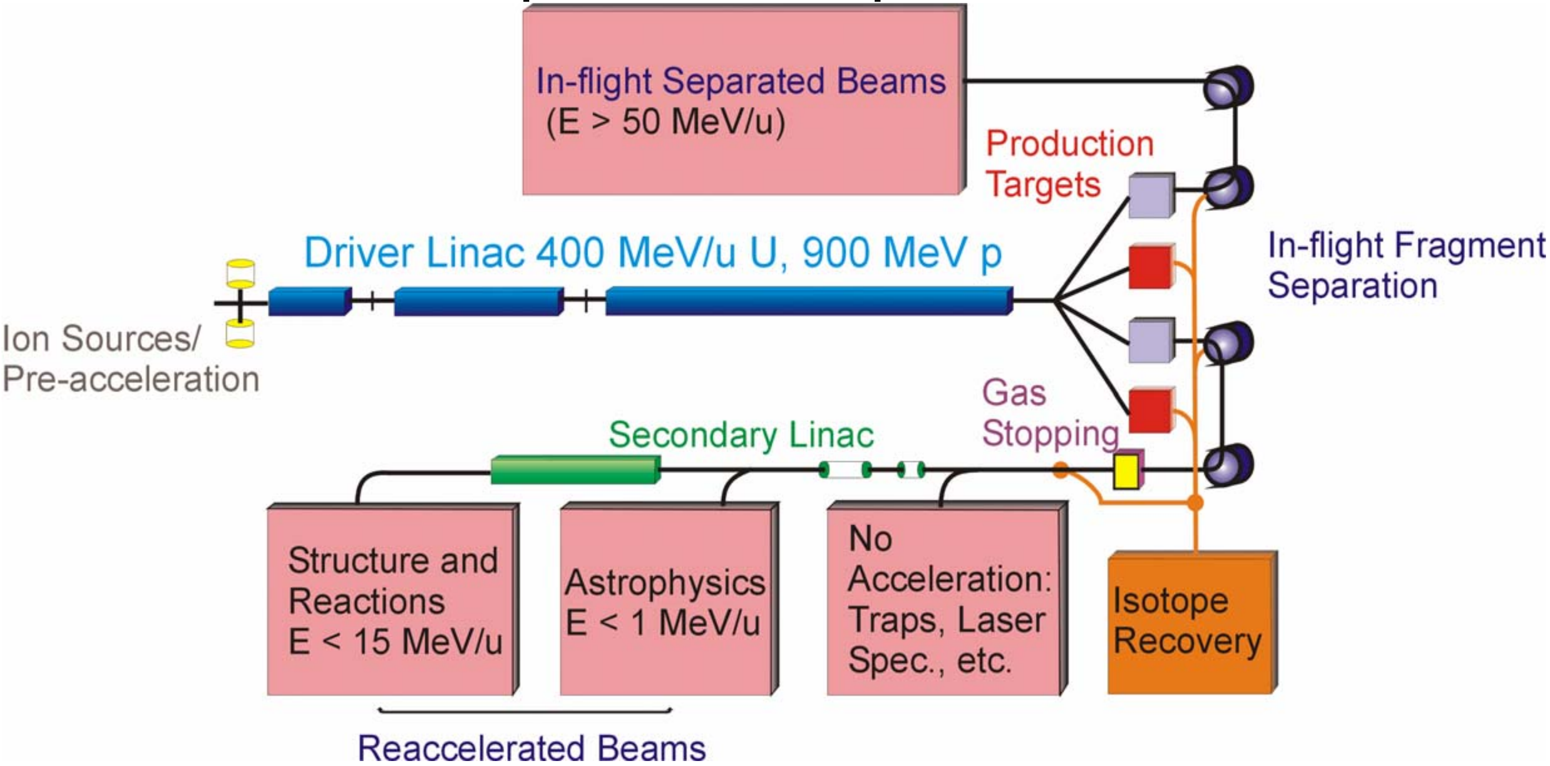
cw 200 kW

1 to 15 MeV/u

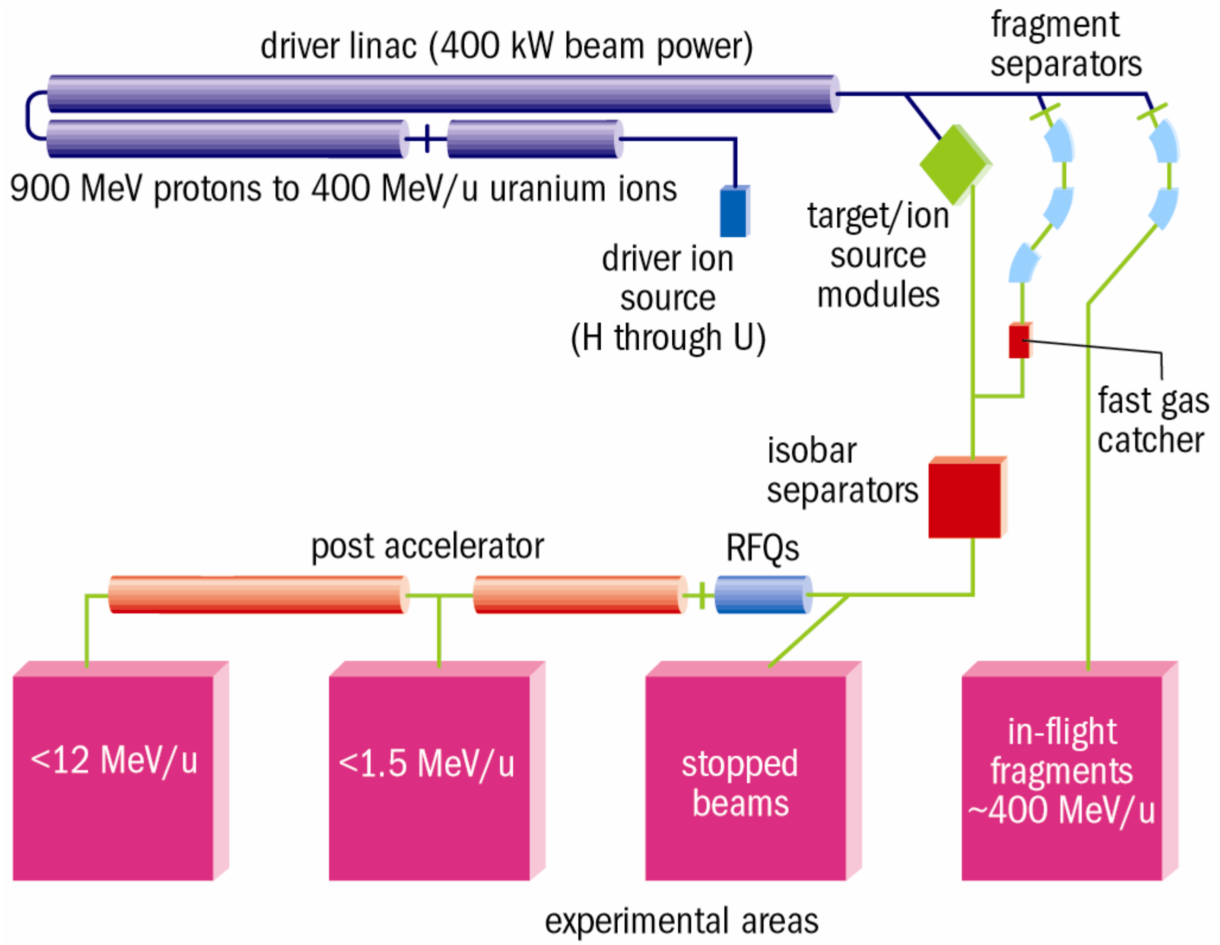
(5 mA d and 1 mA for q/A=1/3)

The Rare Isotope Accelerator (RIA) Concept (US)

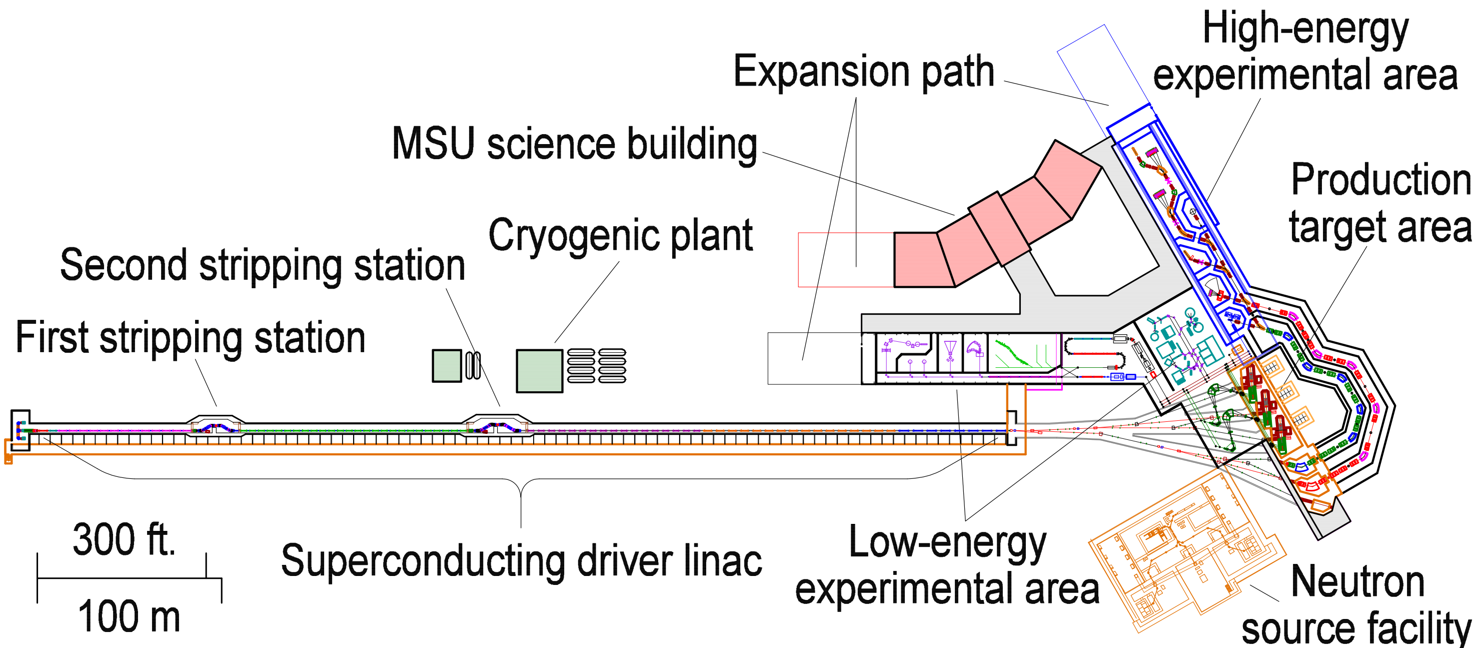
- **Combines advantages of projectile & target fragmentation techniques**
  - **Use all tools developed for rare isotope research worldwide**



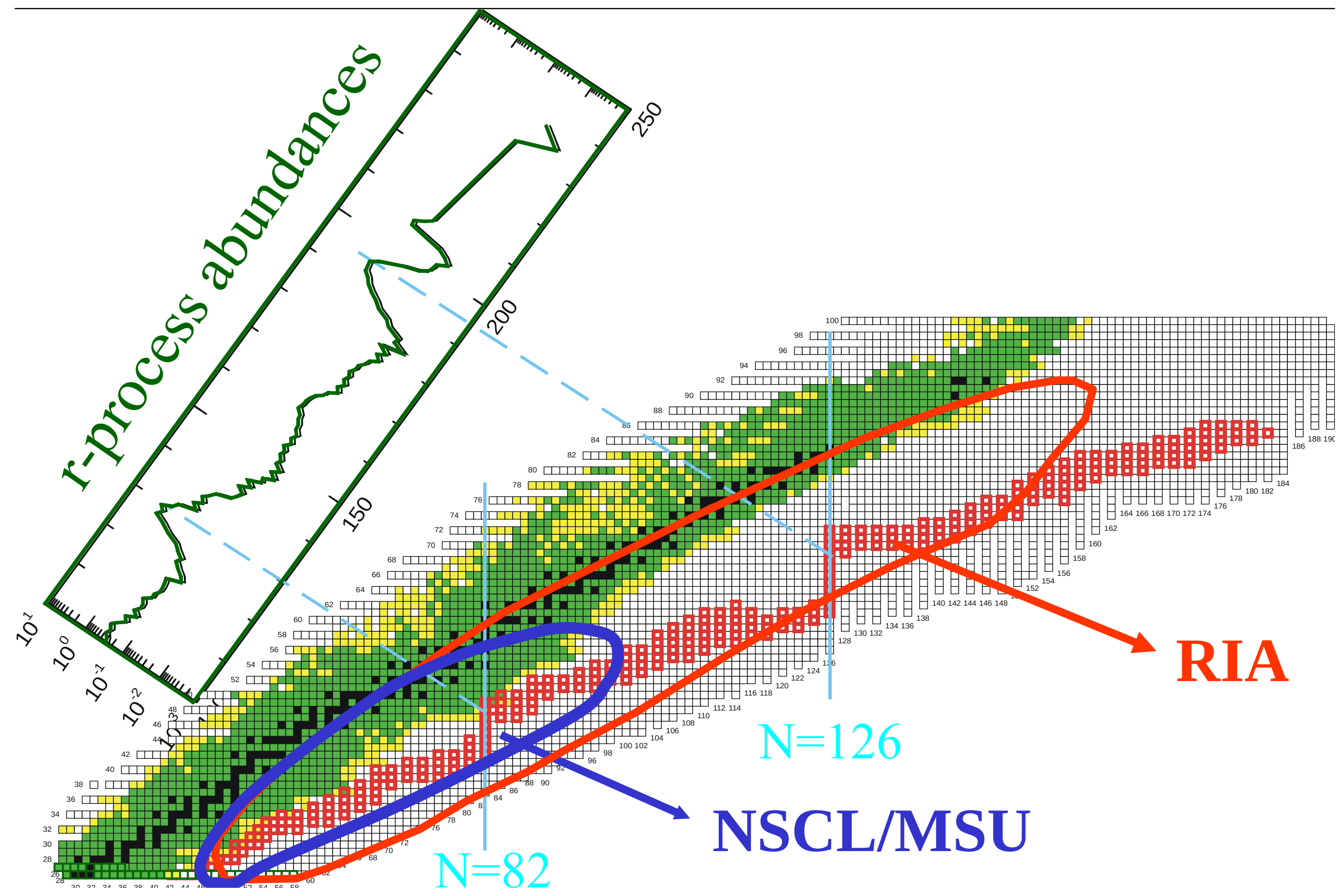
The U.S. Rare Isotope Accelerator Facility



RIA Layout for NSCL/MSU



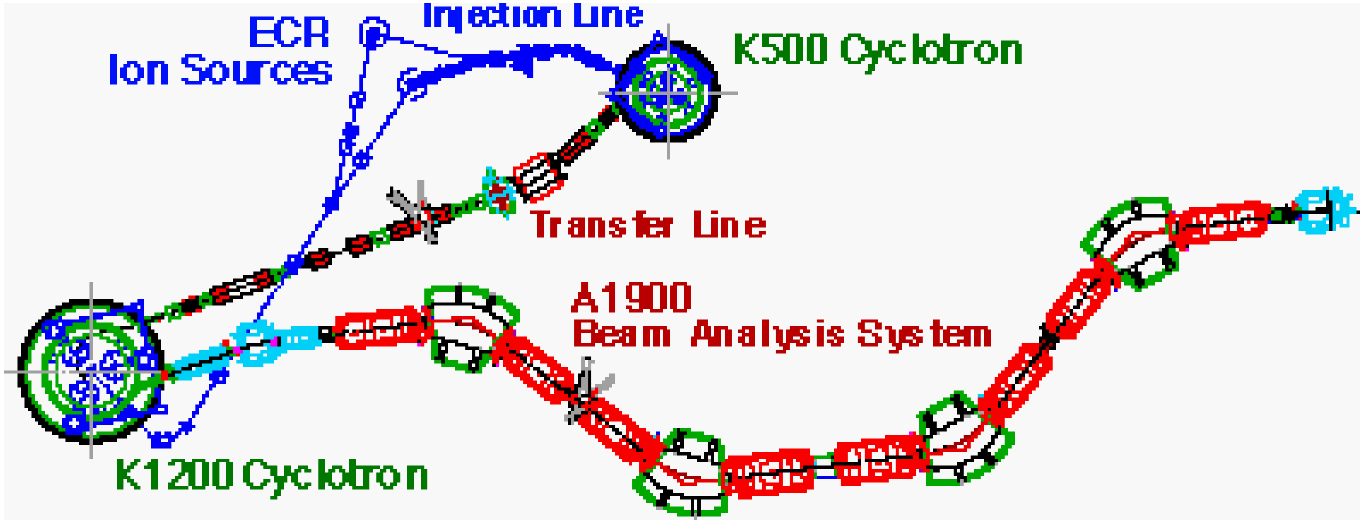
Possibilities to study r-process nuclei



Coupled Cyclotron Facility

Premier fast beam rare isotope research facility in North America

- Richard York, Project Director: on time, on budget
- New A1900 is world's largest-acceptance fragment separator
- Intensity gains for rare isotopes by factors of 100 - 10,000



➔ Major additional upgrades and reconfigurations in progress

The Scientific Reach of RIA

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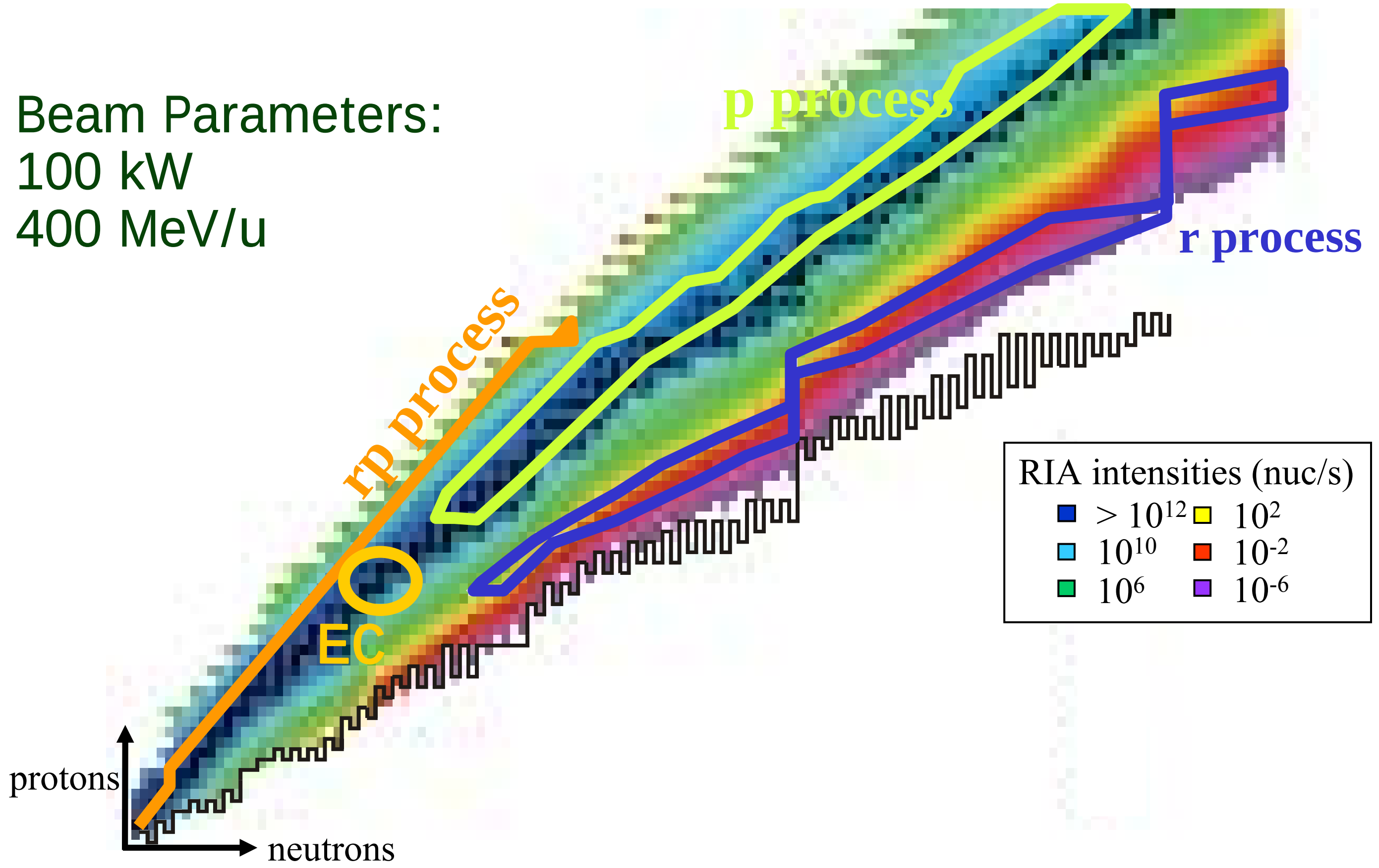
Beam Parameters:
100 kW
400 MeV/u



RIA still a Proposal
(DOE funding R&D -- $3.5M this fiscal year)

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- **Two organizations (with help from many other entities) working design issues – ANL & MSU.**

  ⇓ **In agreement with Ken Shepard's statements Wednesday.**
- ***Both linac concepts are feasible* – can provide the beam specifications 400 kW for 400 MeV/u U to 900 MeV p.**
  - **Two accelerator designs are close in generality.**
  - **Details differ (e.g. recent ANL 3-spoke cavity study [Ken Shepard WeO08])**
  - **Much to be done:**
    - **Optimization.**
    - **Demonstrating availability of key components.**
    - **Performance demonstrations for all aspects of control and beam loads.**
    - **Error tolerances.**
    - **Beam dynamics code comparisons: 6D phase space as calculated by each team easily meets stringent requirements.**
  - **Big future efforts could be:**
    - **Meeting construction schedule with demonstrated technology.**
    - **Cost optimization.**
    - **Flexibility for future upgrades.**
    - **Reliability and component counts/backups.**
    - **Ease of control and ion species change-over times.**
- **Besides accelerator:**
  - **Much work remains on targets, rare-isotope transport, shielding and experimental stations.**

RIA

Relative to RIA parameters and expected performance

- **Compared to GSI**
  - **Intensities for most isotopes at least a factor of 100 higher for RIA (varies from *5 for heavy and >*1000 for light).**
  - **Higher energy per nucleon for GSI.**
- **Compared to ISAC II**
  - **Isotope reach much higher in A for RIA.**
  - **Intensities for isotopes higher for RIA.**
- **Compared to GANIL SPIRAL II**
  - **Intensities higher for RIA.**
  - **More isotopes for RIA.**
- **Compared to RIKEN RIBF**
  - **Intensities higher for RIA.**
  - **Re-accelerated beams for RIA.**

What does this mean for SRF?

BIG impact !?!

- **High quality niobium.**
- **Quarter wave cavities.**
- **Half wave cavities.**
  - **(Cylindrical, spoke, ladder, multi-gap)**
- **Elliptical cavities.**
- **Cryostat designs.**
- **Tuners, couplers.**
- **High fields:**
  - **Reliability, availability, maintainability, repeatability, commissioning ease.**
- ***Cheaper, better faster !?!***

Areas for Advances!

- **Cavity designs (e.g. multi-gap structures, low-loss ellipticals)**
- **Material other than Nb.**
- **Manufacturing techniques.**
- **Improved stacking factor.**
- **Cryostats.**
- **Control and turn-on systems.**
- **Low level rf control.**
- **Transient recovery.**
- **Fast tuners.**
- **Lorentz force compensation.**
- **Microphonics control**

Summary and Conclusions

- Rare Isotope Accelerators have an interesting future.
- This future has a big impact on SRF.
- Much to be learned in R&D, construction, operations and in the scientific output from users.
- Big steps forward.
- Much work to be done by SRF community.
- Collaborations are extremely important.
- A FUN time for all!

Extras Following!!!

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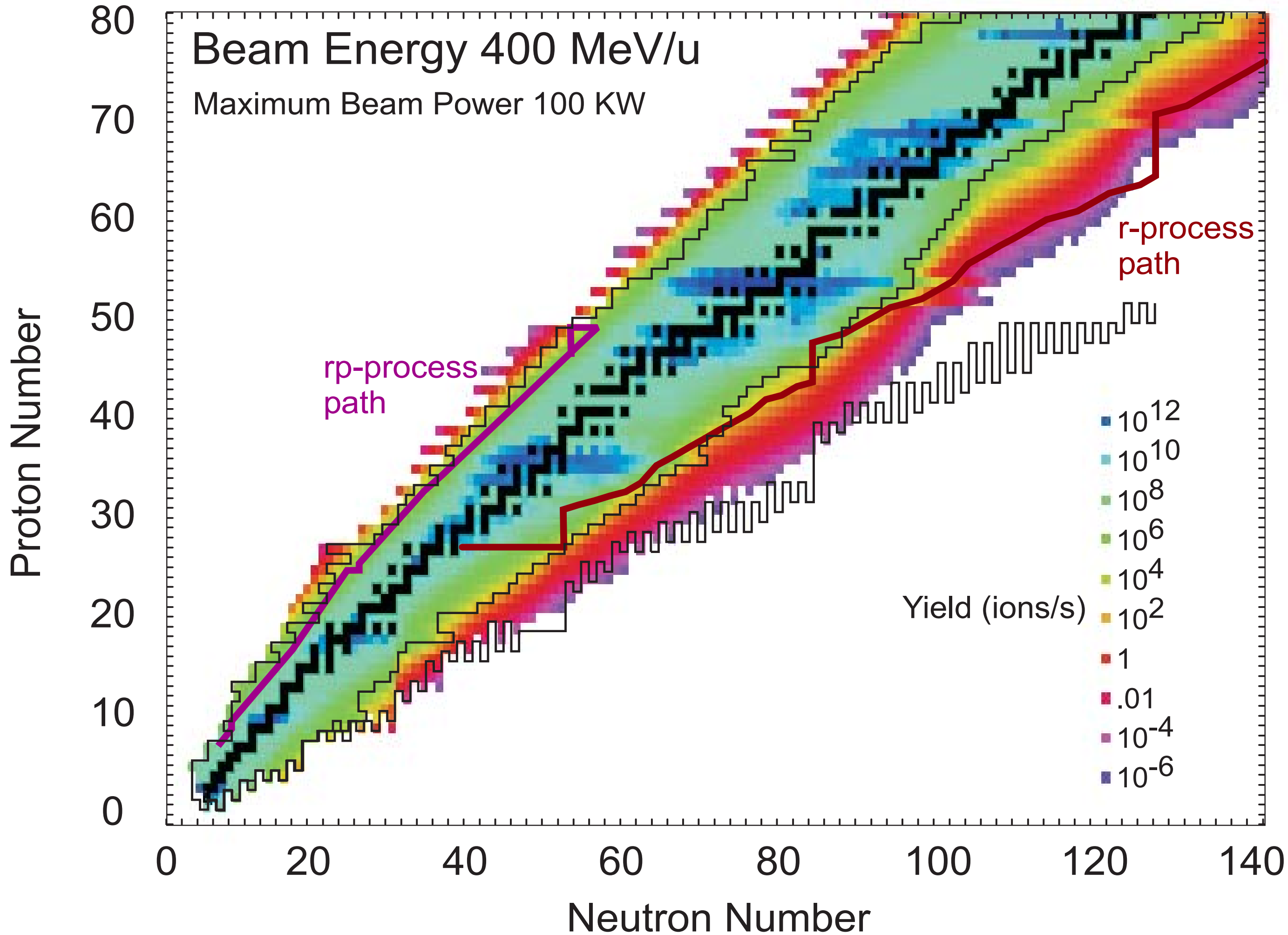
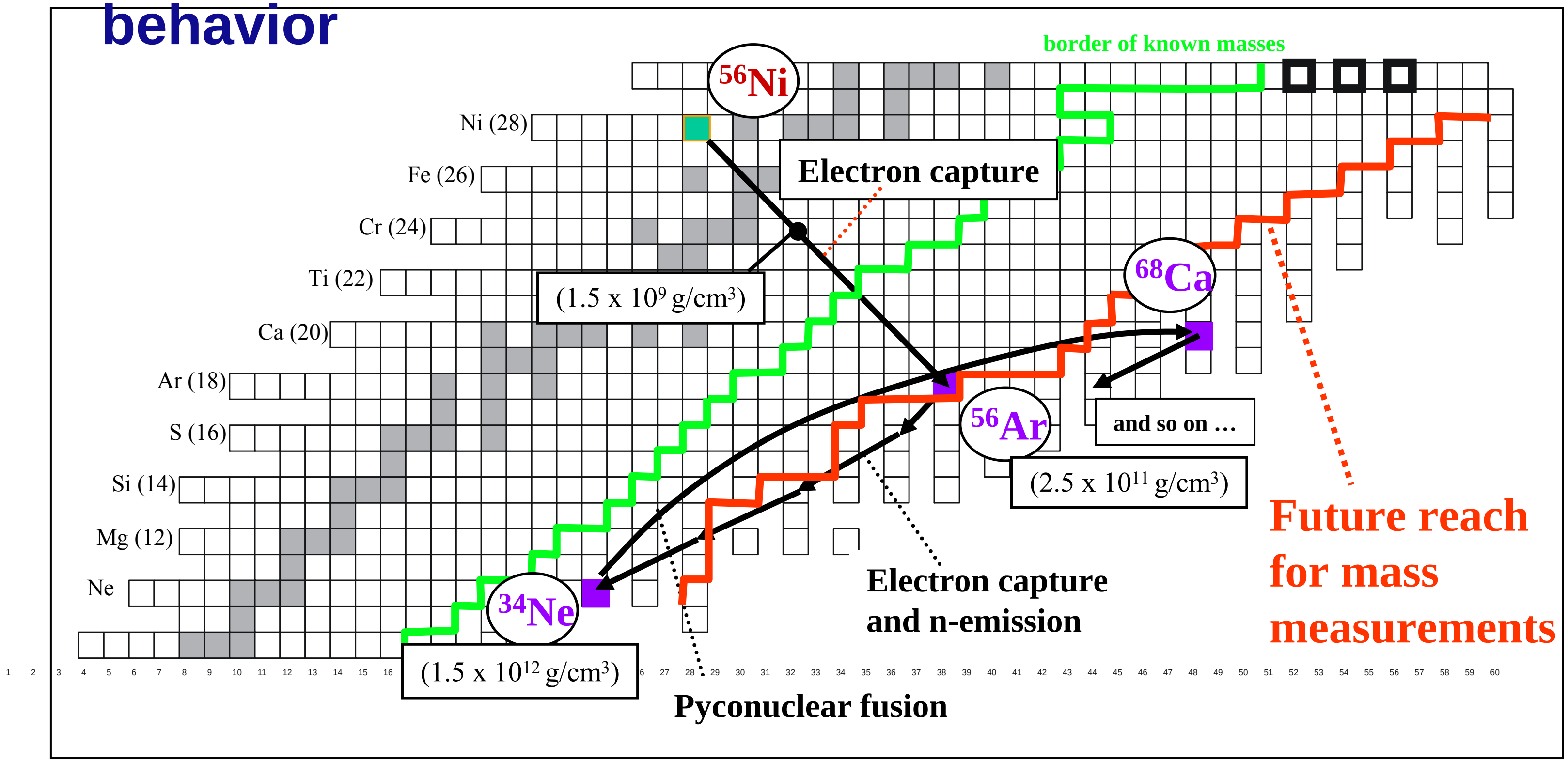
- **Supporting slides for project justification**

The Scientific Reach of RIA



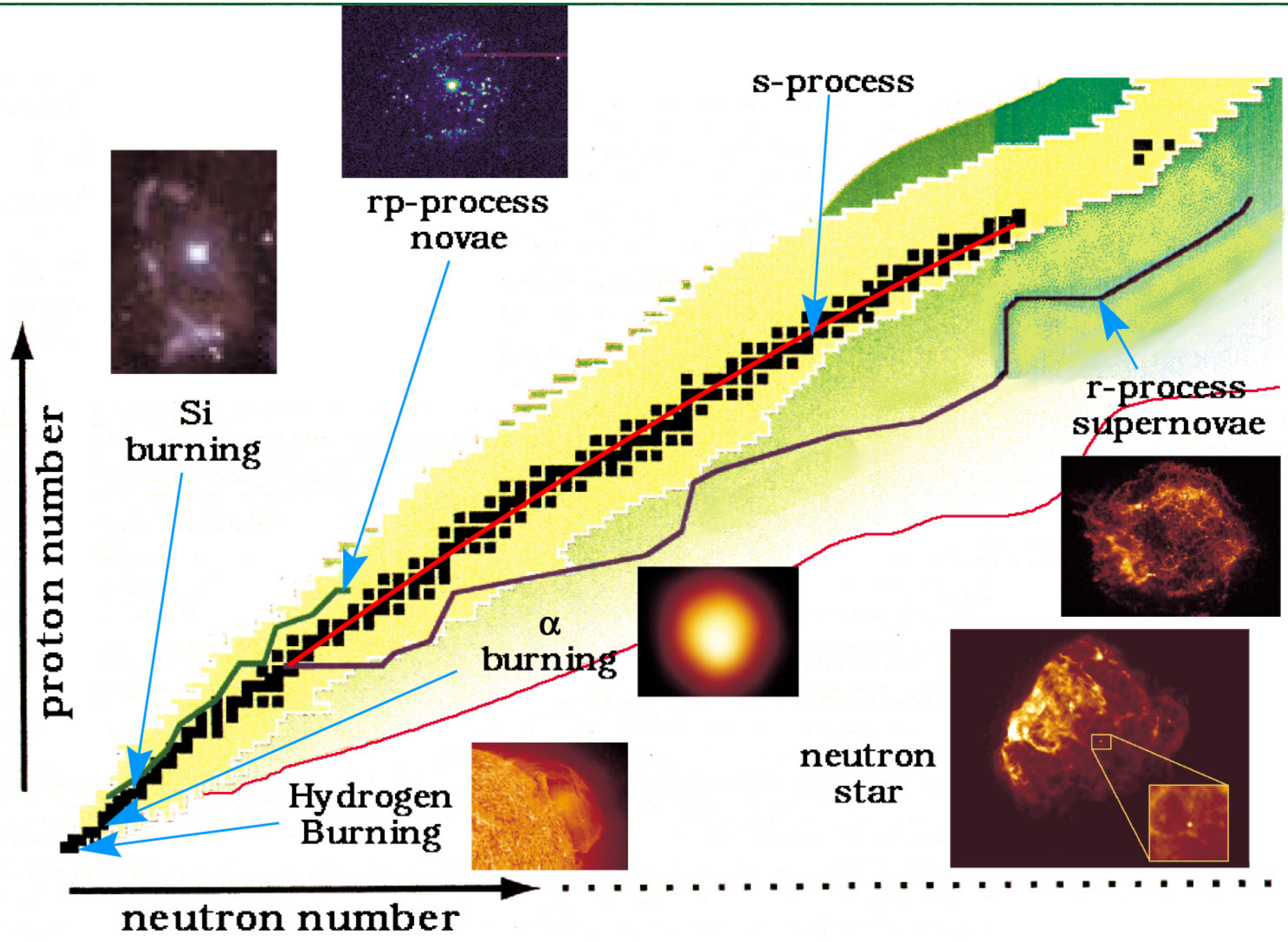
Crust deformation → gravitational wave emission

Crust heating → thermal radiation and burst behavior

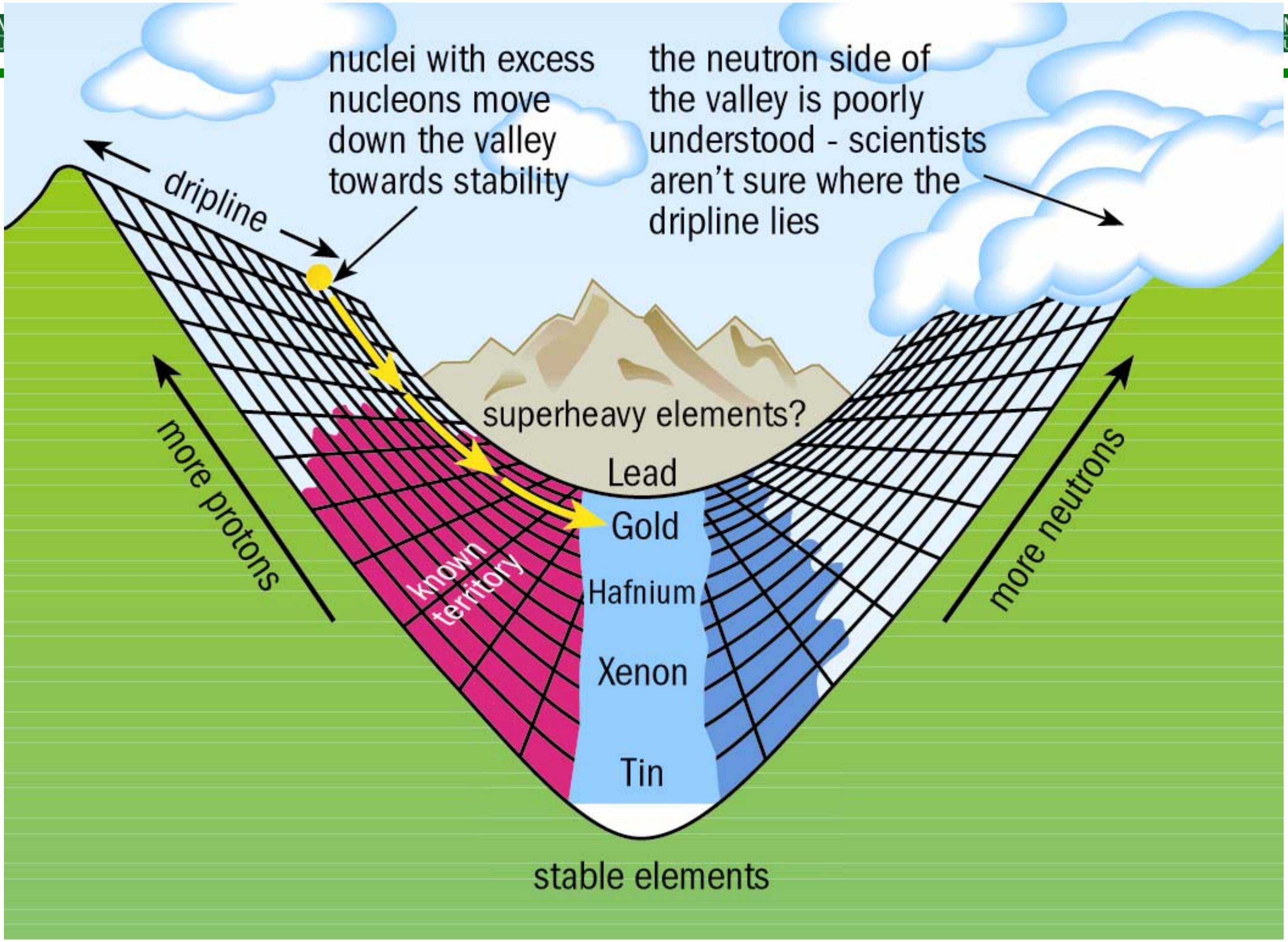


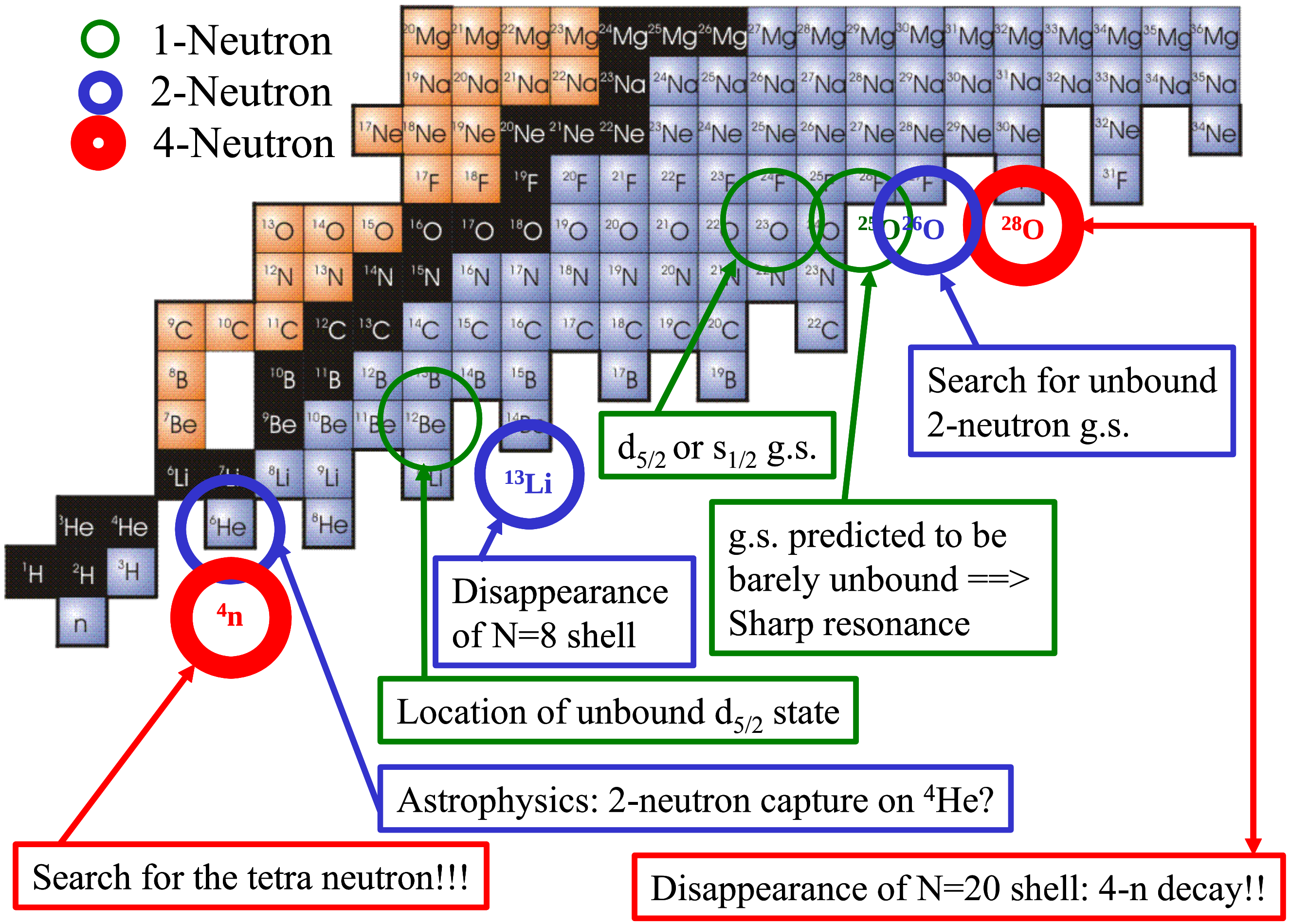
Need: masses and electron capture rates out to the dripline for A = 34-106

Nuclear Astrophysics

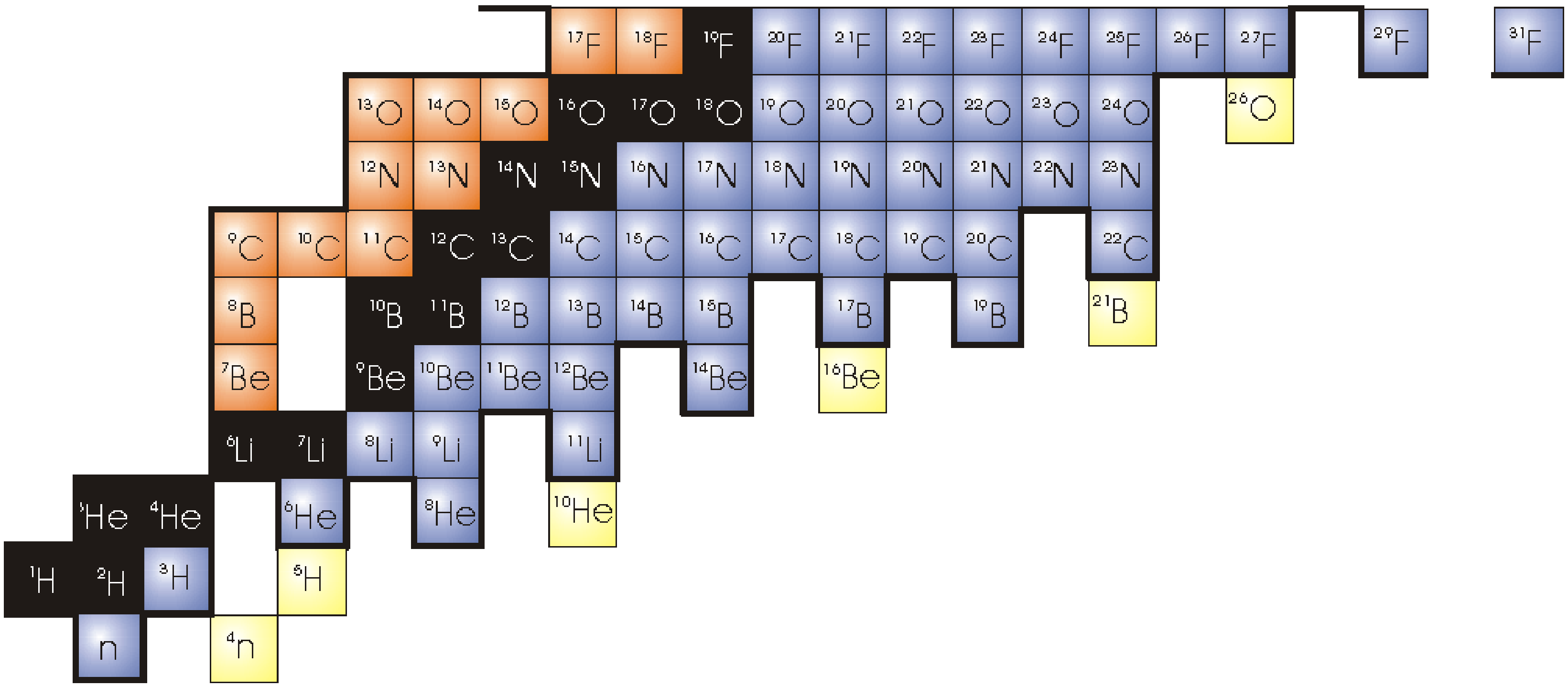


Rare Isotopes Surround the Valley of Stability




1-Neutron
2-Neutron
4-Neutron
Search for unbound 2-neutron g.s.
d5/2 or s1/2 g.s.
g.s. predicted to be barely unbound ==> Sharp resonance
Disappearance of N=8 shell
Location of unbound d5/2 state
Astrophysics: 2-neutron capture on 4He?
Search for the tetra neutron!!!
Disappearance of N=20 shell: 4-n decay!!
4n
13Li
25O
26O
28O

Neutron Dripline Known up to Z = 8 ??



One thing we thought we knew about nuclei

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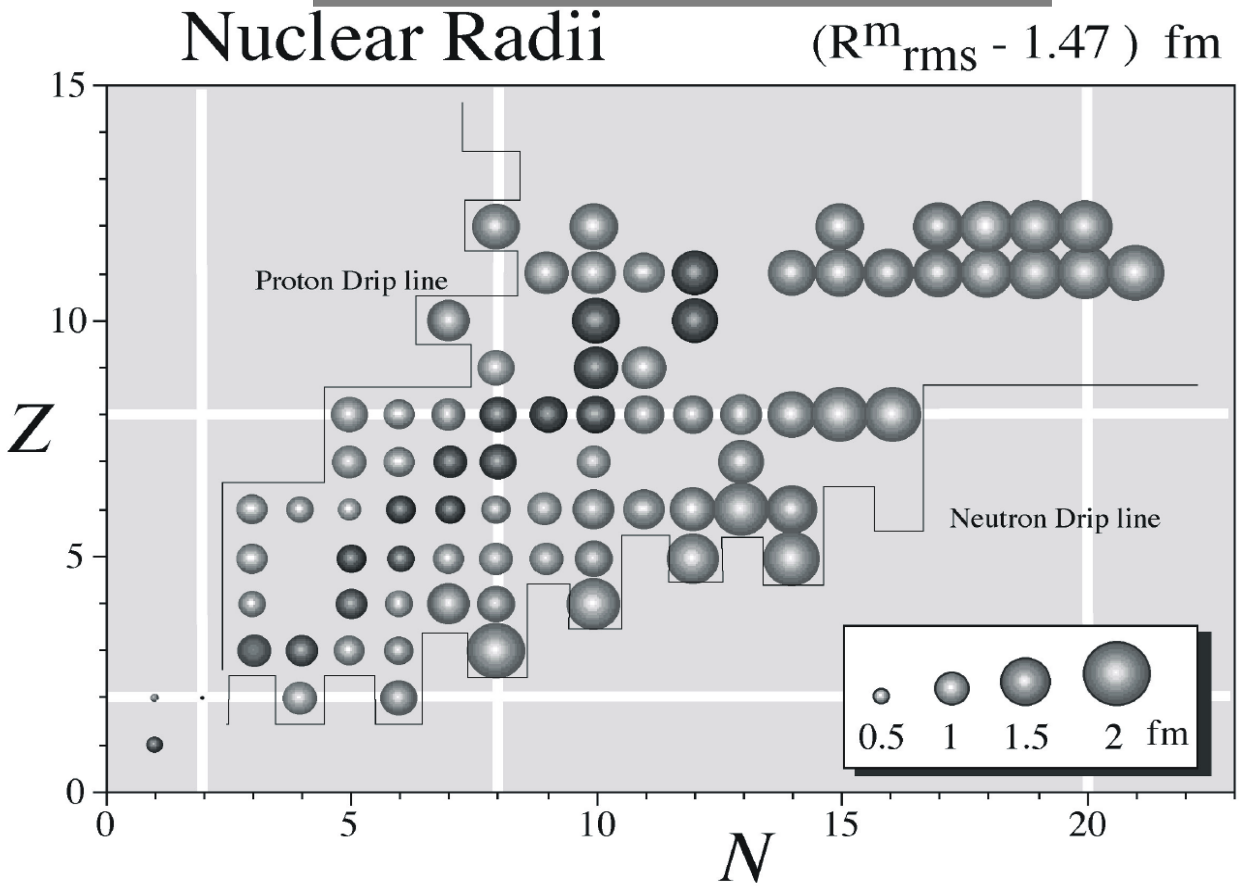
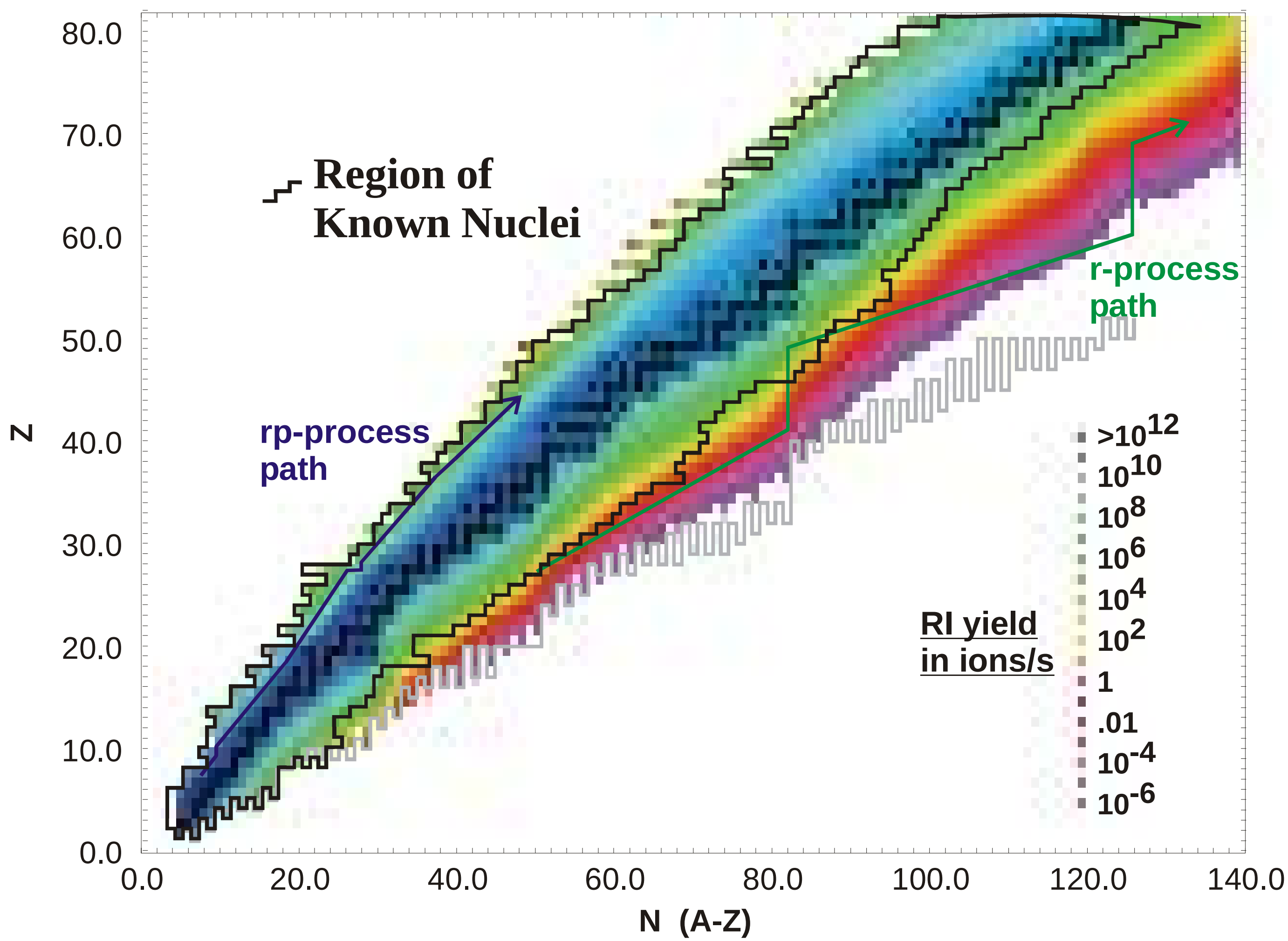
Textbooks: $R = r_0 A^{1/3}$

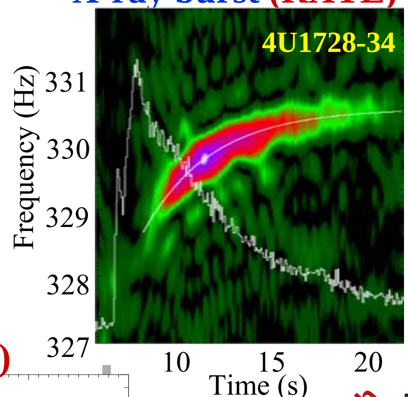


Availability of Secondary Ions

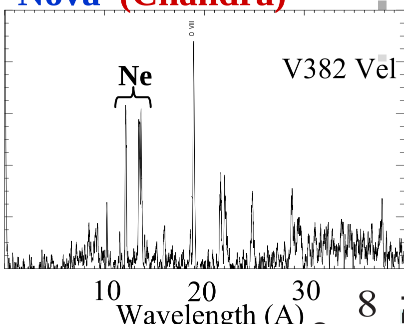


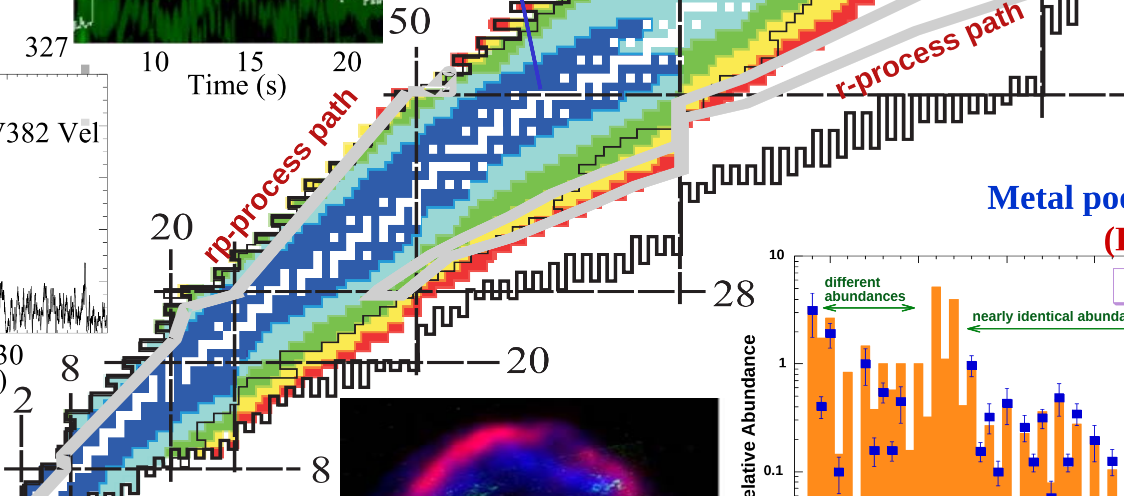
Scientific Reach of CCF

X-ray burst (RXTE)

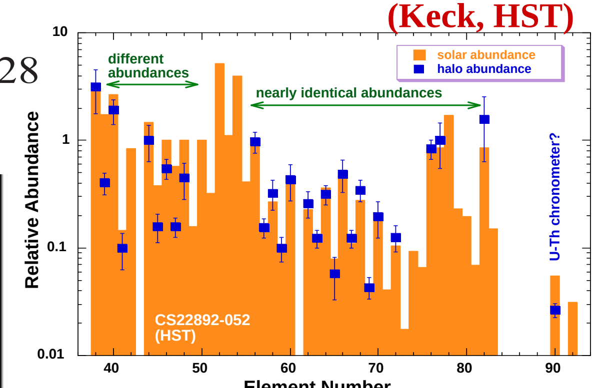


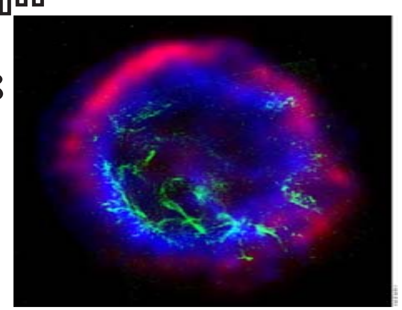
Nova (Chandra)





Metal poor halo star (Keck, HST)





Supernova (HST)