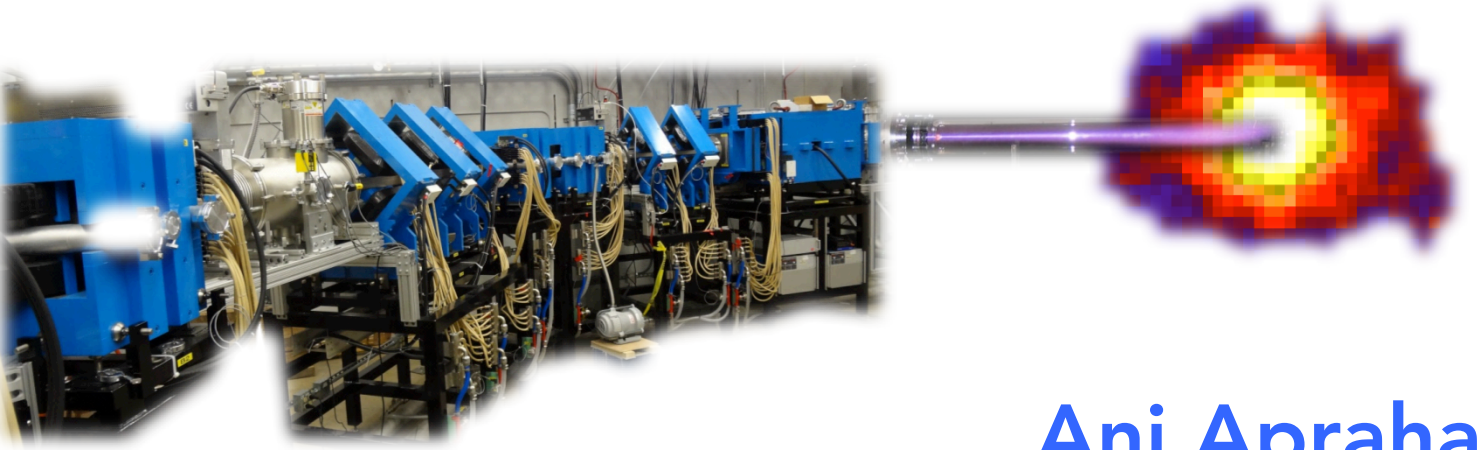
Interfaces with Nuclear Astrophysics



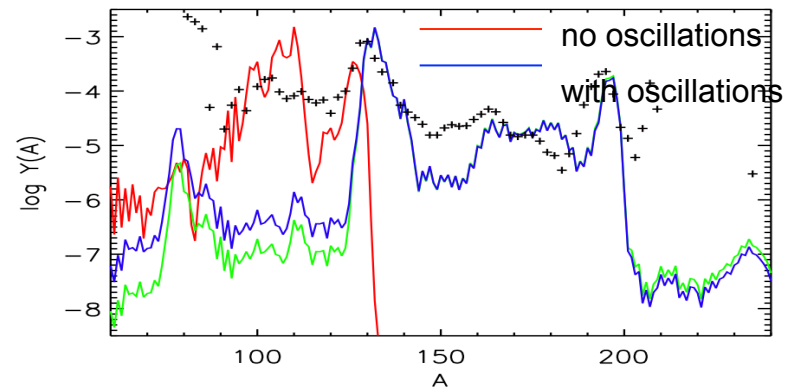
Ani Aprahamian
University of Notre Dame

Fundamental Symmetries, Neutrinos, Neutrons and related Nuclear Astrophysics

Long Range Plan Town Meeting
Sept. 28-29, 2014

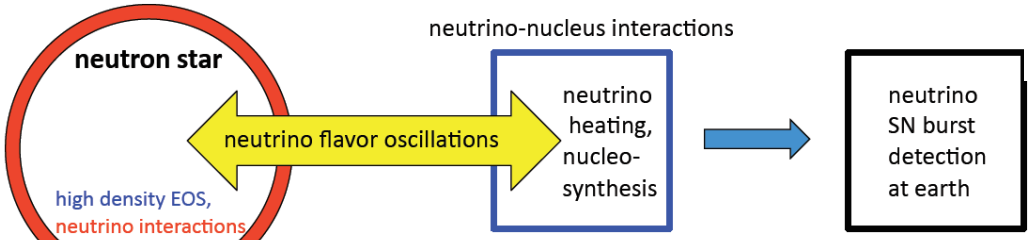
weak interactions and nuclear astrophysics

neutrino oscillations and nucleosynthesis



Malkus, McLaughlin, Kneller, Surman (2012)

neutrinos and nucleosynthesis



$$\nu_e + \mathrm{n} \rightleftharpoons \mathrm{p} + e^-$$
$$\bar{\nu}_e + \mathrm{p} \rightleftharpoons \mathrm{n} + e^+$$

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$$
$$\nu_x + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{Ar}^* + \nu_x$$

Balantekin and Fuller, Prog. Part. Nucl. Phys. **71** 162 (2013).

neutrinos and interactions with hot dense matter

neutrinos and nucleosynthesis

r-process nucleosynthesis and β-decay
stellar evolution, pp, CNO cyle

R. Surman

Interfaces:

stellar evolution, CNO cycle

Experimental: Subthreshold measurements
nuclear reactions

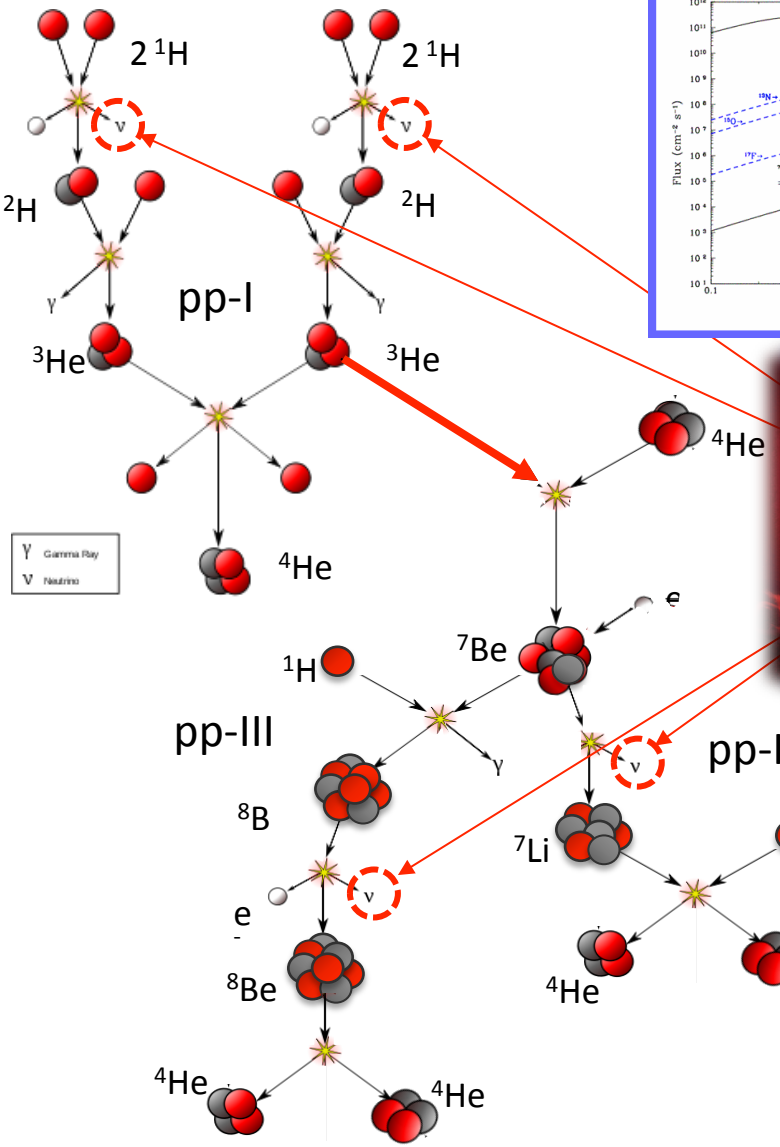
r-process and nucleosythesis

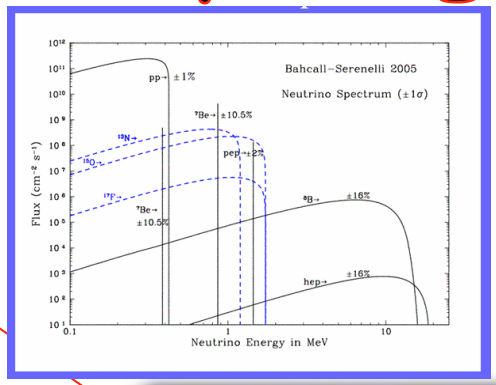
Experimental:Measurements of exotic nuclei

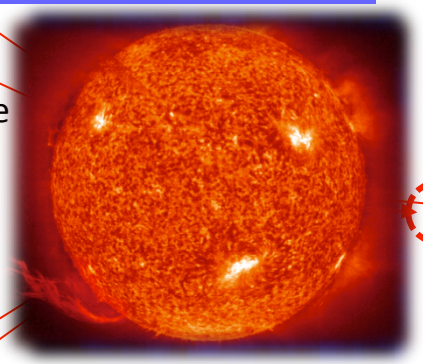
M. Wiescher

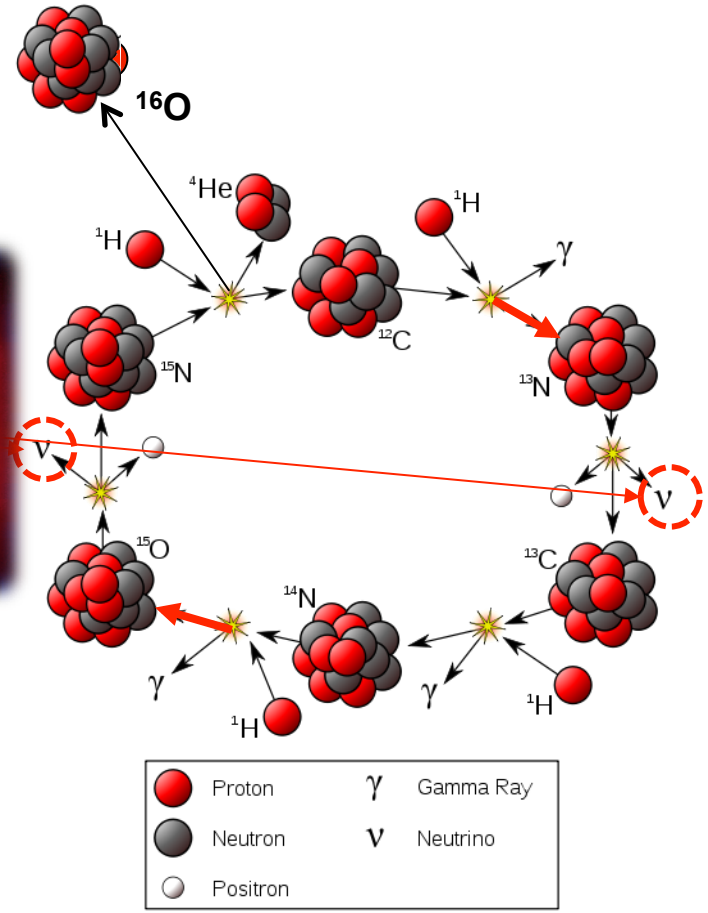
Modes of hydrogen burning

and its neutrino signatures

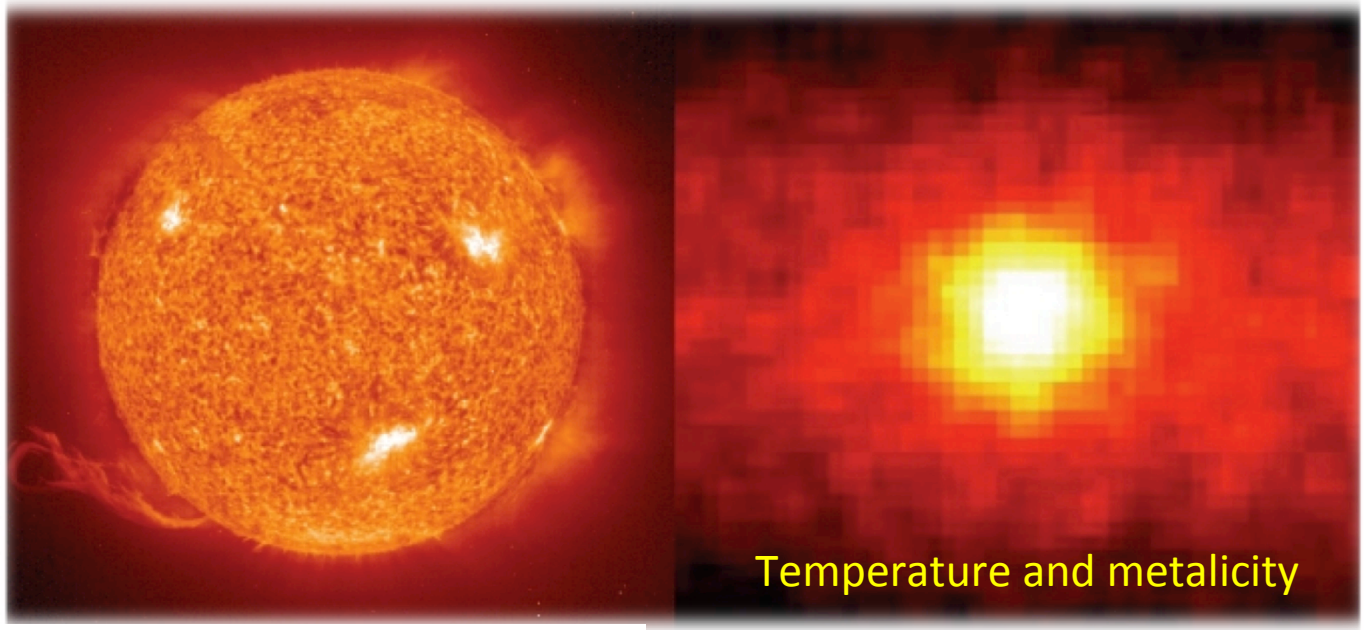


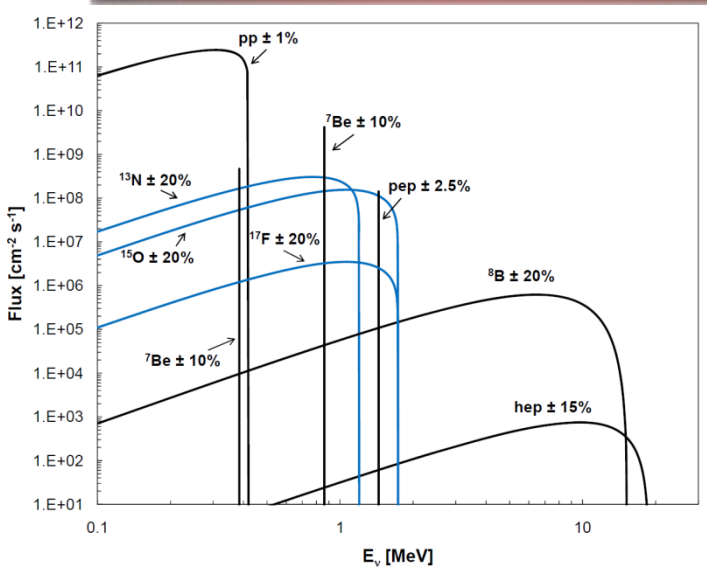


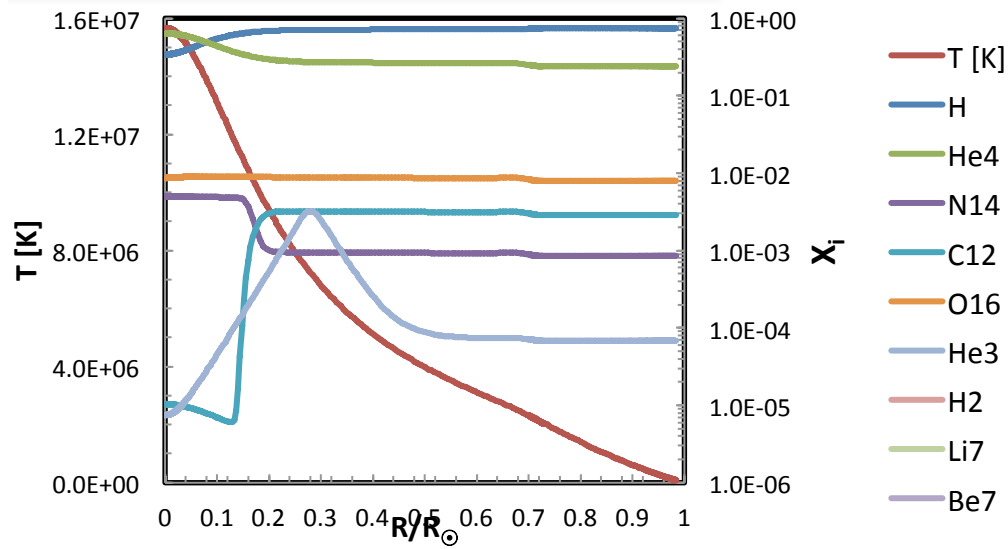




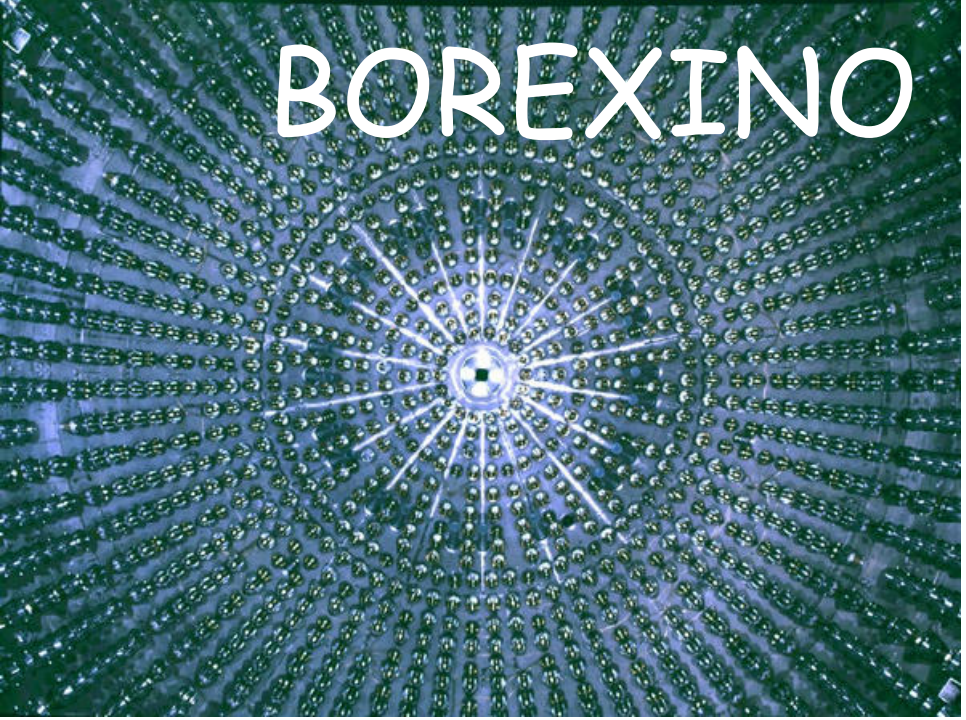
Solar neutrino sources

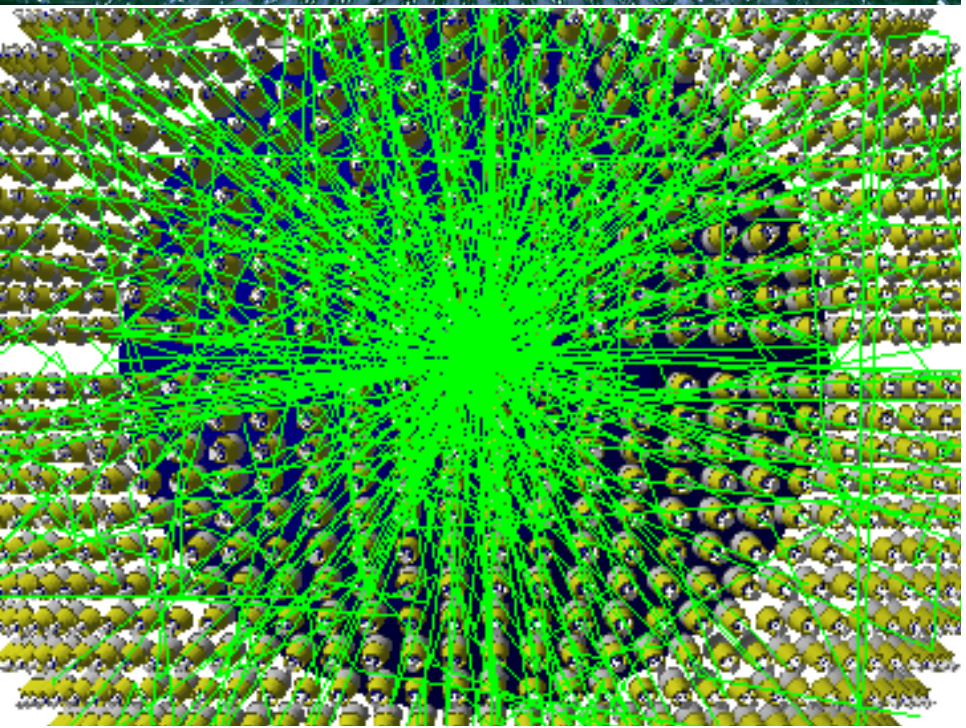




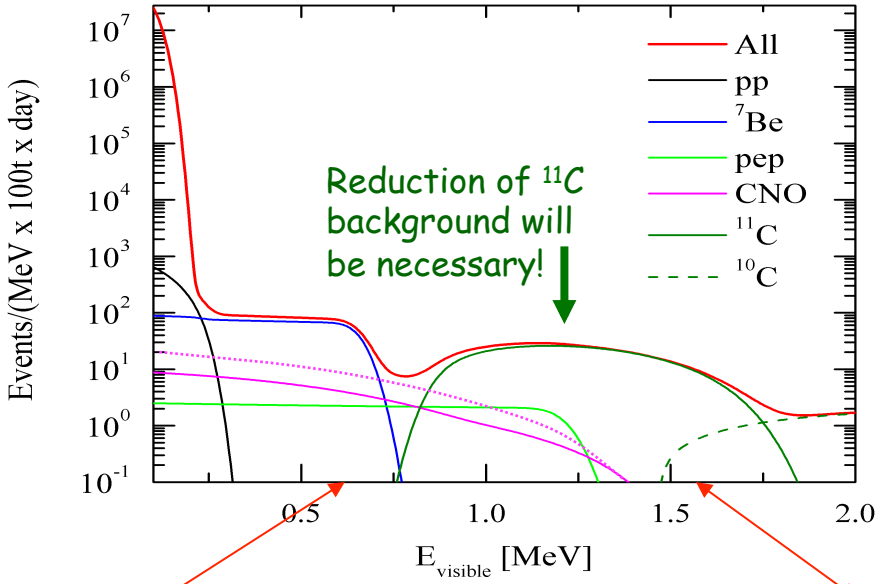


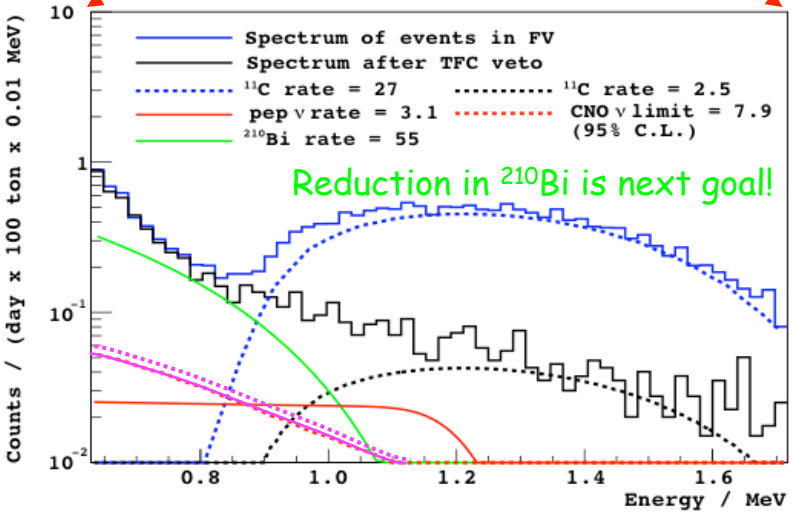
BOREXINO expectations



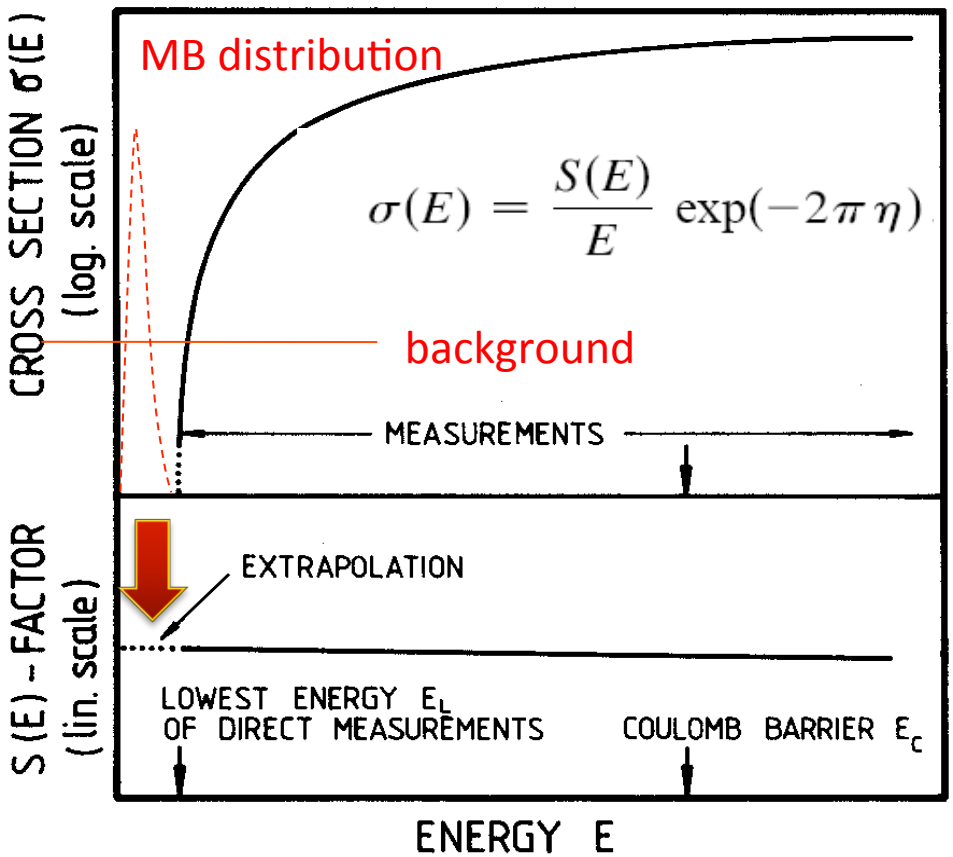


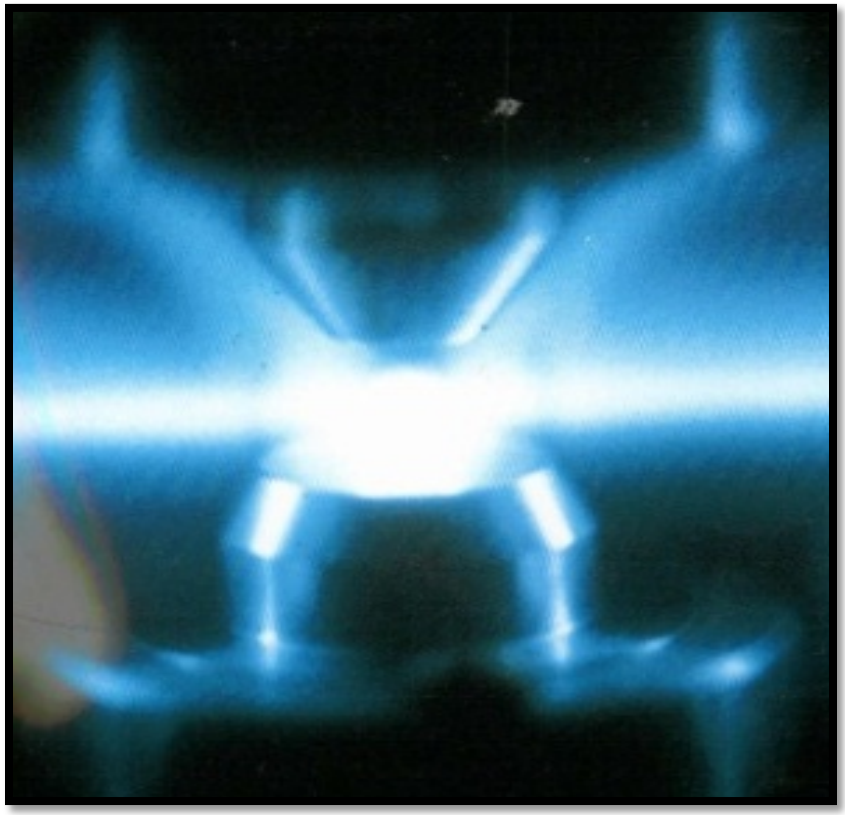
Enhanced flux in ^{13}N neutrinos





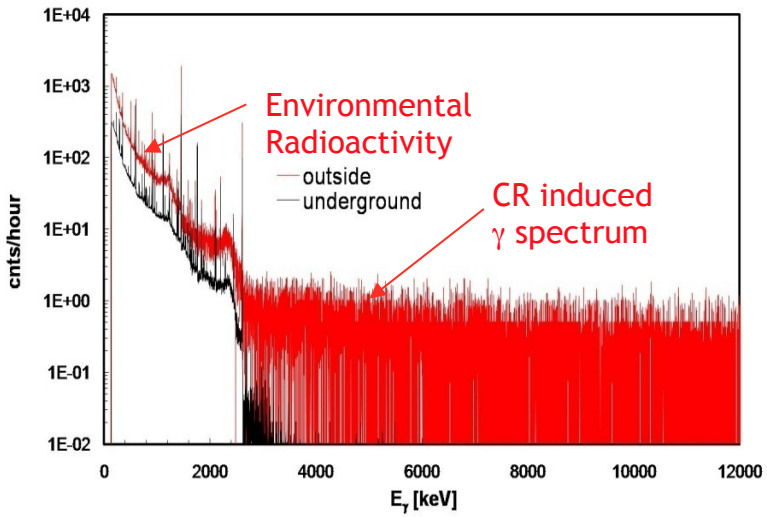
The challenge of reaction rates

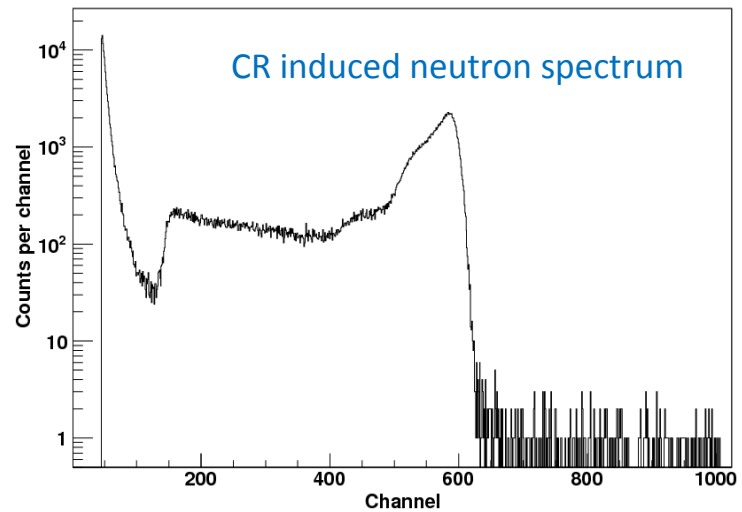


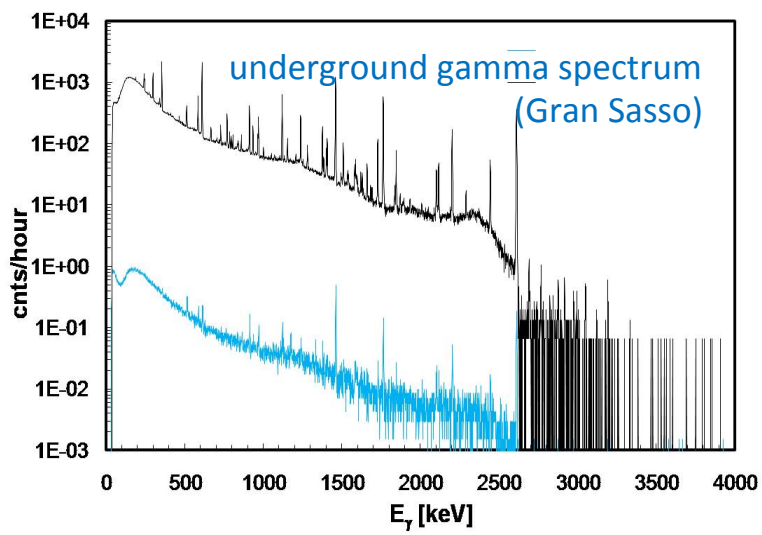


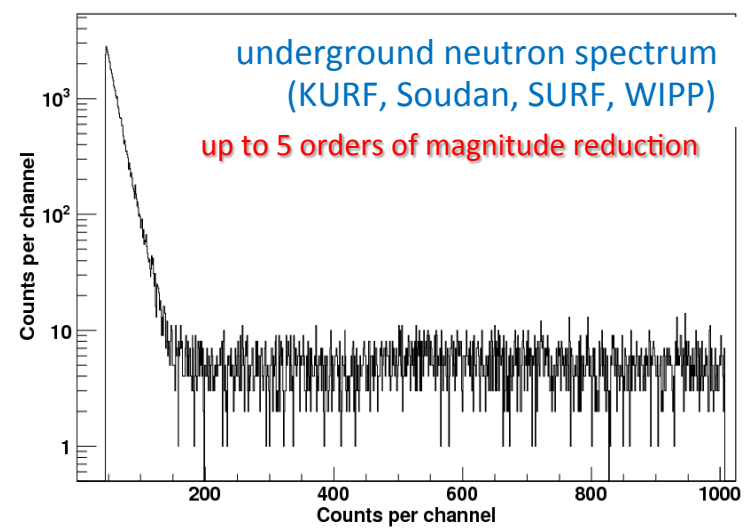
$$N_A\langle\sigma v\rangle = \sqrt{\frac{8}{\pi\cdot\mu}}\cdot(kT)^{-3/2}\cdot\int_0^\infty E\cdot\sigma(E)\cdot\exp\left(-\frac{E}{kT}\right)dE$$

Background Reduction



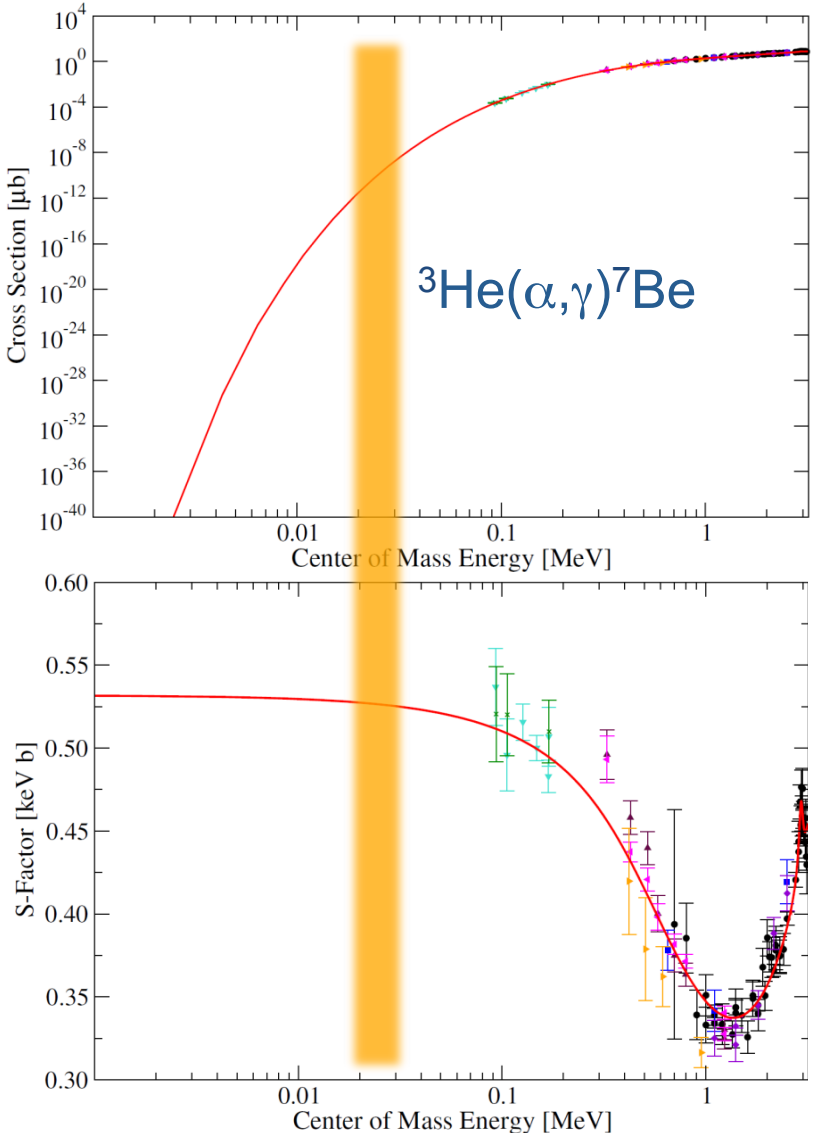


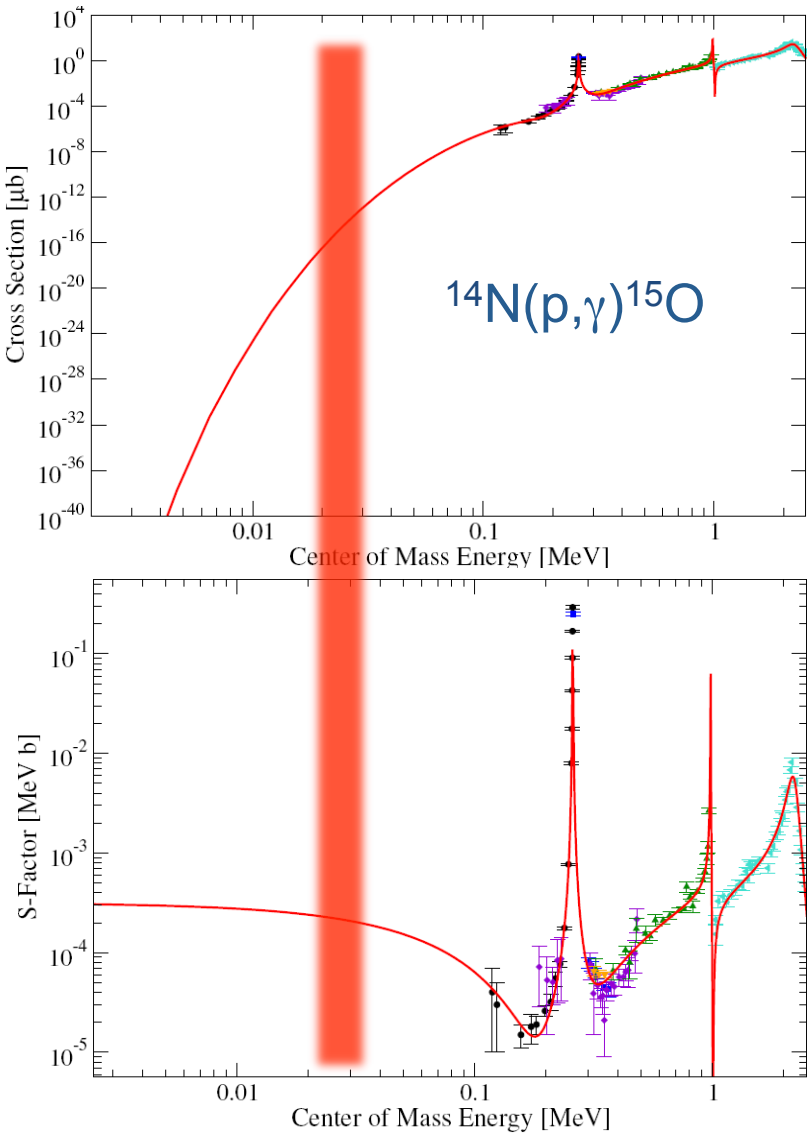




High luminosity, low background experiments

The two most critical Rates





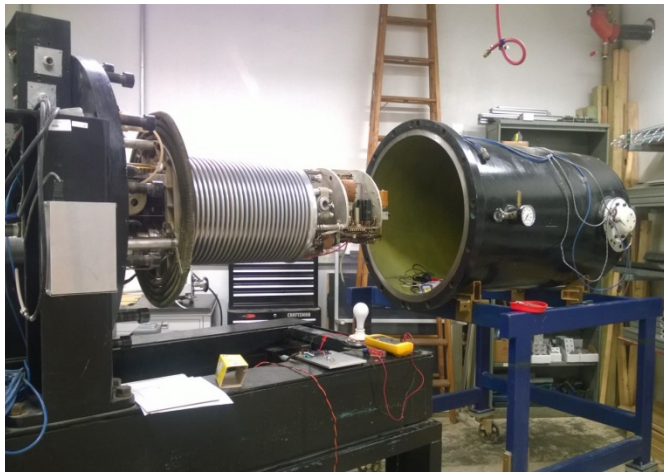
Underground accelerator project DIANA for low energy studies

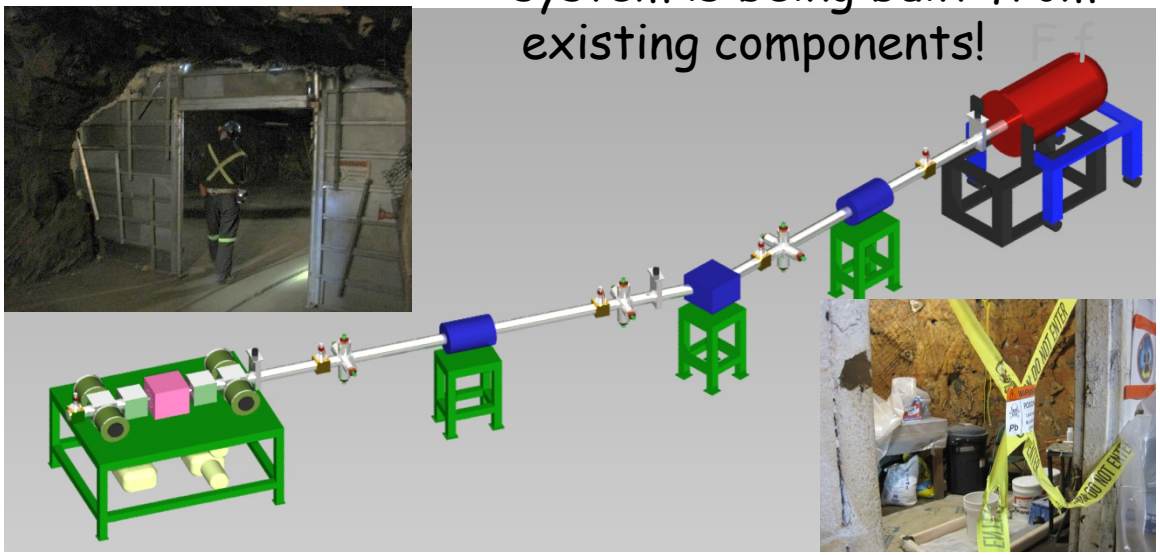
p, α, HI beams
100 x LUNA luminosity

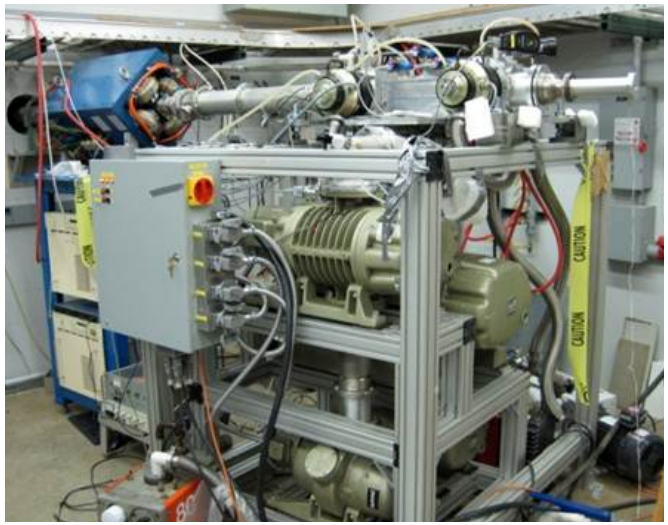
High luminosity, low background experiments

The Caspar Plan

Location is being prepared and accelerator being rebuilt and tested, gas target system is being built from existing components!

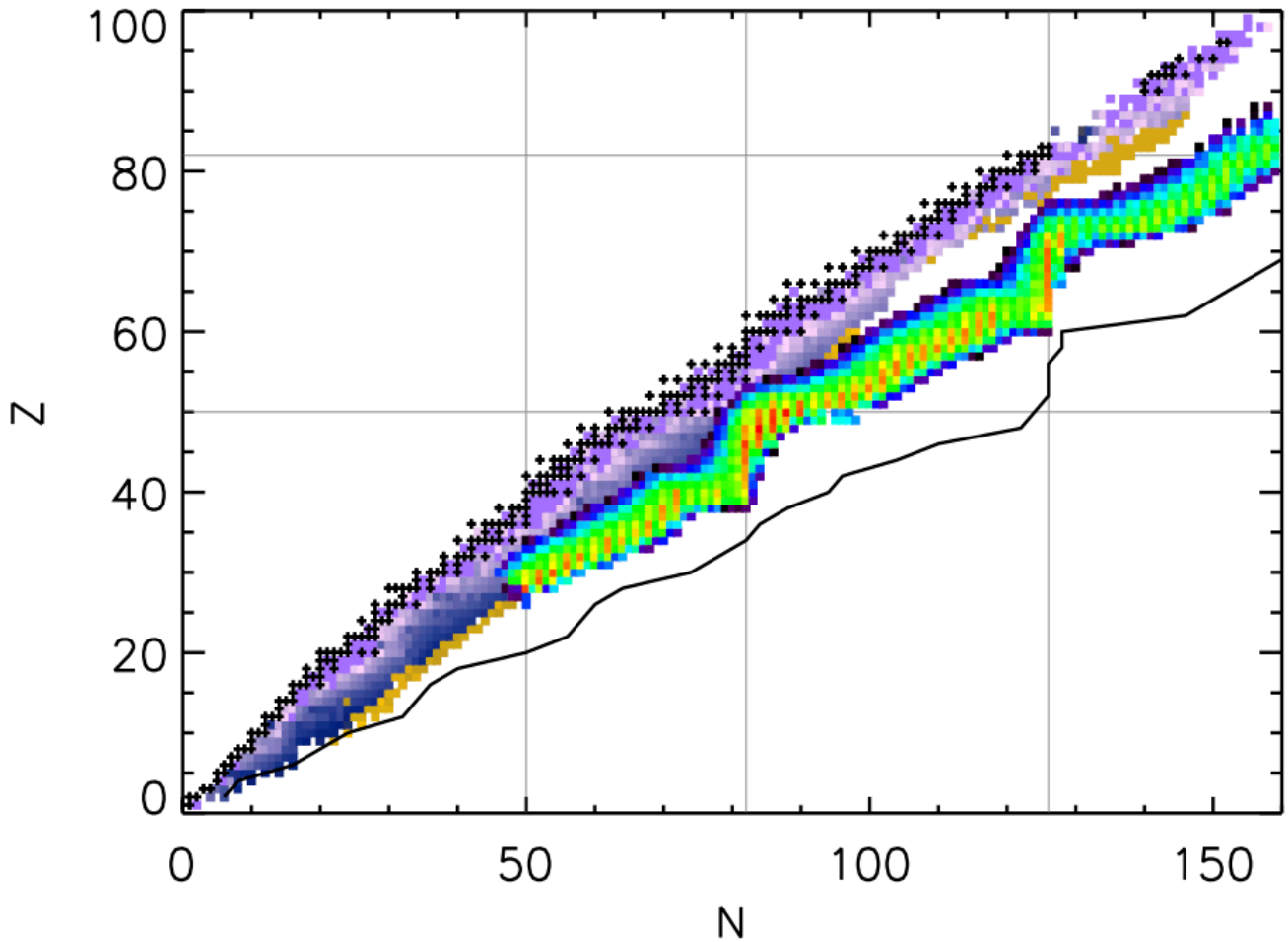






Beyond the initial seeds from early generation stars.. solar system abundances

r-process
LEPP process



β decay and *r*-process nucleosynthesis

R. Surman

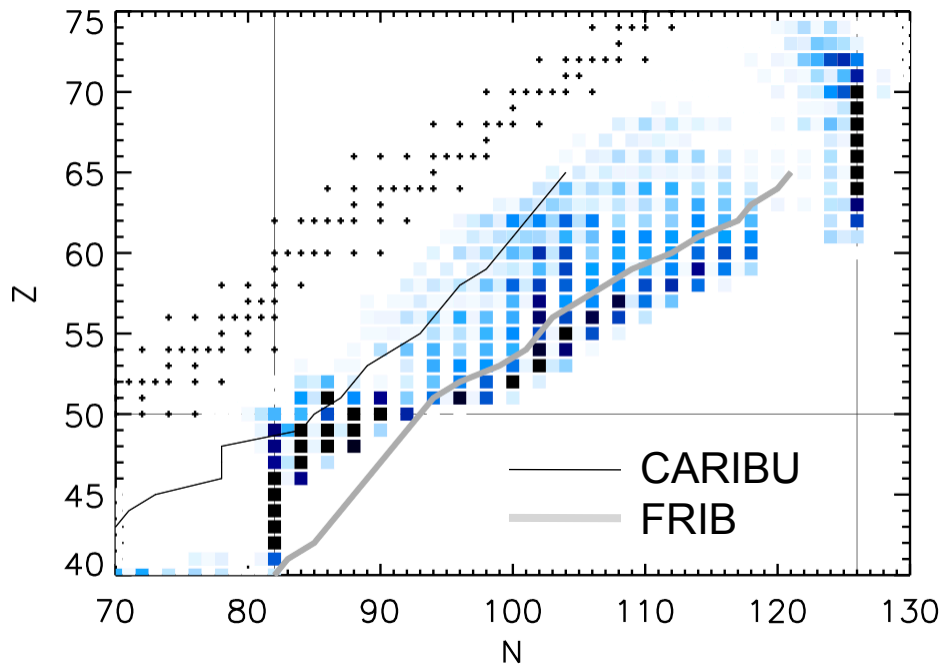
β decay and *r*-process nucleosynthesis

β decay rates:

- determine the relative abundances of the isotopic chains during (n,γ)-(γ,n) equilibrium
- set the overall timescale for the *r*-process
- help finalize the abundance pattern during freezeout

For a given *r*-process scenario, the β decay rates with the greatest leverage on the global abundance pattern are those of the most abundant nuclei

The rates for nuclei closer to stability – particularly near the closed shells or in the rare earth region – are key for understanding the details of the *r*-process abundance pattern



Mumpower, Cass, Passucci, Surman, Aprahamian (2014)

3 different astrophysical scenarios

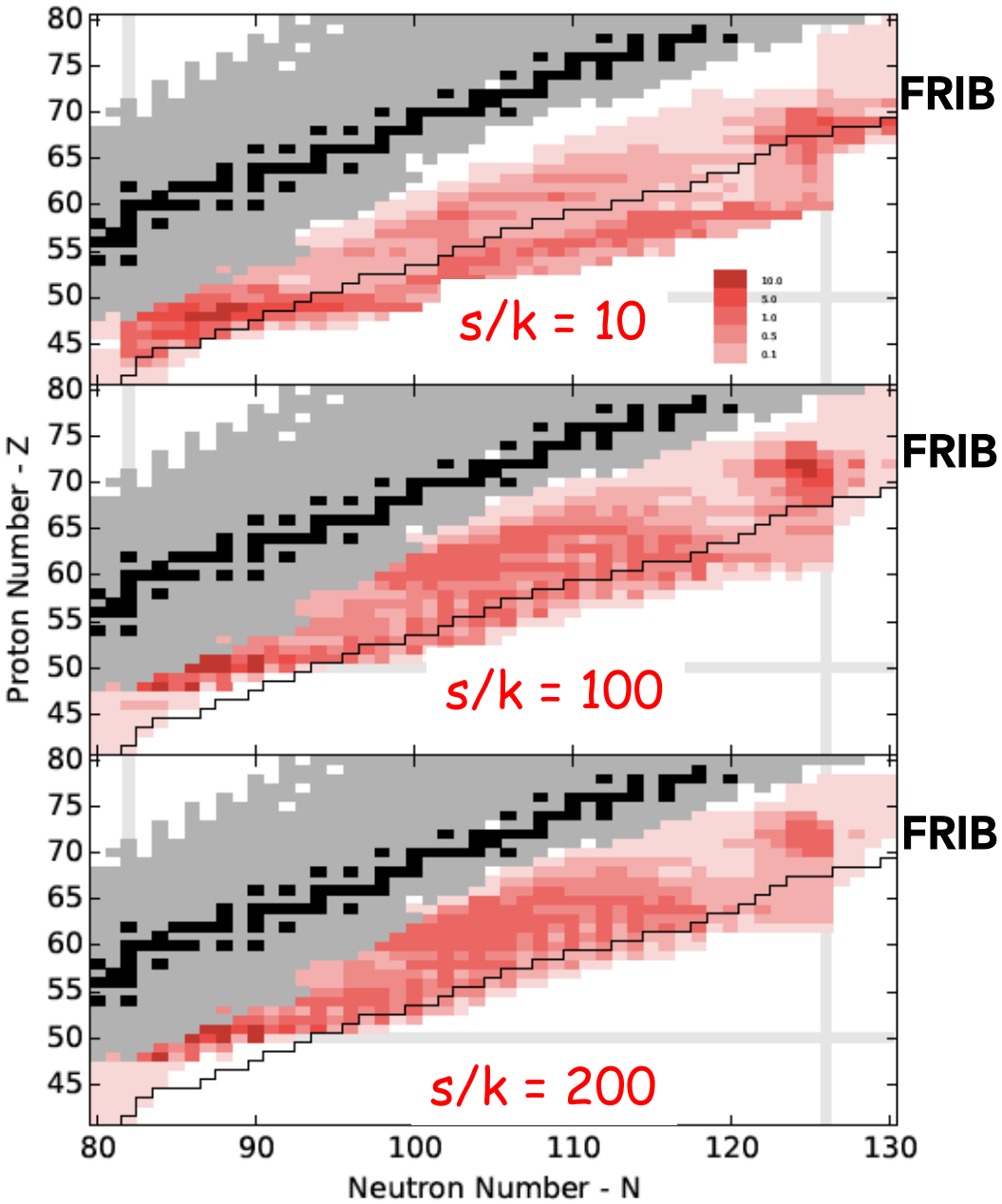


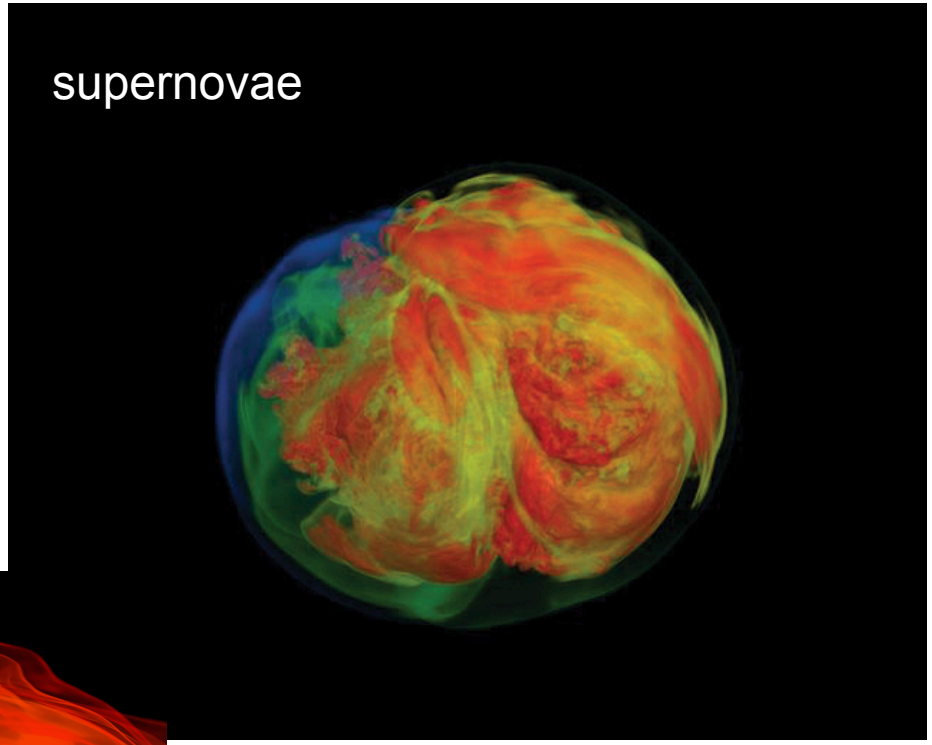
FIG. 3. The sensitivities measures F resulting from three sensitivity studies where binding energies of individual nuclei were varied by ±1MeV. The three sensitivity studies start with three distinct sets of astrophysical conditions, based on the parameterization of Meyer[32] as implemented in Mumpower et al.[33], with dynamic timescale $\tau_{\rm dyn} = 80$ ms and entropy per baryon of $s/k = 10$ (top panel), 100 (middle panel), and 200 (bottom panel). For each set of conditions, the initial composition is chosen to produce a main r-process pattern which is relatively similar to the observed solar abundances. The gray boxes, similar to Fig. 2, show the extent of measurements reported in the AME2012 compilation while the black line is the predicted FRIB production.

Sensitivity studies for the main r process: nuclear masses

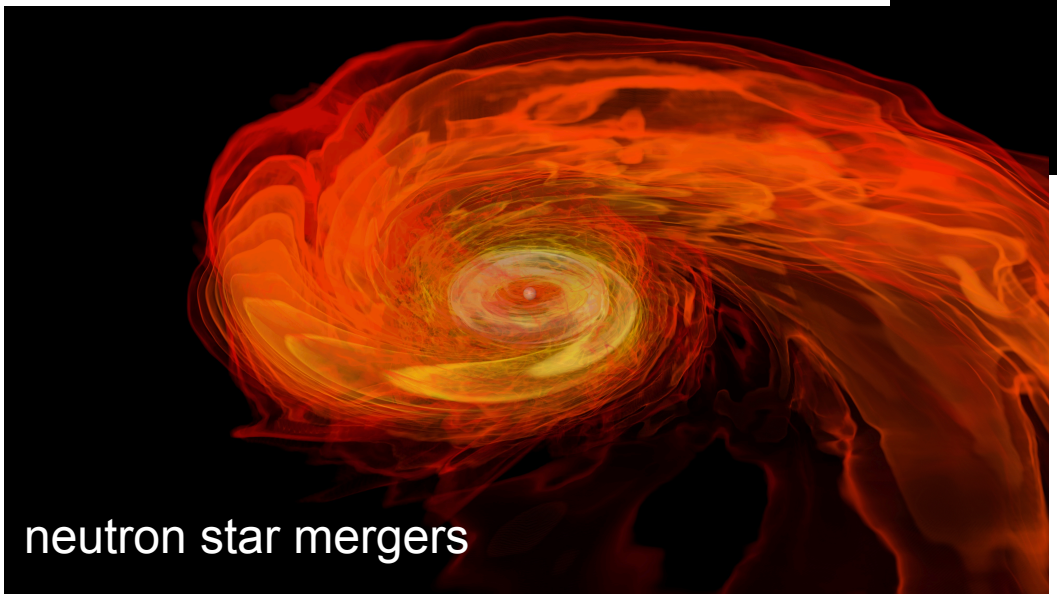
A. Aprahamian,[1] I. Bentley,[2] M. Mumpower,[1] and R. Surman[3]

neutrinos and nucleosynthesis

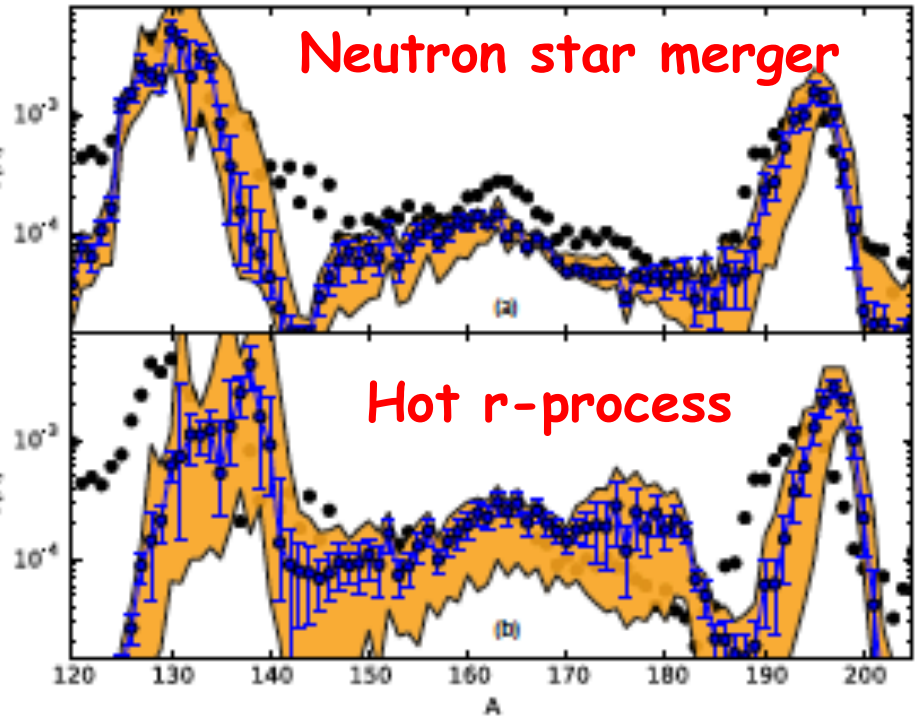
Neutrinos play a crucial role in the dynamics of these sites and help set the neutron to proton ratio in the ejecta



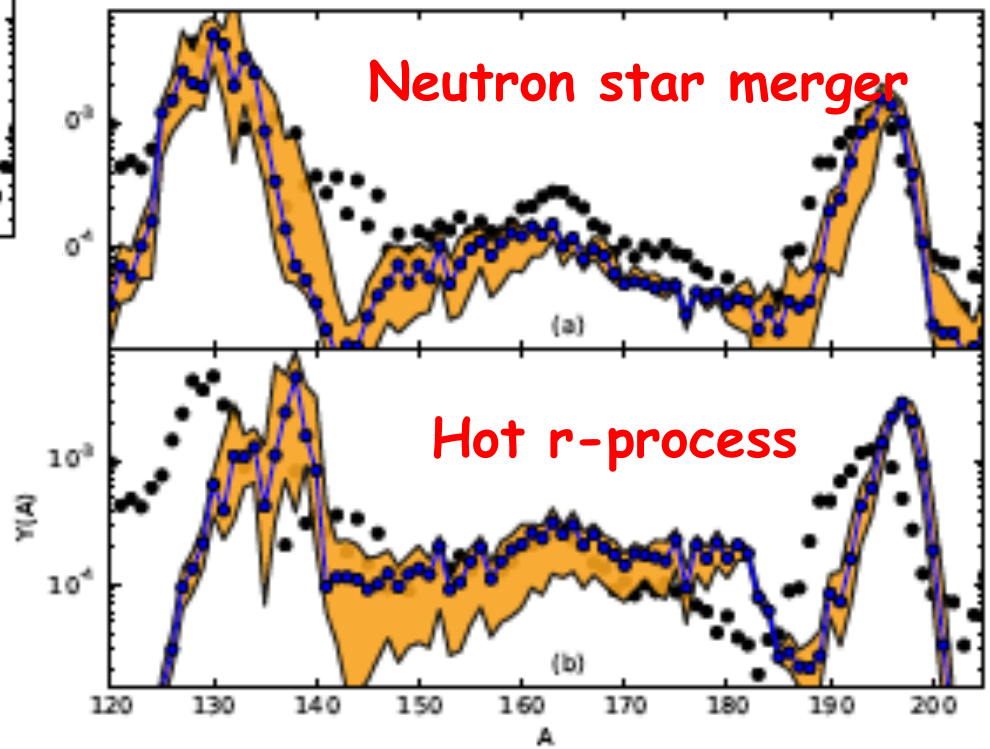
ORNL/UCDavis



NASA/AEI/ZIB



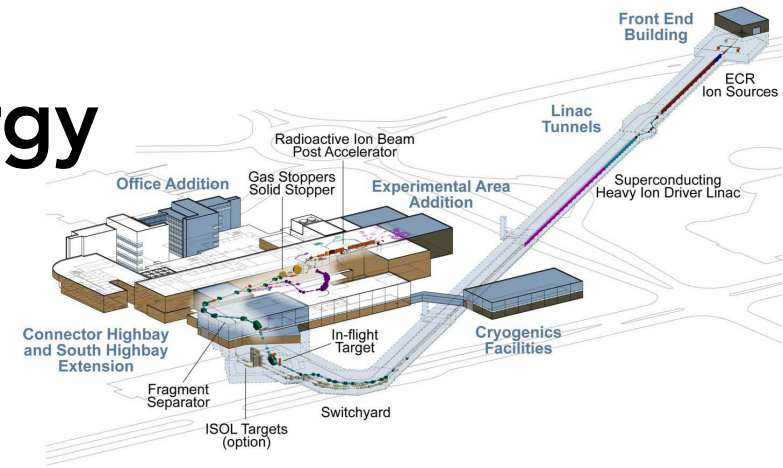
ΔBE = +/-1 MeV



ΔBE =+/-0.5 MeV

Summary and conclusions

1. near/at threshold energy
2. exotic nuclei: FRIB



Interfaces
Experiments:

Underground experiments
with intense light ion beams
in background free
environments with high
efficiency detector arrays

FRIB experiments

Interfaces
Theoretical Approaches:

Nuclear Reaction Theory
Multi-channel R-matrix
Improved reaction theory

Nuclear Models
Mass Models
Beta-decay rates

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