nuclear masses and the site of $r$-process nucleosynthesis

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Hirschegg 2017
Neutron star mergers: From gravitational waves to nucleosynthesis

Hirschegg, Austria
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$r$-process nucleosynthesis

Arnould+2007

$n\gamma\beta$

solar system $r$-process residuals
$r$-process nucleosynthesis

Arnould+2007

elemental abundances from $r$-process-enhanced metal-poor halo stars

solar system $r$-process residuals

Cowan+2011
*r*-process astrophysical site: BNS/NSBH mergers?

**Astrophysical modeling of BNS/NSBH mergers**
- Talks by A Bauswein, S Rosswog, M Wu, T Piran

**Electromagnetic transient: macronova/kilonova**
- Talks by J Barnes, R Wollaeger

**Gravitational waves from merger events**
- Talks by B Sathyaprakash, S Rosswog

**r-process elements in low metallicity stars**
- Talks by A Frebel, T Hansen, C Hansen

**Galactic chemical evolution studies**
- Talks by F Matteucci, T Kajino

**Neutrino physics of merger events**
- Talks by G McLaughlin, H Yasin, M Wu
$r$-process abundance pattern signatures

very neutron rich fission cycling

barely neutron rich limit seed production
$r$-process simulations: required nuclear data

masses
beta-decay rates
beta-delayed neutron emission probabilities
neutron capture rates
fission rates
fission product distributions
neutrino interaction rates
\( r \)-process simulations: required nuclear data

masses
beta-decay rates
beta-delayed neutron emission probabilities
neutron capture rates
fission rates
fission product distributions
neutrino interaction rates

see talks by J Engel, S Nishimura

figure by M Mumpower
$r$-process simulations: required nuclear data

- masses
- beta-decay rates
- beta-delayed neutron emission probabilities
- neutron capture rates
- fission rates
- fission product distributions
- neutrino interaction rates

see talk by K Blaum

figure by M Mumpower
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figure by M Mumpower

see talks by L Atar, M Eichler, S Giuliani
$r$-process simulations: required nuclear data

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figure by M Mumpower

sensitivity study review:
Mumpower, Surman, McLaughlin, Aprahamian
Progress in Particle and Nuclear Physics 86 (2016) 86
Its formation mechanism is sensitive to both the astrophysical conditions of the late phase of the $r$-process and the nuclear physics of the nuclei populated at this time.
rare earth peak formation

FRDM

Mumpower, McLaughlin, Surman 2012
rare earth peak formation

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
rare earth peak formation

Neodymium (Z = 60) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
reverse-engineering the rare earth masses

mass modification parameterization:

\[ M(Z, N) = M_{DZ}(Z, N) + a_N e^{-(Z-C)^2/2f} \]

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
reverse-engineering the rare earth masses

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
rare earth peak formation comparison

hot, $(n,\gamma)-(\gamma,n)$ equilibrium

cold, very neutron-rich

predicted mass surfaces

hot, \((n,\gamma)-(\gamma,n)\) equilibrium

cold, very neutron-rich

Neodymium \((Z = 60)\) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
predicted mass surfaces

persistent feature, multiple astrophysical trajectories

hot, \((n,\gamma)-(\gamma,n)\) equilibrium

cold, very neutron-rich

Neodymium \((Z = 60)\) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
predicted mass surfaces

localized feature, multiple astrophysical trajectories

hot, $(n,\gamma)-(\gamma,n)$ equilibrium

cold, very neutron-rich

Neodymium ($Z = 60$) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted
uncertainties in nuclear masses

Mumpower, Surman, Fang, Beard, Aprahamian 2016
systematic uncertainties in nuclear masses: impact on $r$-process simulations

Surman, Mumpower, McLaughlin 2016

masses from massexplorer.frib.msu.edu: Olsen, Nazarewicz:

see also Martin+2016
uncertainties in nuclear masses

Surman, Mumpower, Aprahamian 2016

\[ \Delta M = M_{\text{FRDM}} - M_{\text{AME}} \]

\[ \Delta S_N = S_{N,\text{max}} - S_{N,\text{min}} \]
random uncorrelated uncertainties in masses: impact on $r$-process simulations

Surman, Mumpower, McLaughlin 2016

FRDM masses + Monte Carlo variations within mass model rms (~0.5 MeV)
impact of upcoming measurements

Surman, Mumpower, Aprahamian 2016
The role of compact object mergers in the synthesis of the heaviest elements is under investigation from many directions.

One such avenue is through nuclear physics, where current and next-generation radioactive beam facilities will continue to push the boundaries of our knowledge of extremely neutron-rich nuclei.

As nuclear physics uncertainties are reduced, we can exploit details of the $r$-process abundance pattern, such as the rare earth peak, to explore the nature of the $r$-process site.

![Summary](image)

- Estimated Possible
- New from FRIB
- Known Isotopes

*figure from B Sherrill*