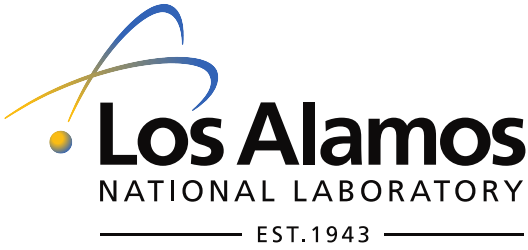
r-Process nucleosynthesis and kilonova overview

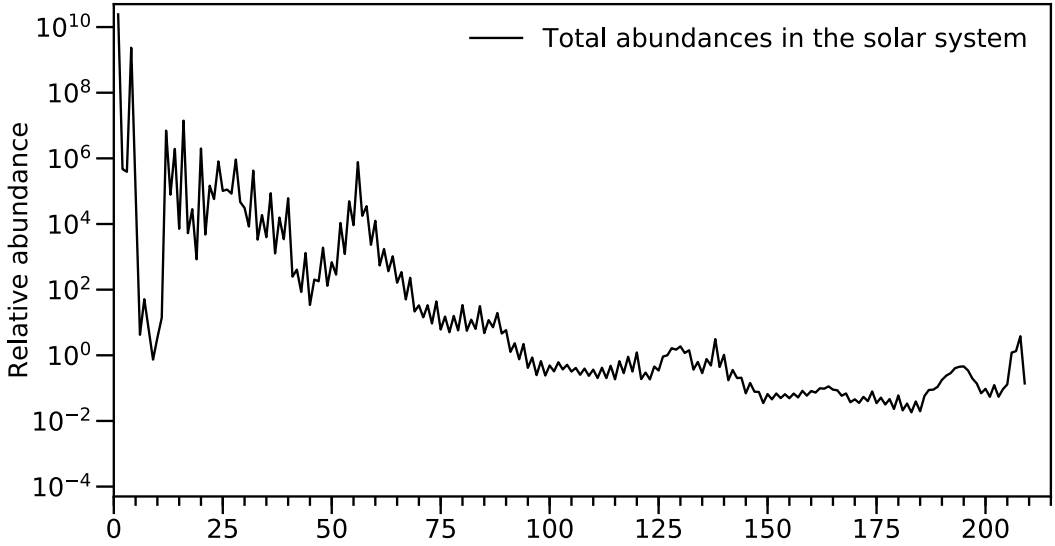


Jonas Lippuner

12th INTEGRAL Conference
February 11, 2019
Geneva, Switzerland

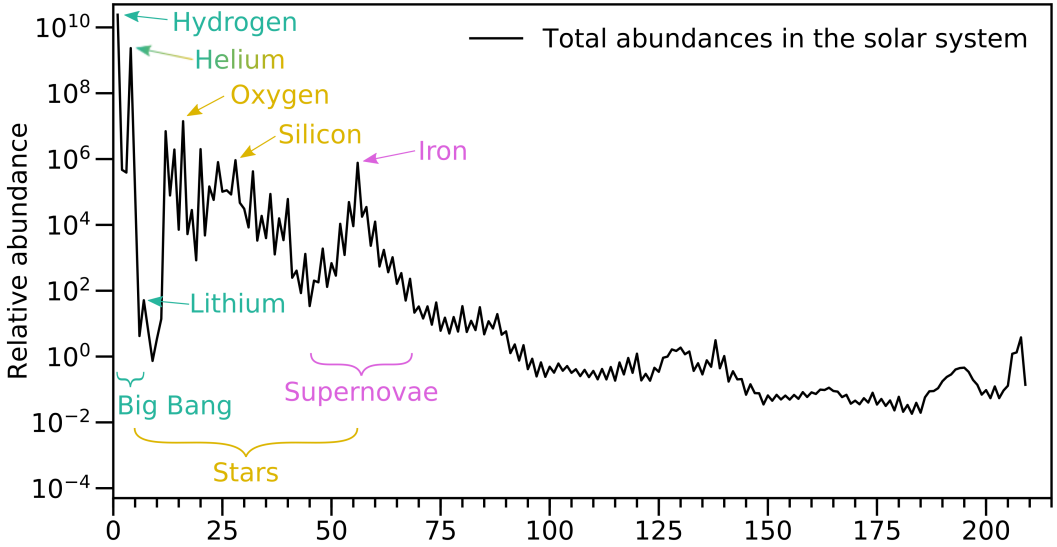
Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

Solar system abundances



Data sources:
K. Lodders, ApJ 591, 1220 (2003)
M. Arnould et al., Phys. Rep. 450, 97 (2007)

Solar system abundances



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K. Lodders, ApJ 591, 1220 (2003)
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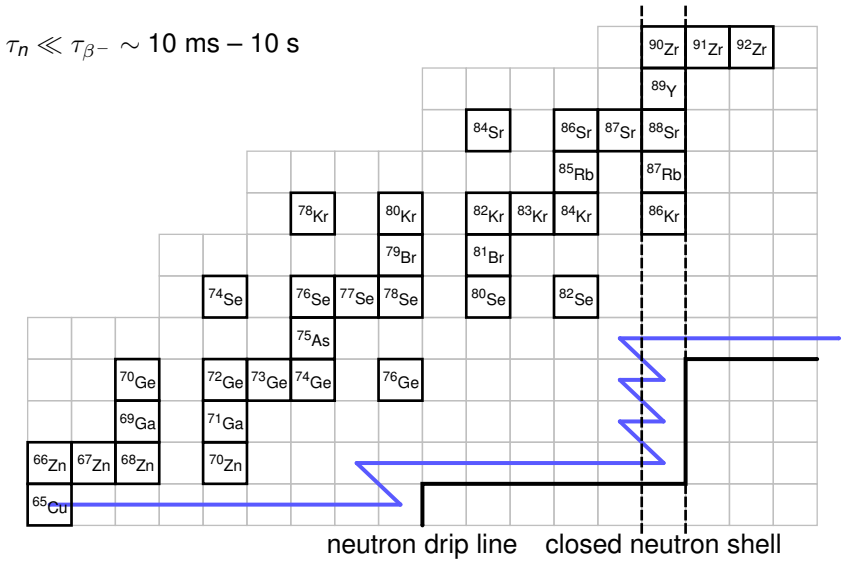
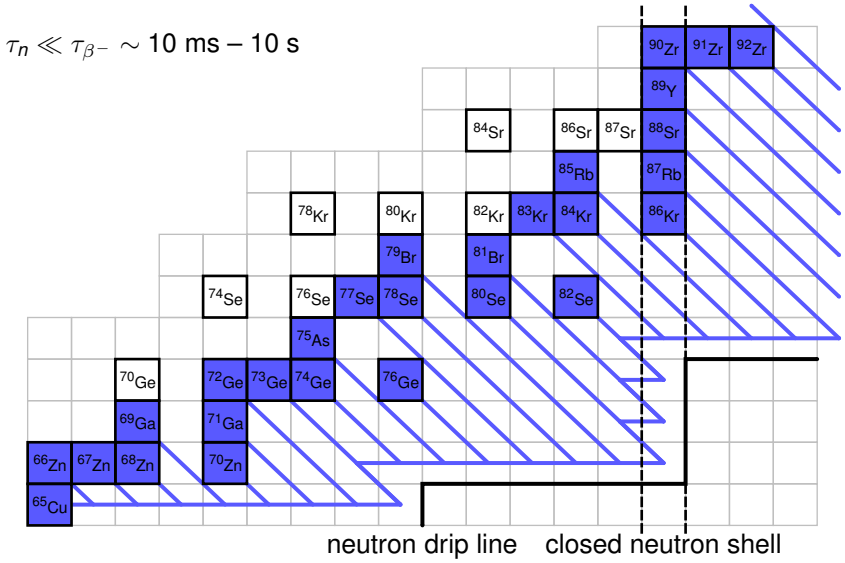
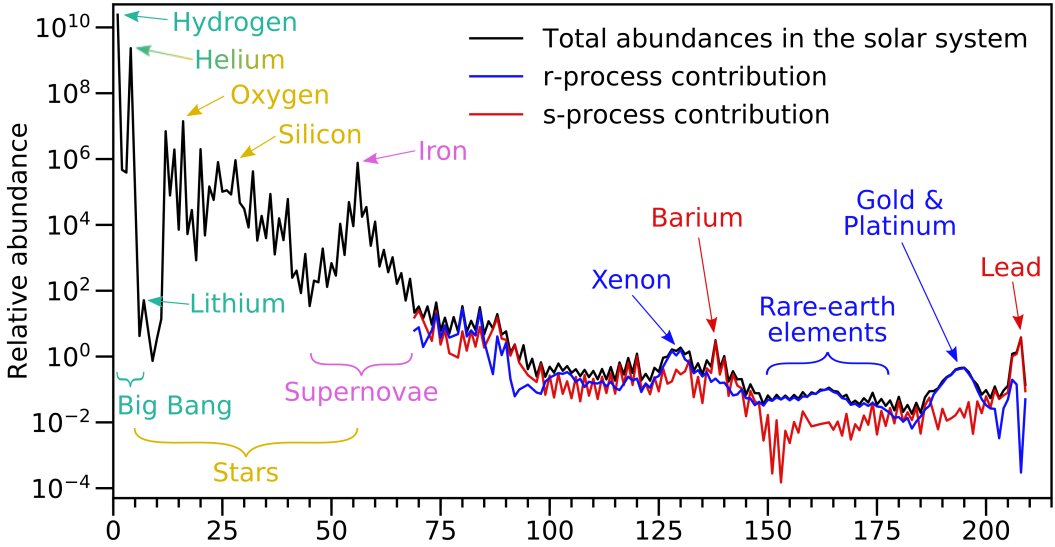
r-Process nucleosynthesis



r-Process nucleosynthesis



Solar system abundances



Data sources:
K. Lodders, ApJ 591, 1220 (2003)
M. Arnould et al., Phys. Rep. 450, 97 (2007)

SkyNet

- General-purpose one-zone nuclear reaction network
- $\sim$8000 isotopes, $\sim$140,000 nuclear reactions
- Input: $\rho(t)$, initial composition, entropy
- Output: Abundances as a function of time

SkyNet Features

Physics

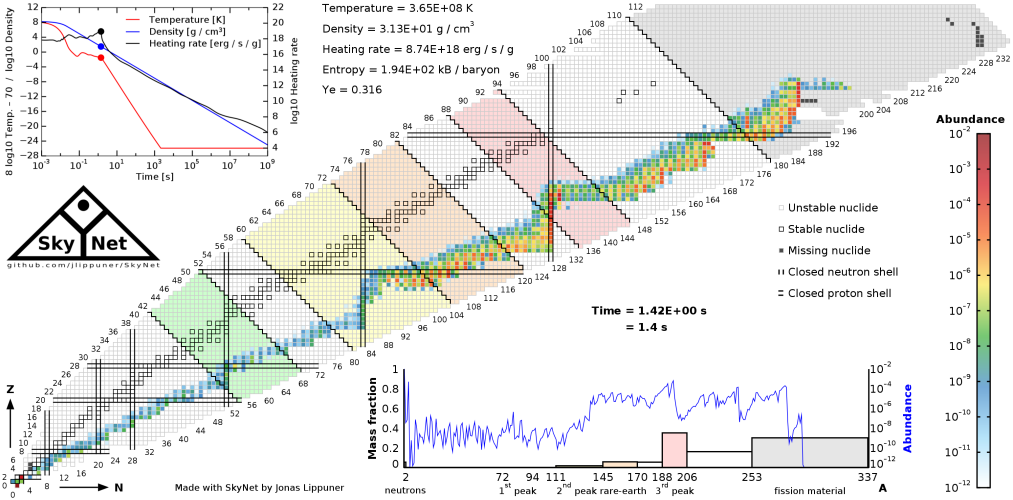
- Extended Timmes equation of state
- Calculate nuclear statistical equilibrium (NSE)
- NSE evolution mode
- Electron screening with smooth transition between weak and strong screening (reactions and NSE)

Code

- Modular and extendible C++ design
- Convenient Python bindings
- Supports various nuclear reaction types
- Make pretty movies
- Open source

Movie

http://jonaslippuner.com/skynet/SkyNet_Ye_0.010_s_010.000_tau_007.100.mp4
http://jonaslippuner.com/skynet/SkyNet_Ye_0.250_s_010.000_tau_007.100.mp4

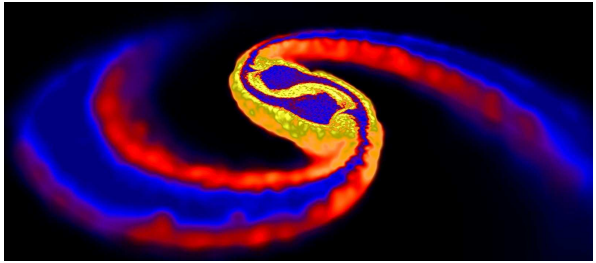


Merger ejecta: Dynamical

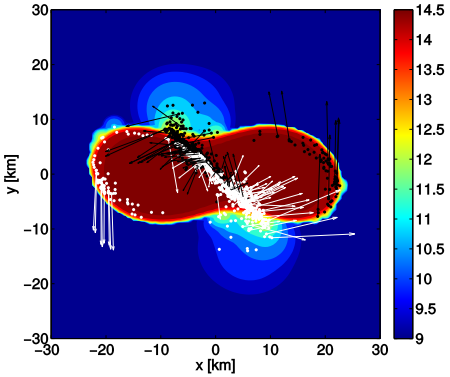
Tidal tails or collision interface

NS–NS: $M_{\rm ej} \sim 10^{-4} -$ few $\times\, 10^{-2}\, M_\odot$, $Y_e \sim 0.05 - 0.45$

Bauswein+13, Hotokezaka+13, Foucart+14, Sekiguchi+15, Kyutoku+15, Radice+16



From Price+06



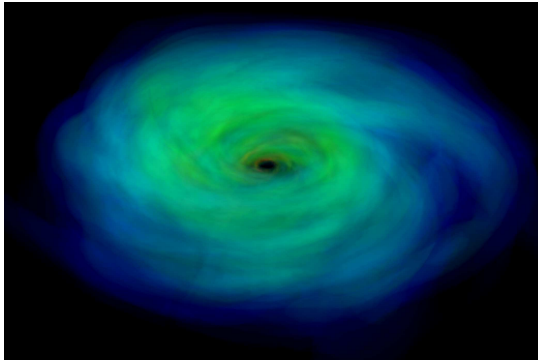
From Bauswein+13

Merger ejecta: Disk outflow

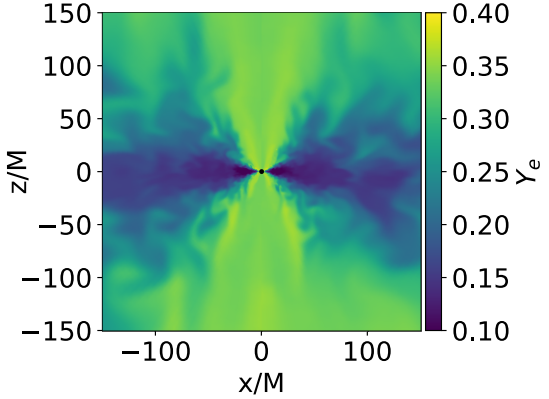
Neutrino driven wind or outflow due to viscous heating and α recombination

$M_{\rm ej} \sim$ few $\times 10^{-3}\, M_\odot$, $Y_e \sim 0.2 - 0.45$

Surman+08, Wanajo+11, Fernández+13, Perego+14, Just+15, Foucart+15

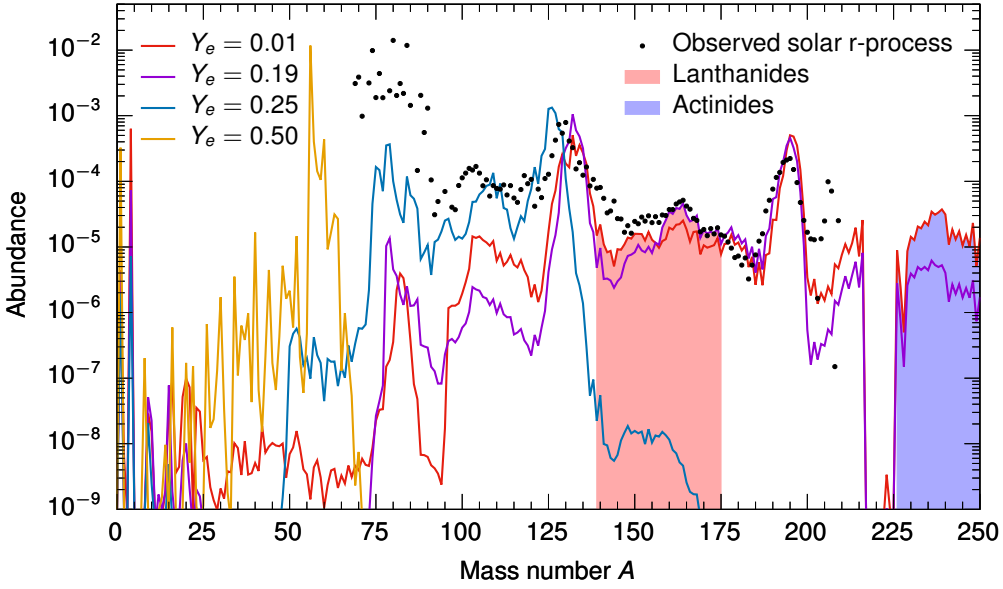


From Miller+19 (in prep)

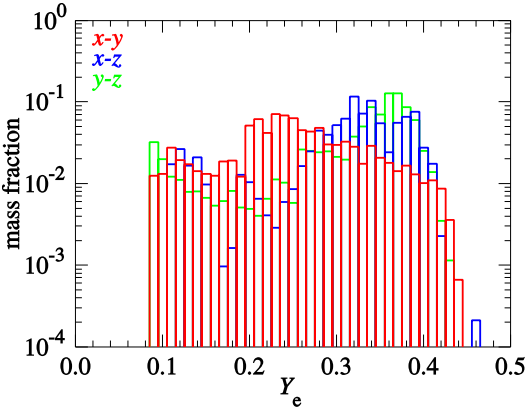


From Miller+19 (in prep)

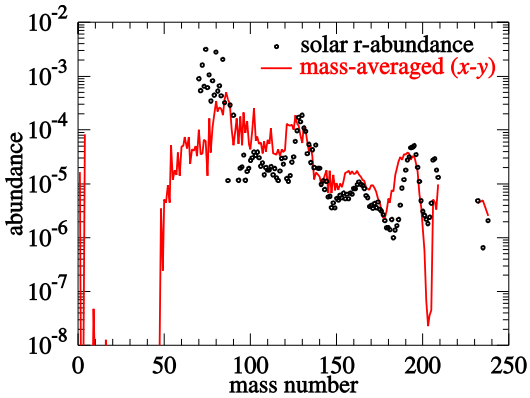
Impact of electron fraction



Full range of electron fractions



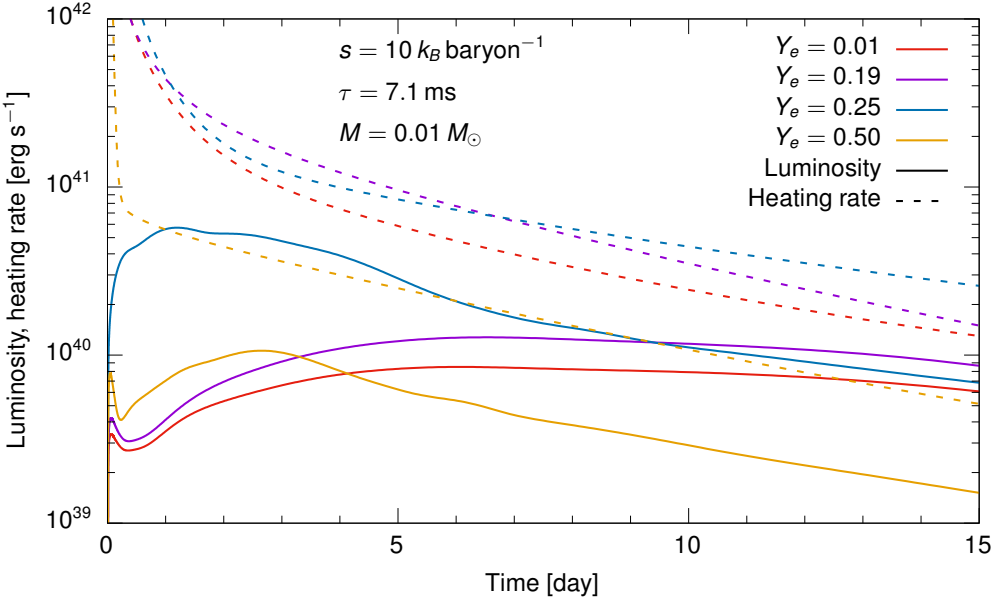
From Wanajo+14



From Wanajo+14

See also Goriely+15

Impact of lanthanides



Conclusions

- r-Process produced about half of heavy elements above iron
- r-Process happens in different types of neutron star merger ejecta
- Electron fraction determines if lanthanides are produced or not
- Lanthanides drastically increase opacity, thus making light curve peak later, dimmer, and redder/infrared
- SkyNet is an open-source nuclear reaction network available to anyone for r-process nucleosynthesis calculations