Constraints on heavy element production from spectral analysis of a binary neutron star merger

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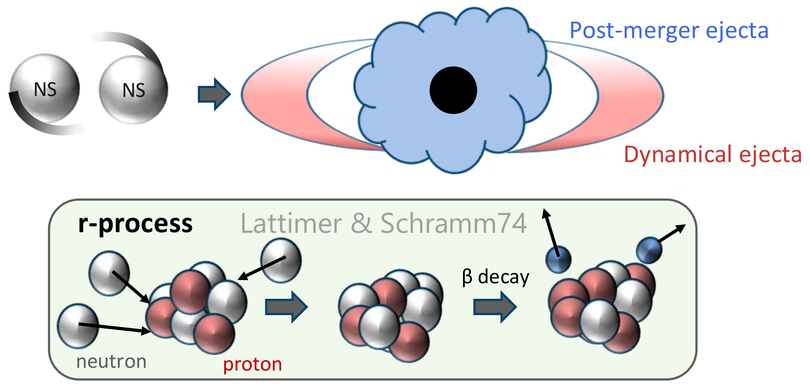
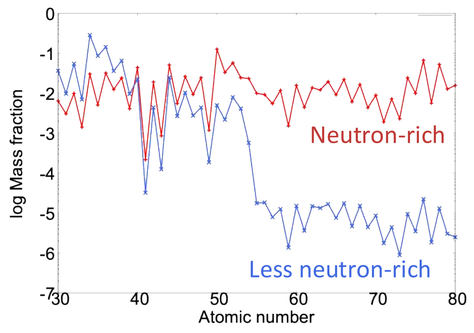
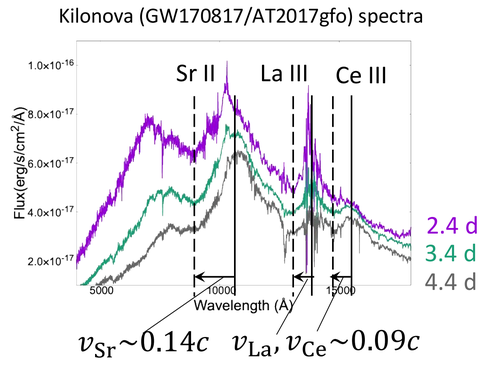
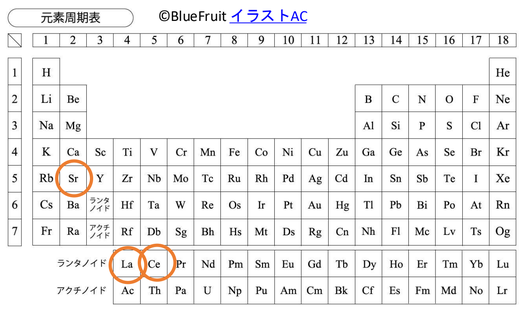
1. Introduction

- **Binary Neutron Star Merger** is a major site of **heavy element (e.g., Au, Pt)** production via the **r-process**.









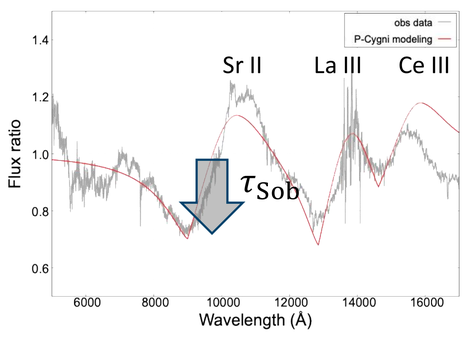
- In **2017**, BNSM was detected (GW + Kilonova). Spectra revealed **Sr (Z = 38), La (Z = 57), Ce (Z = 58)**.
- However, **quantitative constraints** on their production and **nucleosynthesis conditions** remain unclear.

This Work

We constrain **mass fractions** of elements from observed spectra → infer **neutron-rich** / **less neutron-rich** ejecta components.

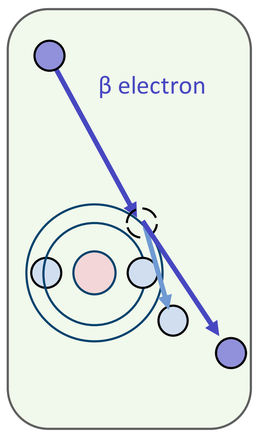
2. Method

Spectra
(2.4 – 4.4 d after merger)
→ P Cygni profile
→ Absorption strength
(Sobolev optical depth $\tau_{\rm Sob}$)



Sobolev47
Jeffery & Branch90
Kasen+02

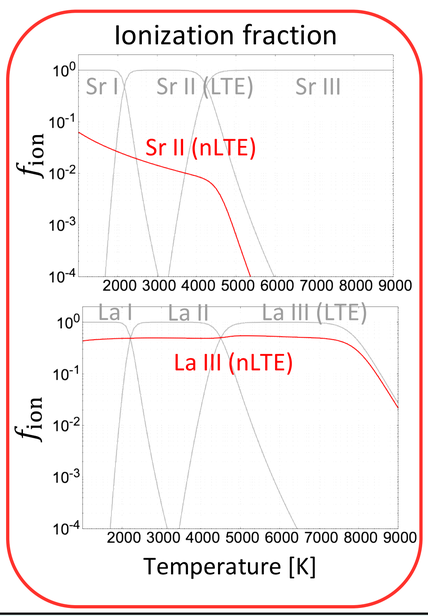
line list
Domoto+22
NIST (Kramida+24)

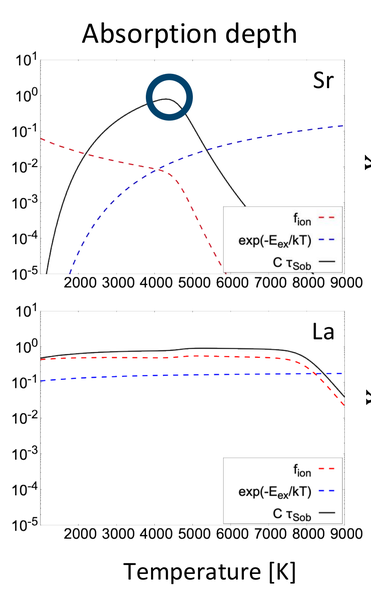


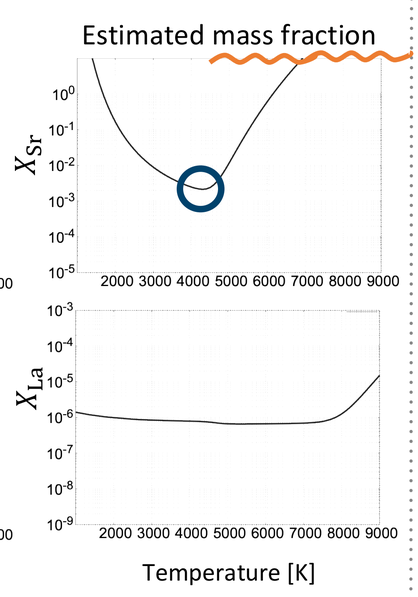
Hotokezaka+21
Tarumi+23
Metzger+10

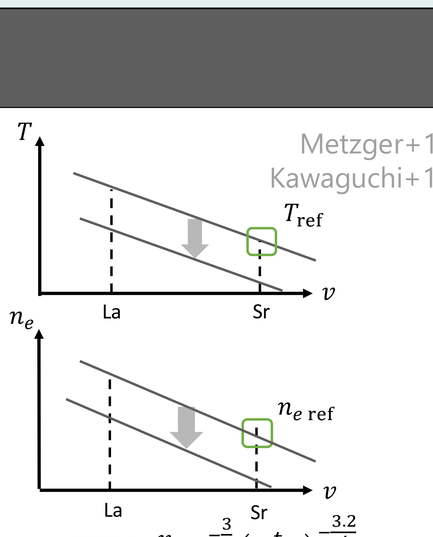
observation

$$\tau_{\rm Sob} \propto X_{\rm Element}\, f_{\rm ion}(n_e, T)\, \exp\left(-\frac{E_{\rm ex}}{k_B T}\right)$$









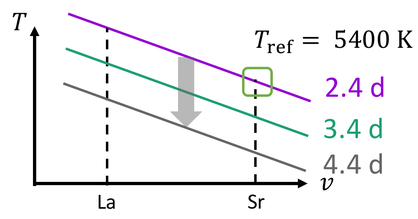
$$T = \boxed{T_{\rm ref}} \left(\frac{v}{0.14c}\right)^{-\frac{3}{4}} \left(\frac{t}{2.4\ \rm d}\right)^{-\frac{3.2}{4}}$$

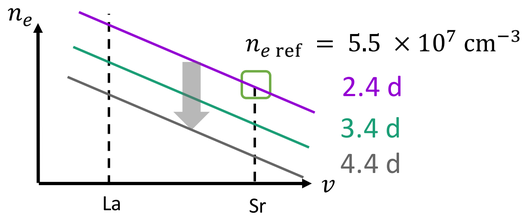
$$n_e = \boxed{n_{e\,\rm ref}} \left(\frac{v}{0.14c}\right)^{-3} \left(\frac{t}{2.4\ \rm d}\right)^{-3}$$

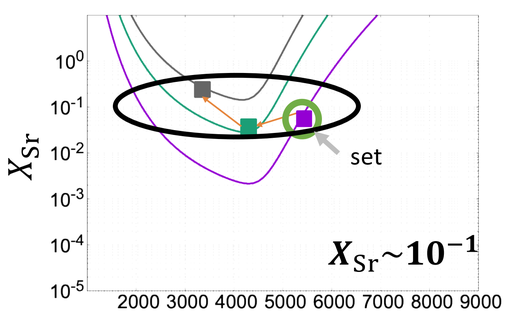
Parameters

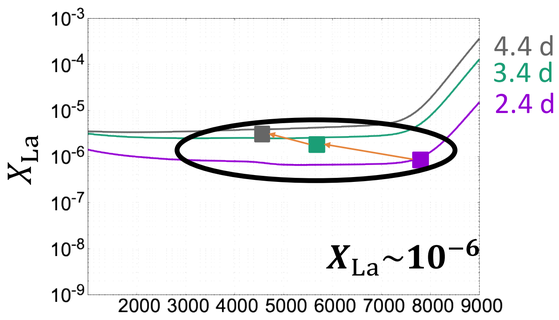
$$3000 \leq \boxed{T_{\rm ref}\ (\rm K)} \leq 7000$$
$$10^6 \leq \boxed{n_{e\,\rm ref}(\rm cm^{-3})} \leq 10^8$$

3. Results







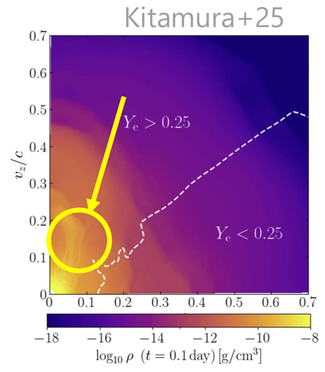


Consistent abundances over 3 epochs
Calculations over a wide range of $n_{e\,\rm ref}$

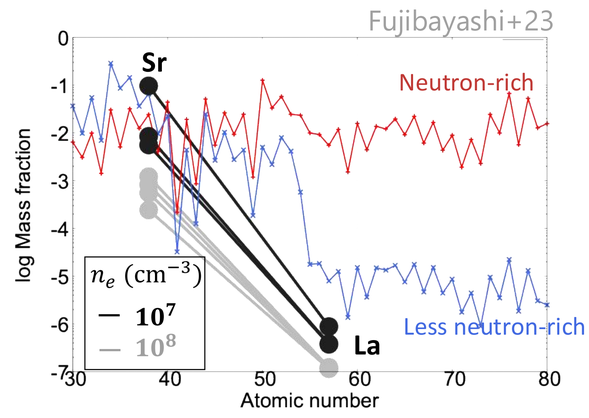
$$\frac{X_{\rm La}}{X_{\rm Sr}} \sim 10^{-5} - 10^{-4}$$

4. Discussion

Kawaguchi+22
Kitamura+25



Fujibayashi+23



Less neutron-rich (Y_e ~ 0.3)

=> fast post-merger ejecta?
polar dynamical ejecta?

5. Conclusions

- Nucleosynthesis of binary neutron star merger
  - Quantifying Mass fraction abundance from Kilonova spectra
- This work
  - Estimating Mass fraction abundance based on wide parameter range -> $X_{\rm La}/X_{\rm Sr}\sim10^{-5}-10^{-4}$
  - In the **0.1c - 0.15c** region of the **polar** direction, **less neutron-rich** element synthesis occurs.
  - Direct observational constraints on element compositions in **fast post-merger ejecta / polar dynamical ejecta**.