Simulations of neutron star merger in early time

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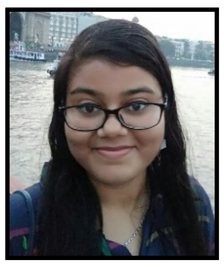
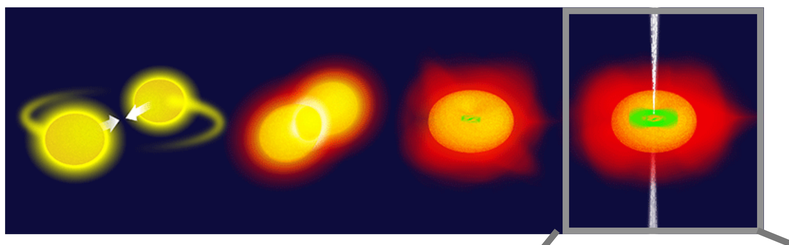


1. Summary

- The first neutron star merger event GW170817 showed a **bright blue emission in early time**
- Neutron star merger ejecta can produce heavy elements, the **opacity is different from the supernova ejecta**
- In early time, due to a high temperature, atoms are highly ionized, no atomic data was available
- We have calculated **opacity of atoms** from **n = 26-58** considering **ionization state** of **12** for the **first time**
- Using this opacity, **lightcurves of early time (~1 hour) for high Ye ejecta** is calculated

2. Kilonova

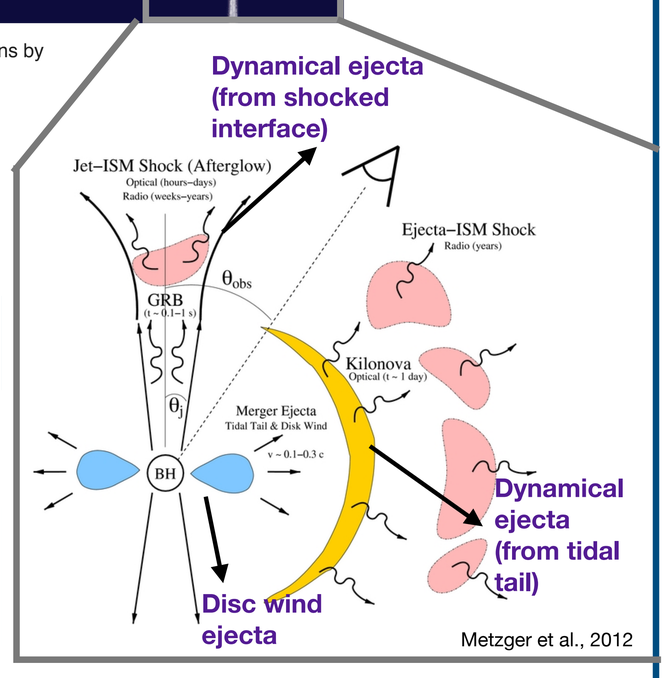


APS/**Alan Stonebraker**, adapted from simulations by NASA/AEI/ZIB/M. Koppitz and L. Rezzolla

Electron fraction:

$$y_e = \frac{n_p}{n_p + n_n}$$

Ejecta components	Electron fraction
Dynamical from tidal tail	Low
Dynamical from shocked interface	Low to moderate
Wind ejecta	High

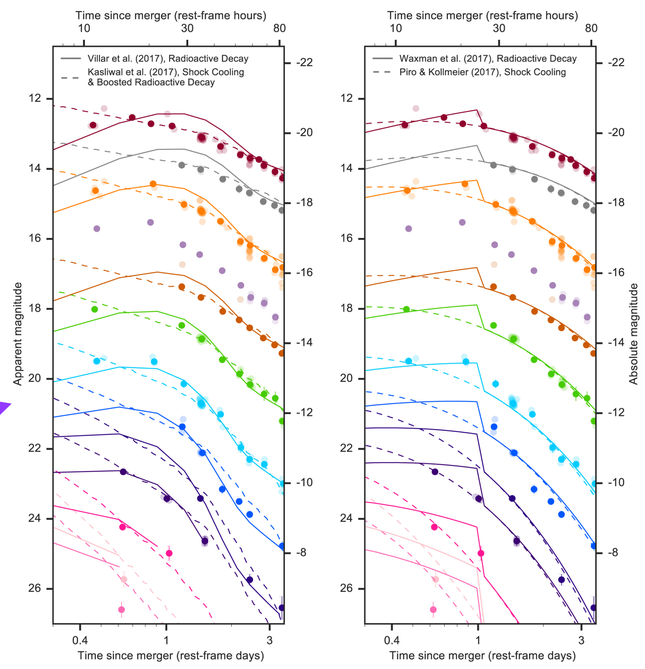


Metzger et al., 2012

The first observation of electromagnetic counterpart from a neutron star merger: GW170817

- Gamma rays : 2 s
- Optical and IR : 10.9 hours
- UV : 16.9 hours
- X-rays : 9 days
- Radio : 16 days

Abott et al., ApJ 2017



Arcavi, 2018

- No model can be proven correct or ruled out based on the data available yet

Peak timescale

$$t_{peak} = 8.4\,\text{days}\left(\frac{M_{ej}}{0.01M_\odot}\right)^{\frac{1}{2}}\left(\frac{v}{0.1c}\right)^{-\frac{1}{2}}\left(\frac{\kappa}{10\,\text{cm}^2\,\text{g}^{-1}}\right)^{\frac{1}{2}}$$

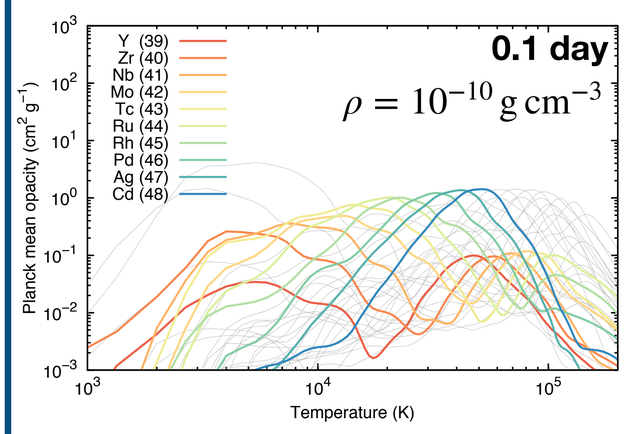
Peak luminosity

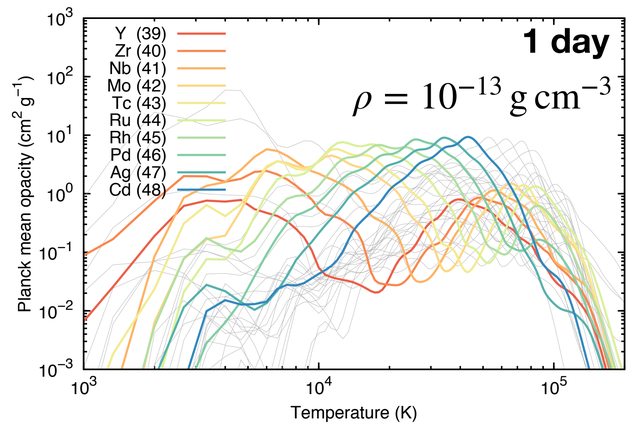
$$L_{peak} = 1.3\times10^{40}\,\text{erg s}^{-1}\left(\frac{M_{ej}}{0.01M_\odot}\right)^{0.35}\left(\frac{v}{0.1c}\right)^{0.65}\left(\frac{\kappa}{10\,\text{cm}^2\,\text{g}^{-1}}\right)^{-0.65}$$

- One of the main determining factors is **opacity**
- In early time, **systematic opacity calculation was not done**
- How much this new opacity affects the light curve?

3. Opacities at early time

Total opacity: $\kappa_{tot} = \kappa_{bound-free} + \kappa_{free-free} + \kappa_{bound-bound} + \kappa_{electron-scattering}$





Temperature considered:

$10^3 - 2\times10^5\,(\text{K})$

Expansion opacity:

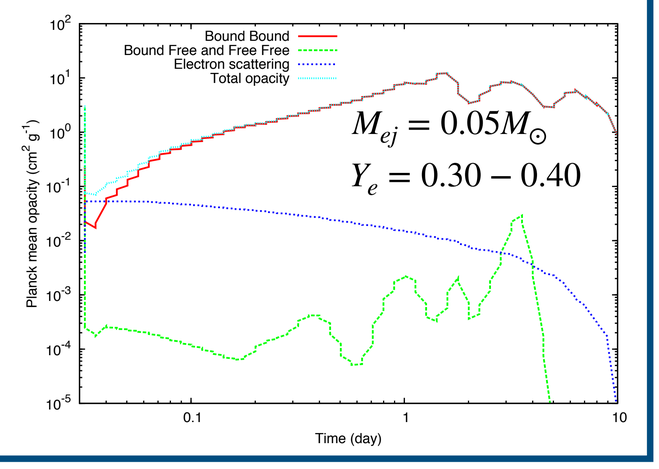
$$\kappa_{exp}(\lambda) = \frac{\alpha^{bb}_{exp}(\lambda)}{\rho} = \frac{1}{ct\rho}\sum_l \frac{\lambda_l}{\Delta\lambda}(1 - e^{-\tau_l})$$

Ionization considered upto: 12

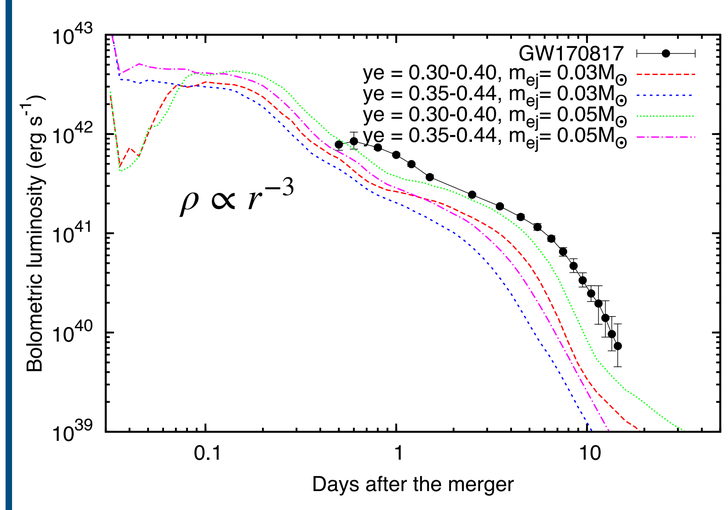
Optical depth: $\tau_l = \frac{\pi e^2}{m_e c^2} f_{ij} n_i t \lambda_{ij}$

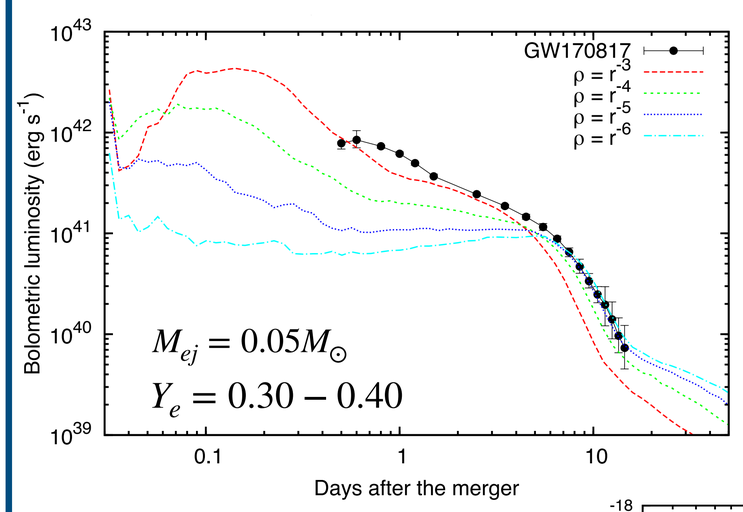
- At any time, the **bound-free opacity** is **not important**
- **Electron scattering** is **important** at **early time**
- The main component of opacity at 1day is **bound-bound opacity**

The opacity evolution for the point in the ejecta fixed at $3\times10^9\,\text{cm s}^{-1}$



4. Lightcurve





Obs. data: Waxman et al., 2017

- Lightcurves show a **bright peak** at early time
- In future, early time observations are important to differentiate between models

Assumptions:

- The homologous expansion of the ejecta
- Homogeneous abundance pattern

Mass of the ejecta	Electron fraction
$0.05M_\odot$	0.30-0.40
$0.03M_\odot$	0.35-0.44

Model : Simple merger model with **density structures:**

$\rho \propto r^{-3}$	$\rho \propto r^{-4}$
$\rho \propto r^{-5}$	$\rho \propto r^{-6}$

