Studying Magnetically-driven Outflows from Magnetized Neutrino-cooled Accretion Disks

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Two ejecta components for Kilonova GW170817

- The light curves show a rapid decline in brightness and a rapid transition of the spectral peak from the UV to the IR.
- Both the light-curves and spectra resemble predictions for a ‘kilonova’ a transient powered by radioactive decay of heavy nuclei and isotopes synthesized through the *r*-process.
- This is the first demonstration that *r*-process nucleosynthesis occurs in neutron star binary mergers.
- The presence of transitory UV emission, followed by the longer term IR emission hints at two ejecta components:

1- **Dynamical ejecta**: Lower-mass, high-velocity, neutron-rich component => Dimmer and red/IR emission

2- **Disk winds outflows:** Slower, higher-mass, less neutron-rich component => Brighter and blue

The total ejected mass is 0.03-0.06 of a solar mass.

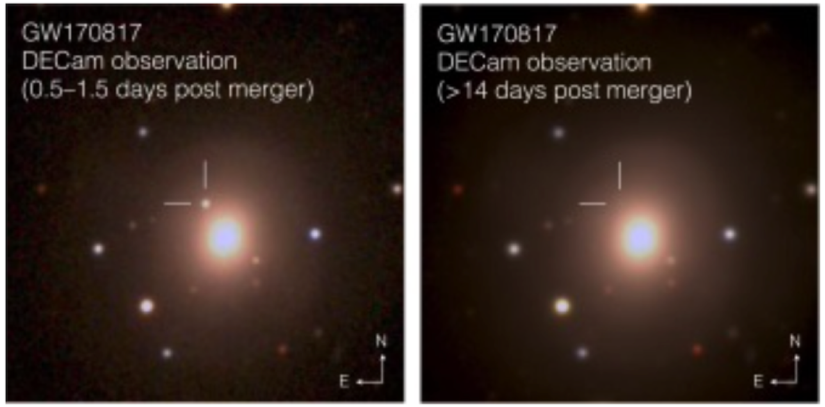
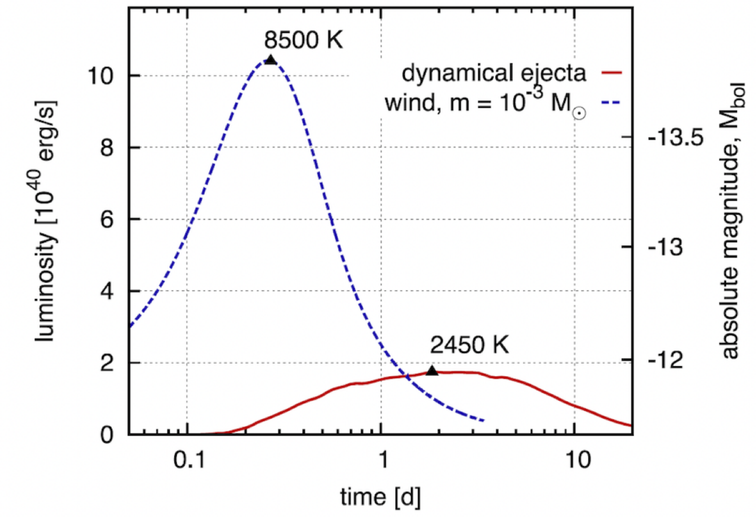


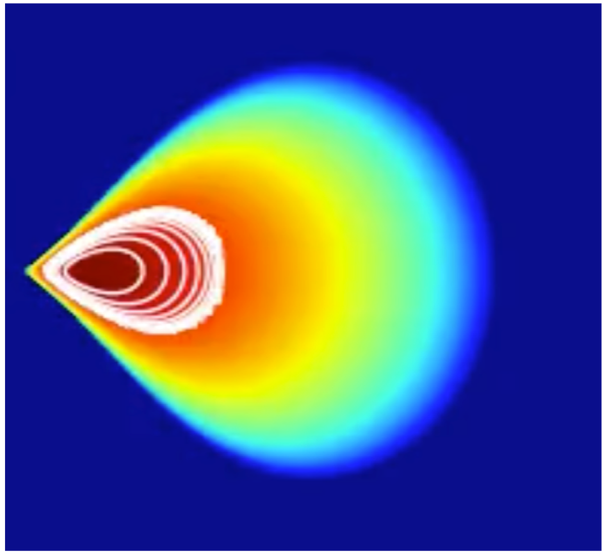
Figure 1 from Soares-Santos, M., et al. "The Electromagnetic Counterpart of the Binary Neutron Star Merger LIGO/Virgo GW170817. I. Discovery of the Optical Counterpart Using the Dark Energy Camera." 2017, ApJL, 848, L16.



Grossman et al. (2014)

Numerical Setup and Initial Data

- HARM_COOL finite volume code with HLL shock capturing scheme.
- Using the analytical solution of accretion disk around a Kerr BH (**Fishbone & Moncrief** 1976)
- BH spin [-0.9,+0.98]
- Disk mass [0.01,0.3] $M_{\odot}$



- **Equation of state:** Realistic nuclear matter composed of free protons, neutrons, electron–positron pairs, and helium nuclei. (Reddy et al. 1998), considering weak interactions to determine neutrino opacities in hot dense matter.
- **Initial magnetic field** has pure poloidal configuration and confined within the torus.

$$\beta = P_{gas,max}/P_{B,max} = 50$$

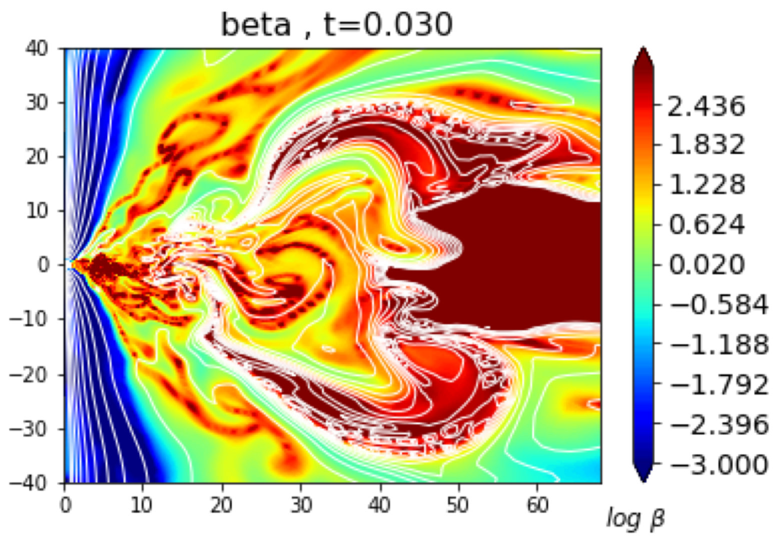
- The grid is 2D spherical coordinated with resolution 288*256 for (r, θ) running on 96 cores
- Evolution time: ~0.2 s
- Particle tracer technique is used to measure the outflows.

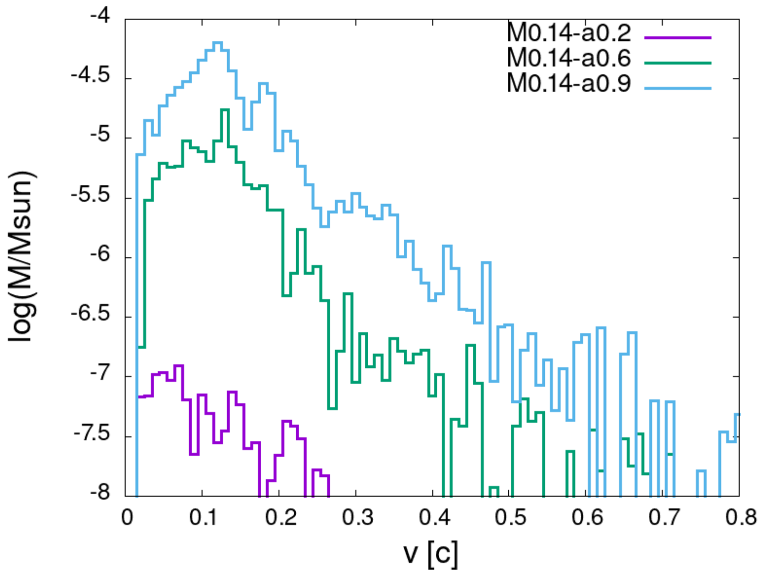
Magnetized Accretion Disk Models

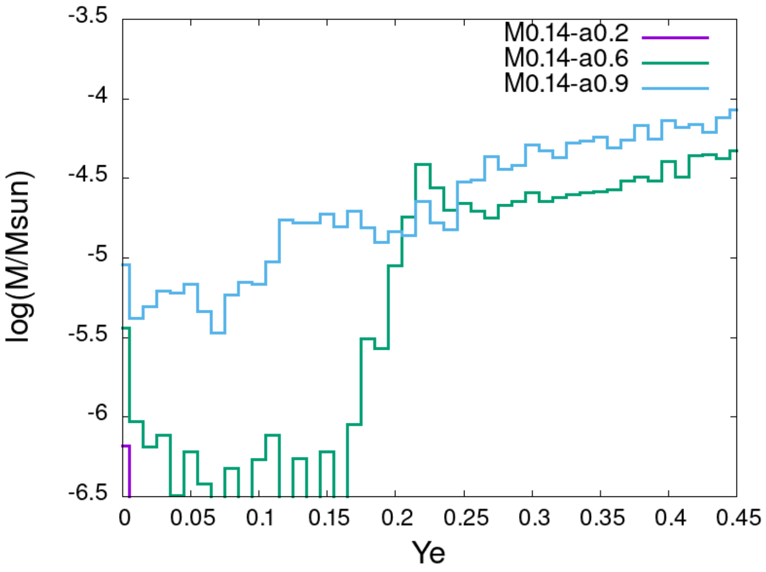
Model	BH Mass $[M_\odot]$	BH Spin	M_{disk} $[M_\odot]$	r_{in}	r_{max}	l_{FM}	mass ratio
*M1.0-0.14-a0.98	1.0	0.98	0.1375	6	12	4.293	0.14
M1.0-0.14-a0.9 (done)	1.0	0.9	0.1375	6	12	4.293	0.14
M1.0-0.14-a0.6 (done)	1.0	0.6	0.1375	6	12	4.293	0.14
*M1.0-0.14-a0.4	1.0	0.4	0.1375	6	12	4.293	0.14
M1.0-0.14-a0.2 (done)	1.0	0.2	0.1375	6	12	4.293	0.14
*M5.0-0.3-a0.9	5.0	0.9	0.3020	6.5	13.4	4.44	0.3
M1.5-0.1-a0.9 (done)	1.5	0.9	0.1	5.4	11	4.189	0.0635
M2.0-0.05-a0.9 (done)	2.0	0.9	0.05	4.8	9.75	4.0617	0.0225
*M3.0-0.02-a0.9	3.0	0.9	0.02073	3.8	8.6	3.950	0.0066
*M6.0-0.14-a0.9	6.0	0.9	0.1435	3.8	10	4.087	0.024
*M2.65-0.1-a0.9	2.65	0.9	0.1001	3.8	9.75	...	0.0265
*M6.0-0.14-aR0.9	6.0	-0.9	0.14073	7.8	16.8	5.148	0.024
*M6.0-0.14-aR0.6	6.0	-0.6	0.14073	7.8	16.8	5.148	0.024
*M6.0-0.14-aR0.4	6.0	-0.4	0.14073	7.8	16.8	5.148	0.024
*LowRes of case M1.0-0.14-a0.6 with 288*256 grid points							

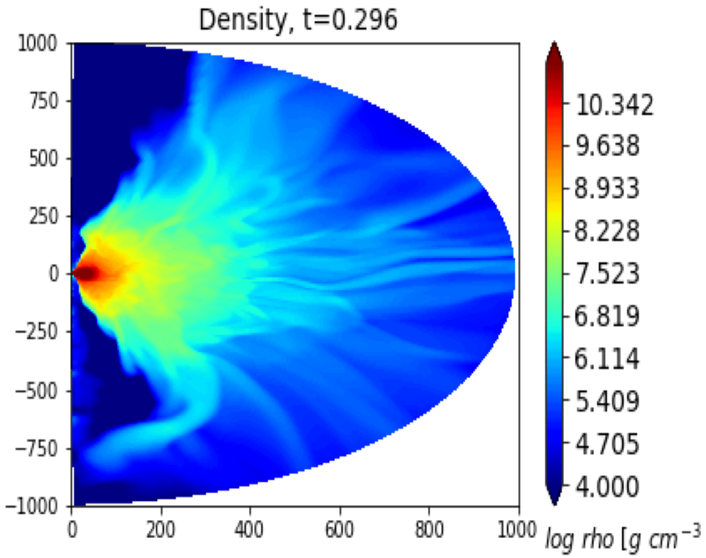
Table 1. Different disk setup for numerical simulations.

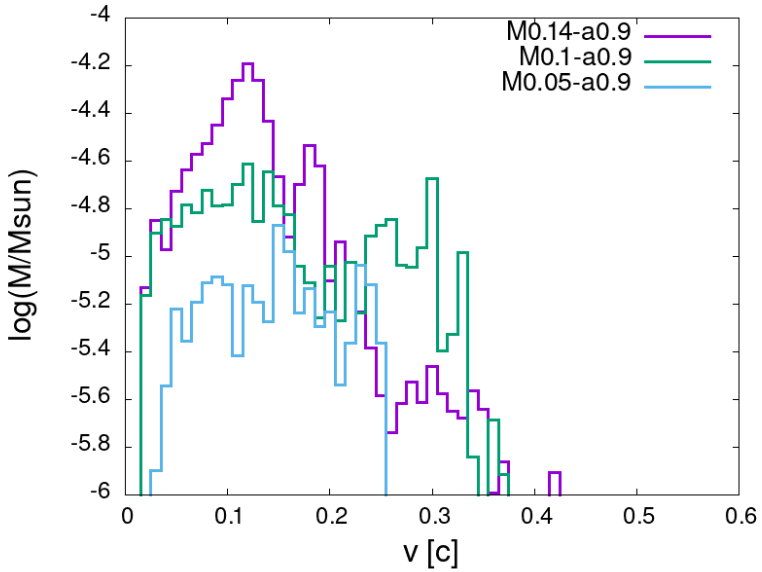
Disk Evolution and Outflows

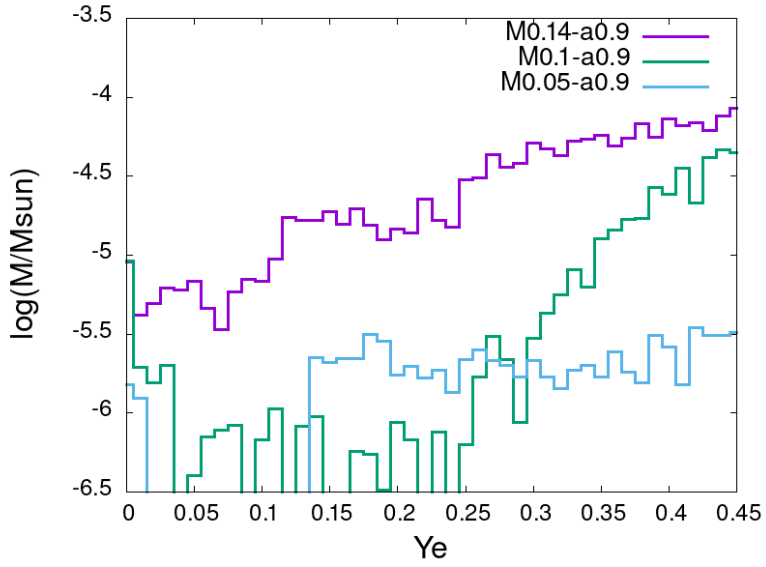












Light-curves and peaks

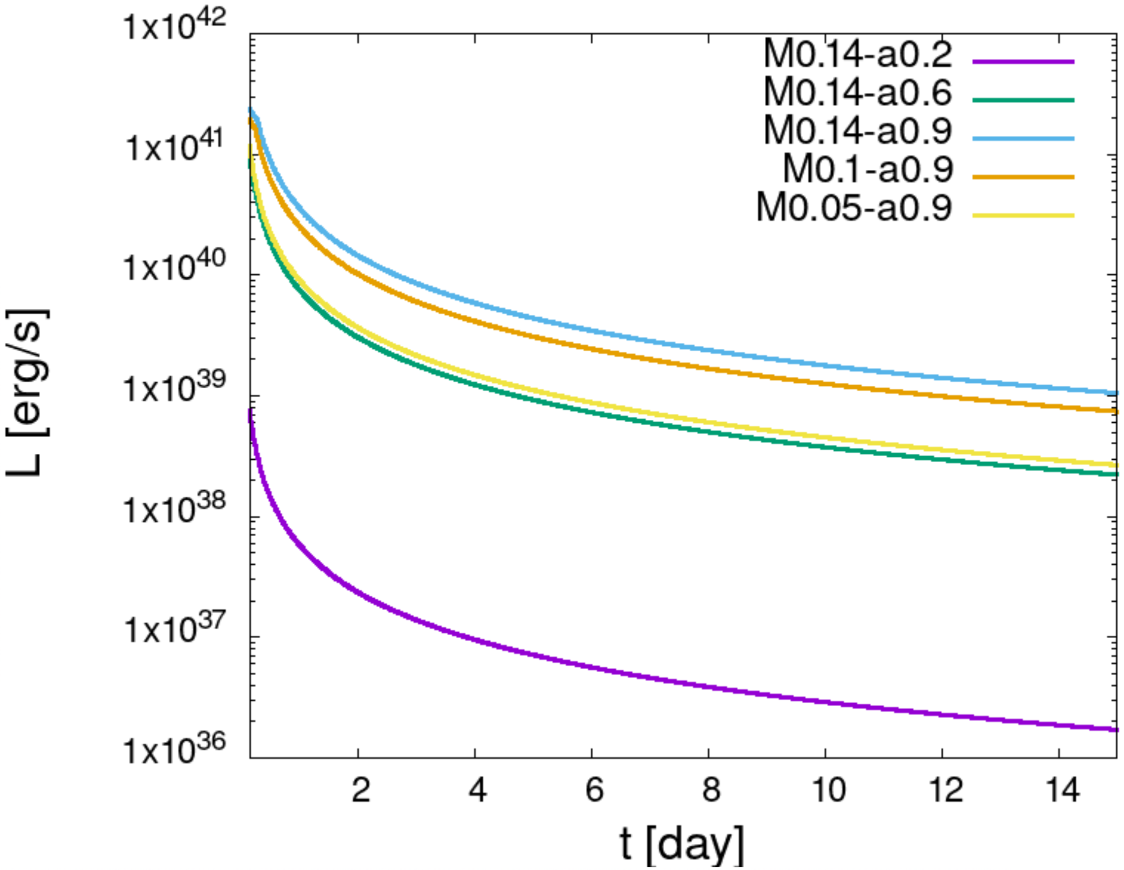
The peak values are estimated using Grossman et al. (2014) analytical fit, while the light-curves are estimated using Kawaguchi et al.(2016) fitting.

$$t_{\text{peak}} = 4.9 \text{ d} \times \left(\frac{M_{ej}}{10^{-2} M_\odot}\right)^{\frac{1}{2}} \left(\frac{\kappa}{10 \text{ cm}^2\text{g}^{-1}}\right)^{\frac{1}{2}} \left(\frac{v_{\text{ej}}}{0.1}\right)^{-\frac{1}{2}},$$

$$L_{\text{peak}} = 2.5 \cdot 10^{40} \text{ erg s}^{-1} \times \left(\frac{M_{ej}}{10^{-2} M_\odot}\right)^{1-\frac{\alpha}{2}} \left(\frac{\kappa}{10 \text{ cm}^2\text{g}^{-1}}\right)^{-\frac{\alpha}{2}} \left(\frac{v_{\text{ej}}}{0.1}\right)^{\frac{\alpha}{2}},$$

$$T_{\text{peak}} = 2200 \text{ K} \times \left(\frac{M_{ej}}{10^{-2} M_\odot}\right)^{-\frac{\alpha}{8}} \left(\frac{\kappa}{10 \text{ cm}^2\text{g}^{-1}}\right)^{-\frac{\alpha+2}{8}} \left(\frac{v_{\text{ej}}}{0.1}\right)^{\frac{\alpha-2}{8}}.$$

$$L_{\text{bol}}(t) = (1+\theta_{\text{ej}})\epsilon_{\text{th}}\dot{\epsilon}_0 M_{\text{ej}} \begin{cases} \frac{t}{t_c}\left(\frac{t}{1\text{ d}}\right)^{-\alpha}, & t \leqslant t_c \\ \left(\frac{t}{1\text{ d}}\right)^{-\alpha}, & t > t_c \end{cases},$$



Model	Outflow Mass [$M_\odot$]	average Y_e	average v [c]	average θ[°]	t_{peak} [d]	L_{peak} [erg/s]	T_{peak} [K]
M1.0-0.14-a0.9	6.076×10^{-4}	0.26	0.202	11.37	0.27	6.62×10^{40}	8430
M1.0-0.14-a0.6	1.25×10^{-4}	0.35	0.128	0.86	0.15	2.825×10^{40}	11350
M1.0-0.14-a0.2	1.24×10^{-6}	0.47	0.112	0.97	0.016	5.15×10^{39}	24299
M2.0-0.05-a0.9	1.52×10^{-4}	0.36	0.199	8.07	0.13	4.04×10^{40}	10567
M1.5-0.1-a0.9	4.16×10^{-4}	0.41	0.169	2.22	0.24	5.16×10^{40}	9106

Table 2. Properties of the Outflows and kilonova's peaks. The average θ is measured from the equator.