Revisiting on the lower bound of tidal deformability constraint derived by AT2017 gfo

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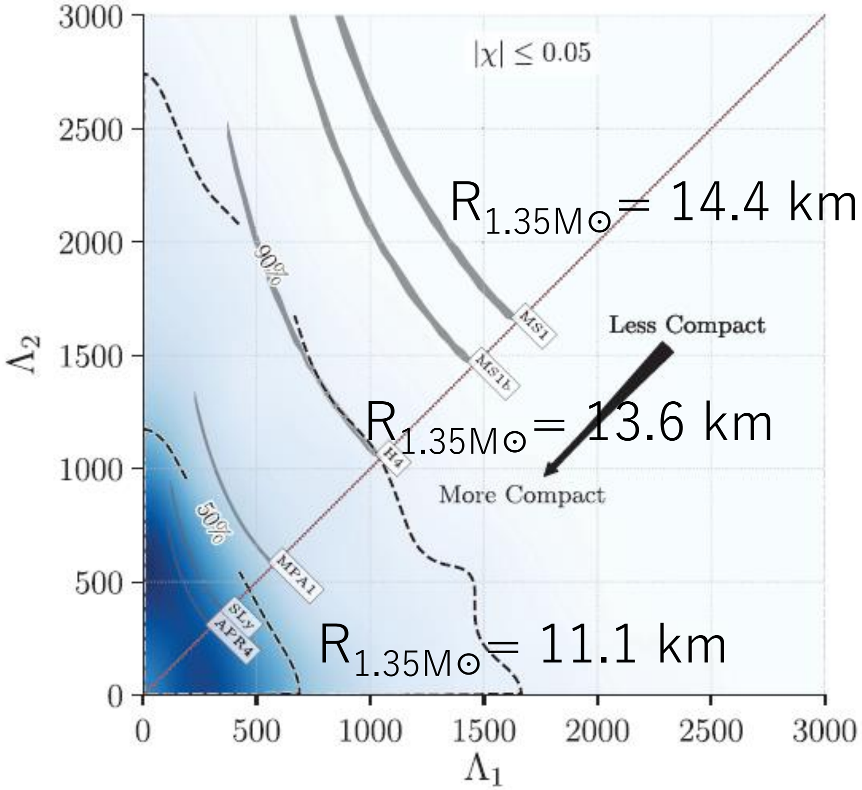
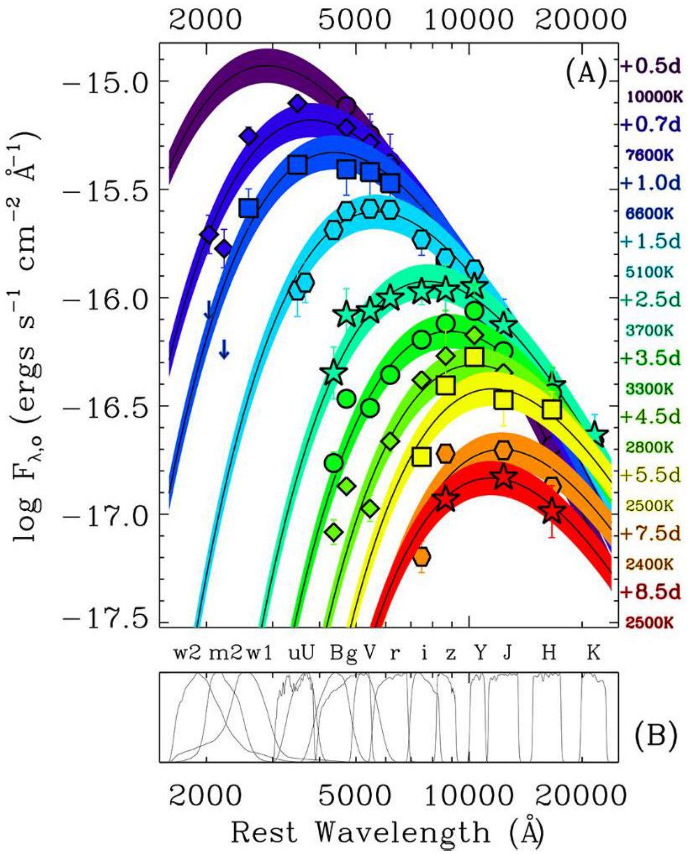
GW170817/AT2017gfo/GRB170817A

Abott et al. PRL 119, 161101 (2017)



Drout et al. Science (aaq0049), 2017



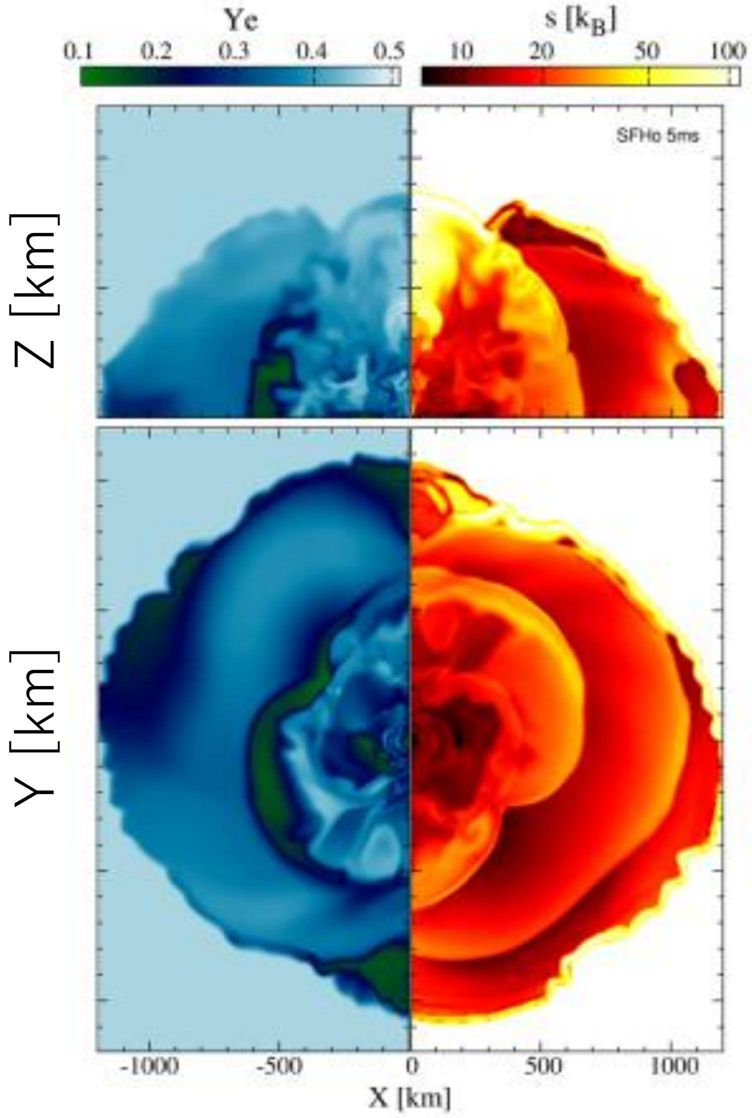
Evans et al.(2017), Kipartrick et al (2017), Kasliwal et al. (2017), Nicholl et al. (2017), Utsumi et al. (2017), Tominaga et al. (2018), Chornock et al. (2017), Arcavi et al. (2017), Diaz et al. (2017), Shappee et al. (2017), Coulter et al. (2017), M. Soares-Santos et al. (2017), Valentin et al.(2017), Pain et al. (2017),Smartt et al. (2017)

- ▶ Tidal deformability Λ is constrained for the first time : 100 ≤ Λ ≤ 800
- ▶ Blue & Red kilonova model indicates M_{eje}～$0.05M_\odot$(e.g., Drout et al. 2017)

Where does neutron rich ejecta come from?

Dynamical ejecta: Tidal component & Shocked component

Disk ejecta: Viscous heating/Angular momentum transfer with neutrino absorption

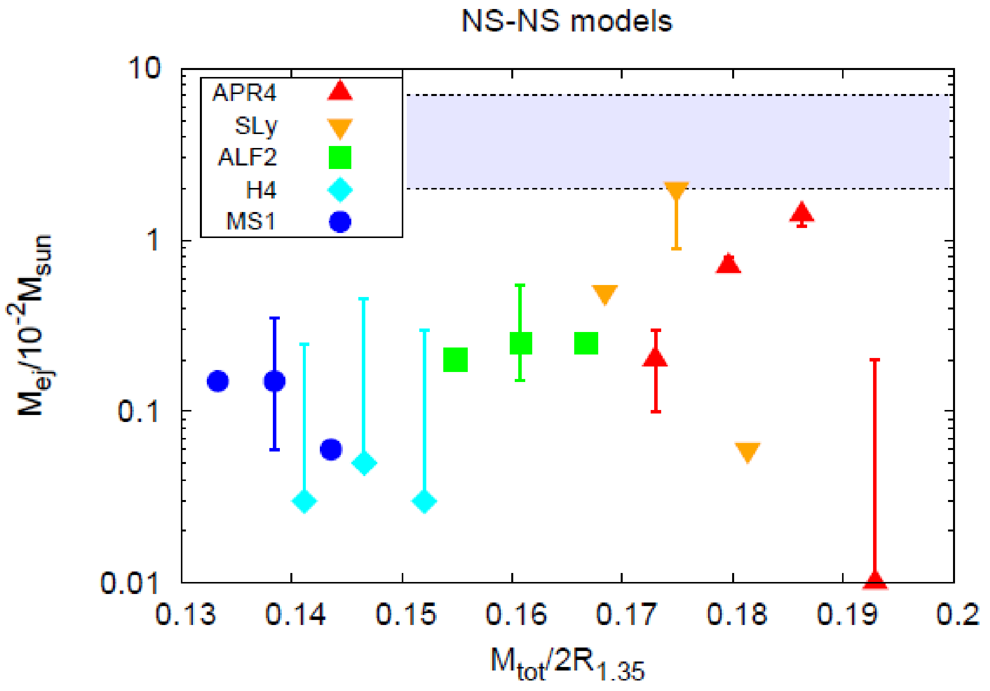


Fujibayashi, KK et al. 2018

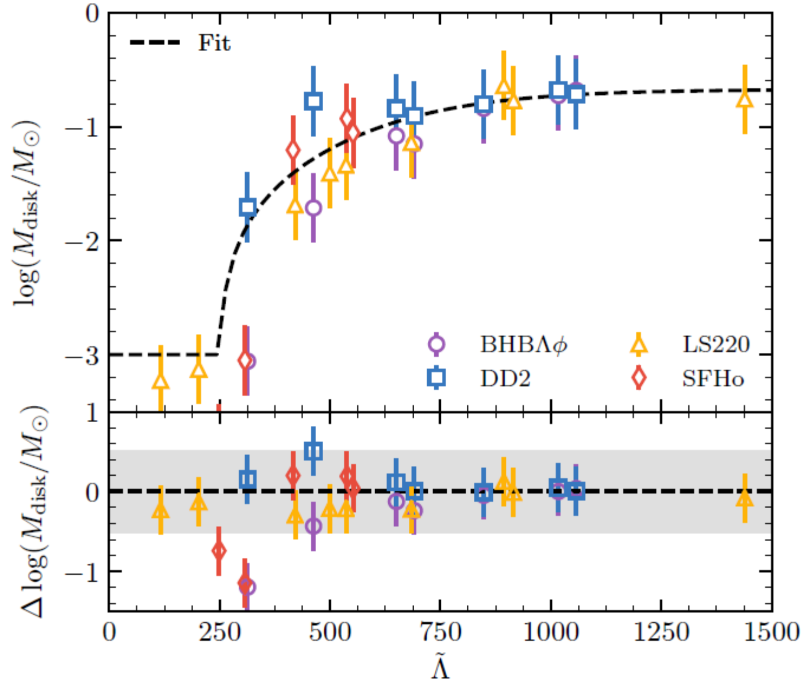
Sekiguchi, KK et al. 2015, 2016

Dependence M_{dyn} and M_{disk} on Λ

Hotokezaka, KK et al. 13



Radice & Dai 18



▶ Small/Large Tidal deformability Λ favors large M_{dyn}/M_{disk}
Joint analysis of GW and EM gives a lower limit on $\Lambda \gtrsim 400$ (Radice et al. 17, Radice & Dai 19), (similar statement in Bauswein et al. 17)

Is it true? With their limited class of EOSs (RMF), $M_{TOV,max}$ and Λ has a tight correlation.

Why is $M_{TOV,max}$ important ?

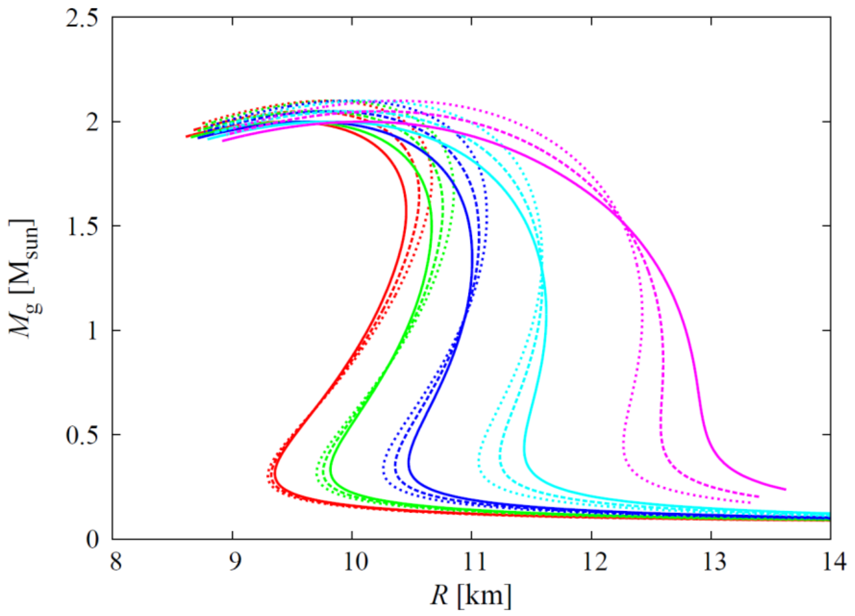
In general, a BNS with large $M_{TOV,max}$ tends to have a long lifetime after merger. ⇒ It has a chance to form a massive disk.

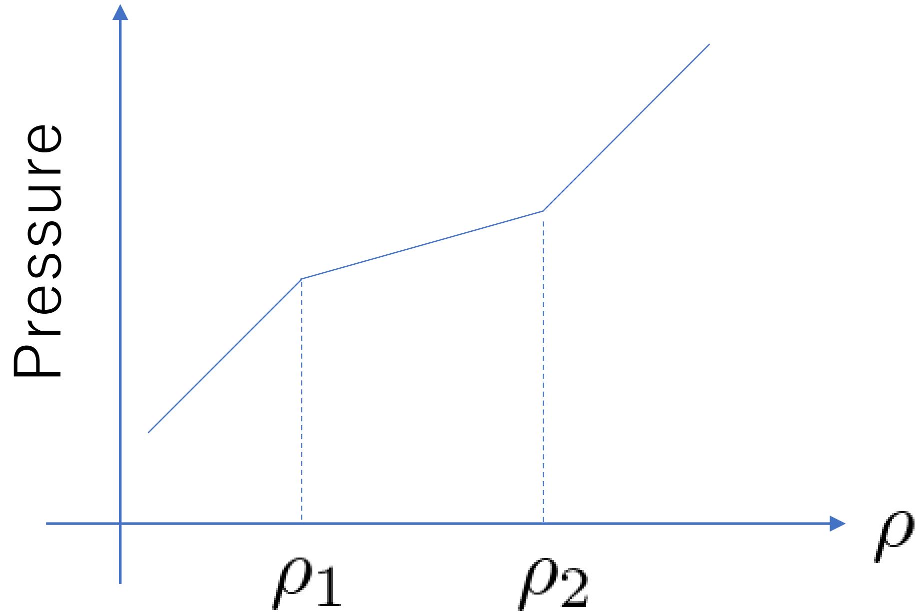
If $M_{TOV,max}$ correlates with Λ as the EOSs in Radice's paper, a model with small Λ tends to be rejected from AT2017 gfo observation.

We revisit this problem in NR simulation of BNSs with a Piece-Wise-Polytrope (PWP) prescription with which we can handle a correlation between $M_{TOV,max}$ and Λ.

Revisiting on the lower bound of Λ

3 segments Piece-Wise Polytropic EOS (Read et al. 2009)





- ▶ $M_{TOV,\,max}$ = 2.00, 2.05, 2.10 $M_\odot$
- ▶ $\tilde{\Lambda}_{2.75M_\odot} \approx 200 - 600$

▶ 1.375-1.375$M_\odot$ (equal mass). 1.2-1.55$M_\odot$ (unequal mass) (cf. $2.74^{+0.04}_{-0.01}M_\odot$ for GW170817)

Three possibilities of a remnant

1. BNS collapses to a BH immediately after merger (we avoid calling it a prompt collapse as in Bauswein 17).

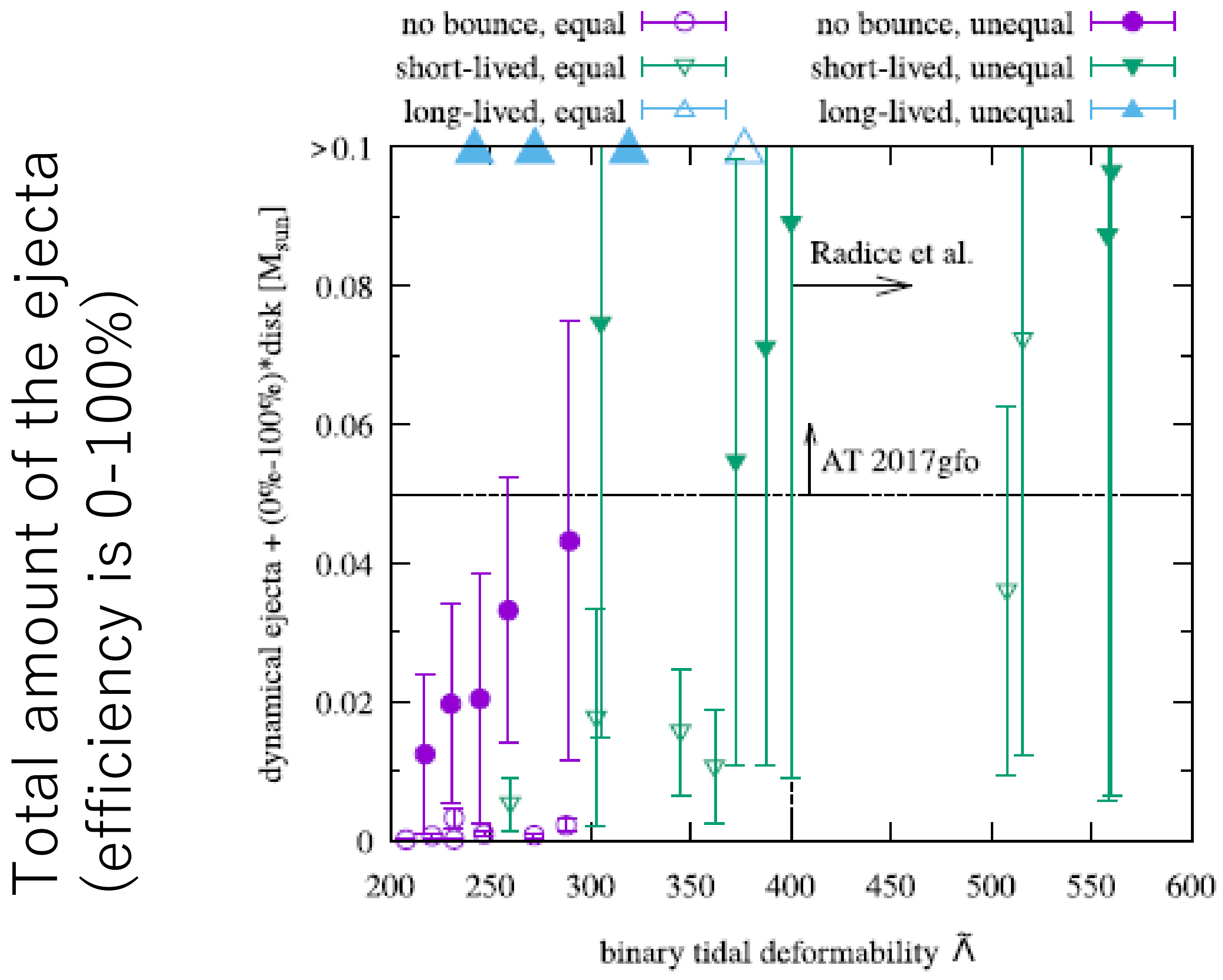
⇒No bounce case because there is no prominence bounce in α_{min}.

2. A transiently formed hyper massive NS collapses to a BH within 20 ms after merger. ⇒Short-lived case

3. A hyper massive NS never collapses to a BH ⇒ Long-lived case

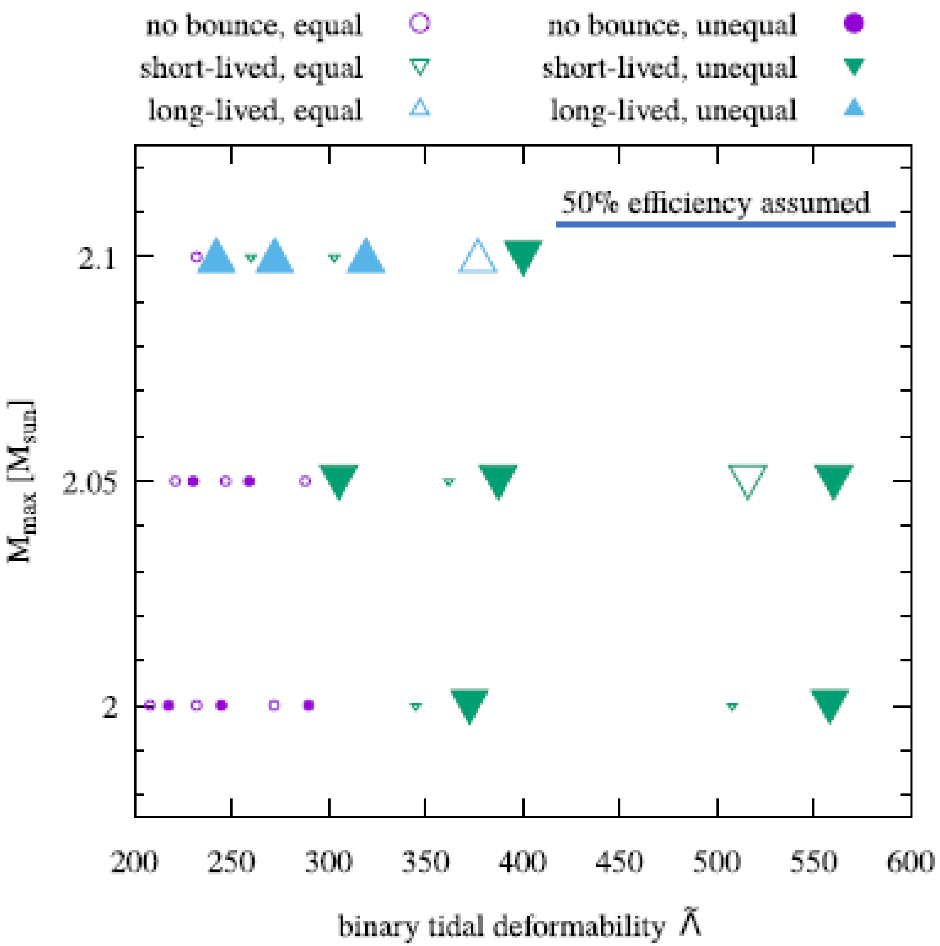
In this case, the disk is defined fluid elements with $\rho \lesssim 10^{13}$g/cc

Result (KK et al. 19)



Some models could explain AT2017 gfo even if their tidal deformability is less than 400 ⇒ Explicit counter example for the claim by Radice et al.

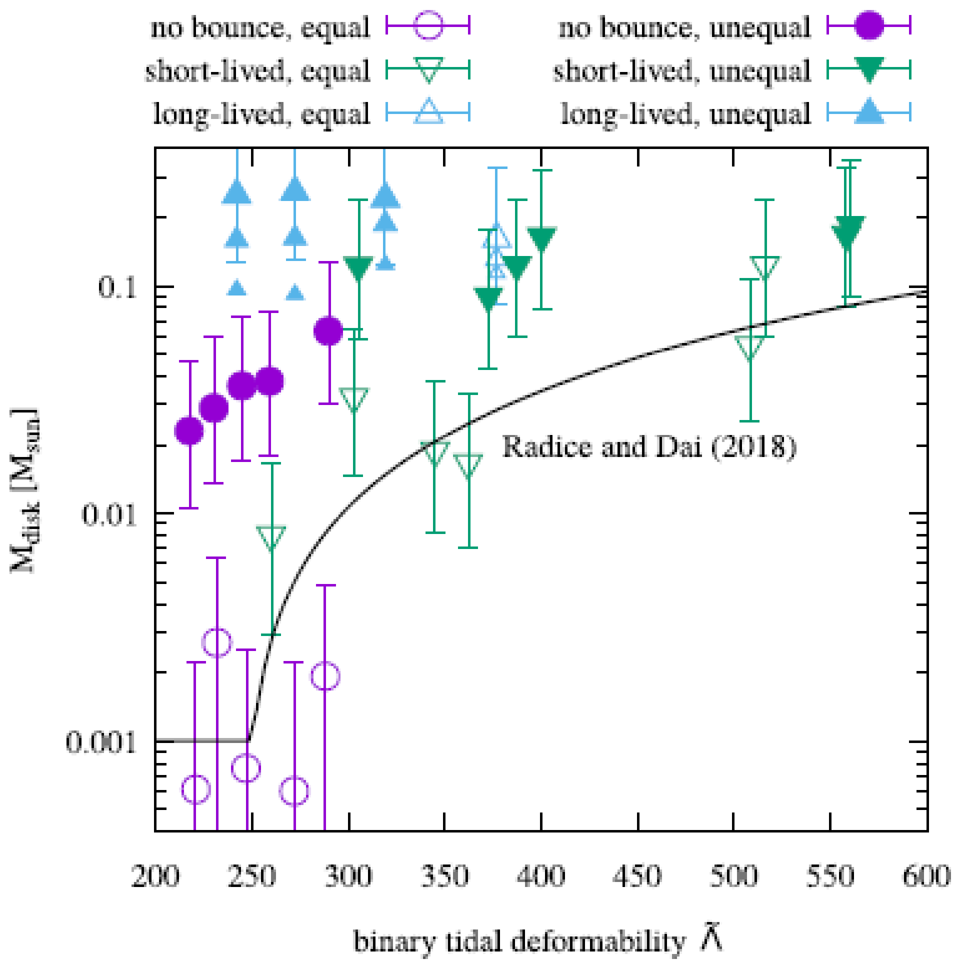
Result (KK et al. 19)



Small symbol ⇒ fail
Large symbol ⇒ success

For symmetric binary, there is no chance for the models with $\Lambda \lesssim 400$.
For asymmetric binary with large $M_{TOV,max}$, the models with $\Lambda \gtrsim 250$ still survive.

Take-home message

1. Accurate mea  a key issue. Otherwise, EM observati ... nstraining the tidal deformability

2. Using nuclea ... d a biased result, e.g., positive corre ... \.

3. Many fitting f ... tions could suffer from a systematics. P

Prompt or not in GW170817

Prompt collapse : BH formation within a dynamical timescale～0.1ms, （original definition）

Definition in Bauswein et al. 17, no bounce in the lapse function before BH formation

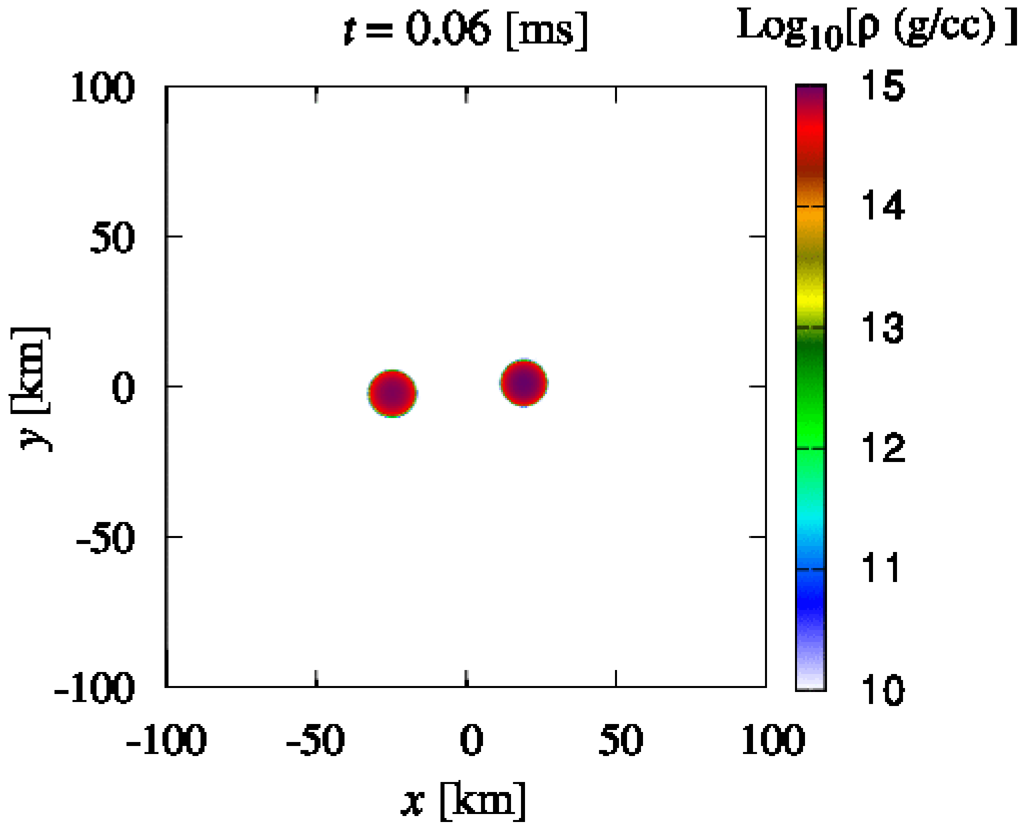
⇒ Since it is hard to produce massive ejecta of ～$0.05M_{\odot}$ in (their) prompt collapse case, GW170817 suggests no prompt BH formation.

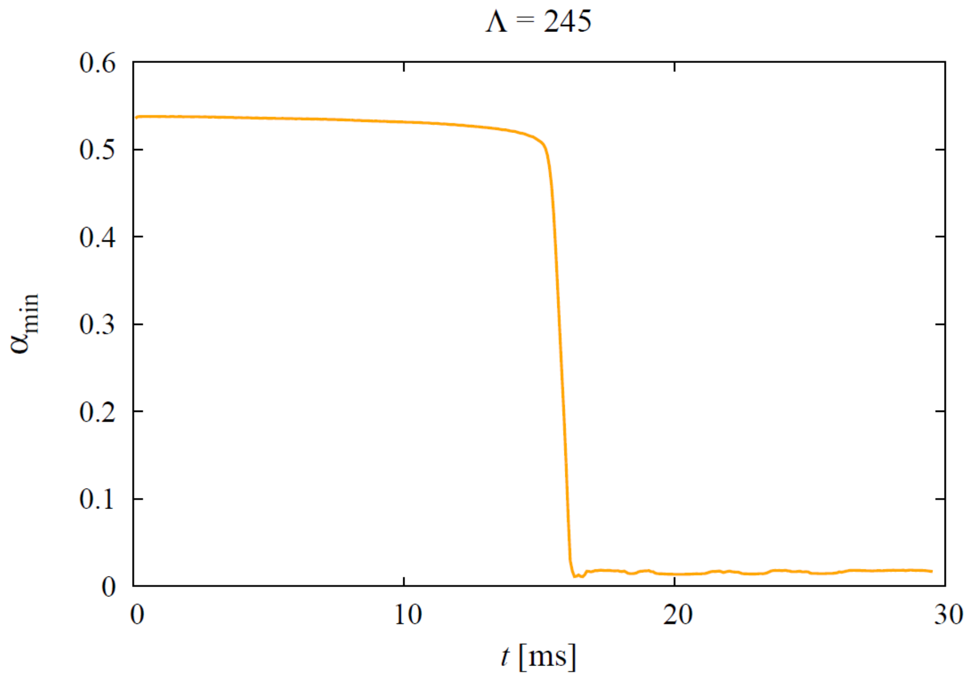
⇒Threshold mass of prompt BH formation relates to a NS radius

⇒GW170817/AT2017 gfo gives a constraint on the NS radius.

Possible counter example of the constraint of Bauswein et l. 2017

$M_{max} = 2.05 M_{\odot}$, $R_{1.35}$=10.7km, 1.2-1.55$M_{\odot}$





It could explain the luminosity of AT2017 gfo if we assume 60% efficiency. Again, the mass ratio is a key quantity.

Appendix: Uncertainty due to numerical resolution

q	$\bar{\Lambda}$	Δx (m)	Type	M_{dyn} ($M_{\odot}$)	M_{disk} ($M_{\odot}$)
1	288	128	no bounce	1.2×10^{-3}	1.9×10^{-3}
		148	no bounce	2.1×10^{-3}	4.8×10^{-3}
		164	short	6.9×10^{-3}	0.013
1	508	149	short	9.4×10^{-3}	0.053
		172	short	0.011	0.055
		191	short	8.5×10^{-3}	0.045
1	516	147	short	0.012	0.12
		170	short	0.013	0.089
		189	short	0.012	0.095
0.774	242	121	long	0.013	0.26
		140	long	0.017	0.26
		156	long	0.019	0.25
0.774	259	128	no bounce	0.014	0.038
		148	no bounce	0.014	0.041
		164	short	0.015	0.31
0.774	290	131	no bounce	0.012	0.063
		152	no bounce	0.013	0.063
		169	no bounce	0.014	0.069
0.774	558	156	short	5.6×10^{-3}	0.16
		180	short	4.7×10^{-3}	0.14
		201	short	4.5×10^{-3}	0.16
0.774	560	154	short	6.4×10^{-3}	0.18
		178	short	5.5×10^{-3}	0.19
		198	short	5.4×10^{-3}	0.15

We conservatory estimate a relative error of a factor of 2 and an absolute bar of $10^{-3} M_{\odot}$.

Appendix: Uncertainty due to thermal effect

q	$\tilde{\Lambda}$	Γ_{th}	Type	M_{dyn} ($M_{\odot}$)	M_{disk} ($M_{\odot}$)
0.774	242	1.8	long	0.013	0.26
		1.7	short	0.011	0.045
		1.6	short	7.6×10^{-3}	0.036
		1.5	short	6.5×10^{-3}	0.033
0.774	272	1.8	long	0.011	0.26
		1.7	long	0.013	0.26
		1.6	long	0.014	0.27
		1.5	short	9.8×10^{-3}	0.042

Thermal effect is important for a boundary between long and short-lived remnant. We should keep in mind it as well.