Resolving Fast Ejecta from Binary Neutron Star Mergers: implications for electromagnetic counterparts

INT Workshop (20R-1b)

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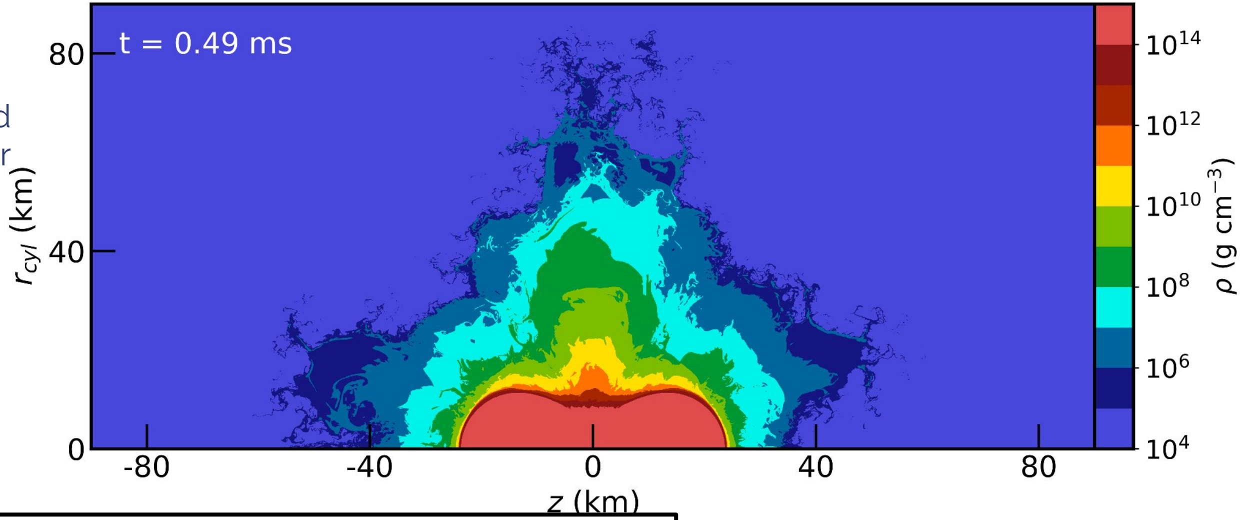


Dean, C., Fernández, R., and Metzger, B. D., 2021 **arXiv:2108.08311**

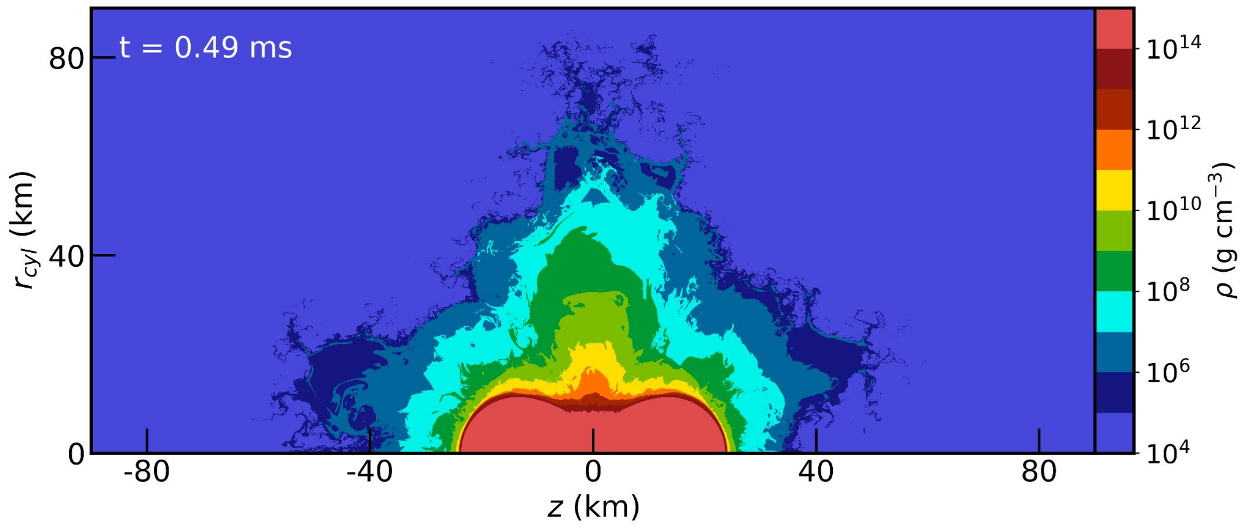
Mass ejection from BNS mergers

Dynamical Ejecta

- Tidal disruption
- Contact plane ejecta
- Remnant oscillation

Secular Ejecta

- Disk outflows



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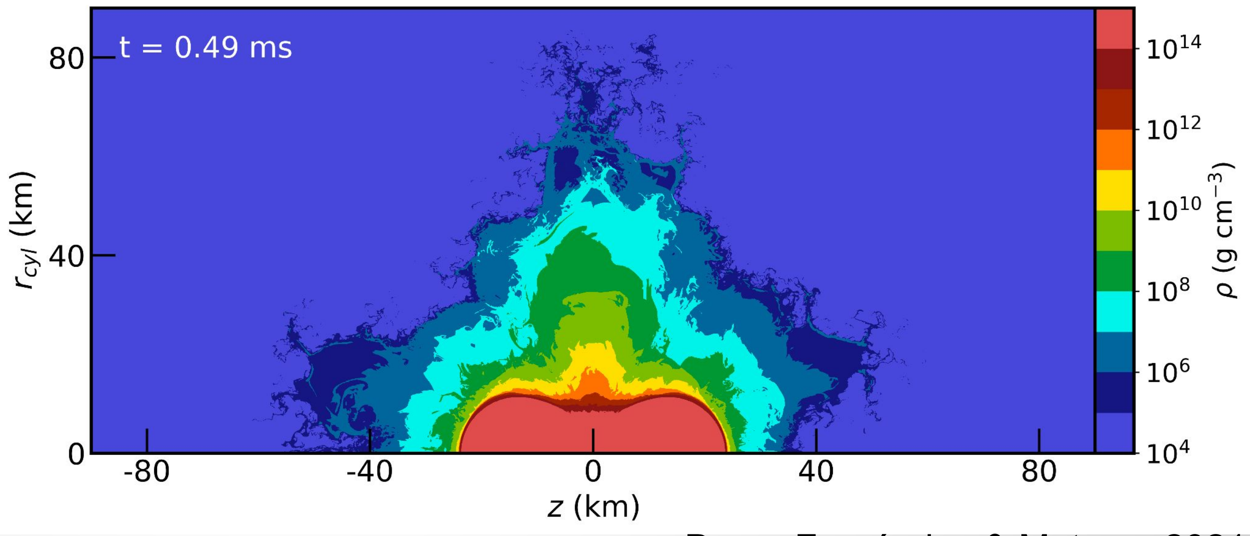

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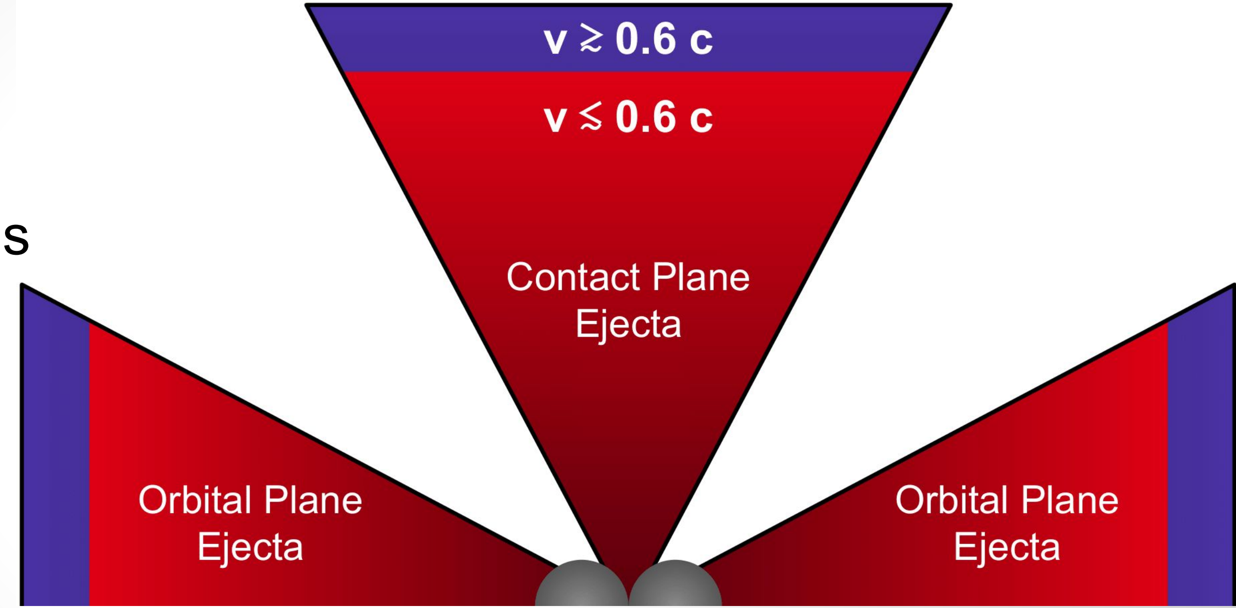
Neutron rich ejecta

Slow Ejecta (v<0.6c)

- r-process
- neutrino interactions
- powers kilonova

Fast Ejecta (v> 0.6c)

- freeze-out
- UV precursor
- non-thermal afterglow



R-process Freeze-out

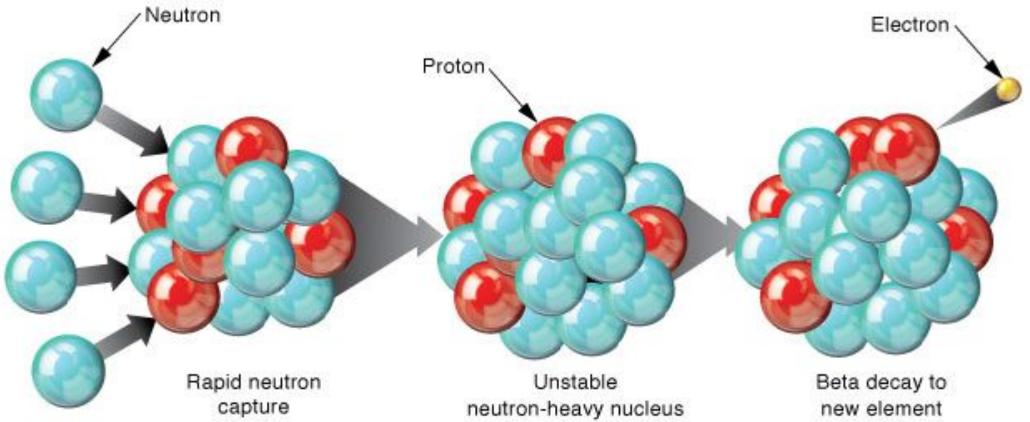
Freeze-out requires a density drop to $\rho < 4 \times 10^4$ g cm^{-3} within 5 ms (Metzger et al. 2015)

τ(capture) > τ(expansion)

Free neutrons escape the r-process and remain free

Maps well to ejecta with

v > 0.6 c



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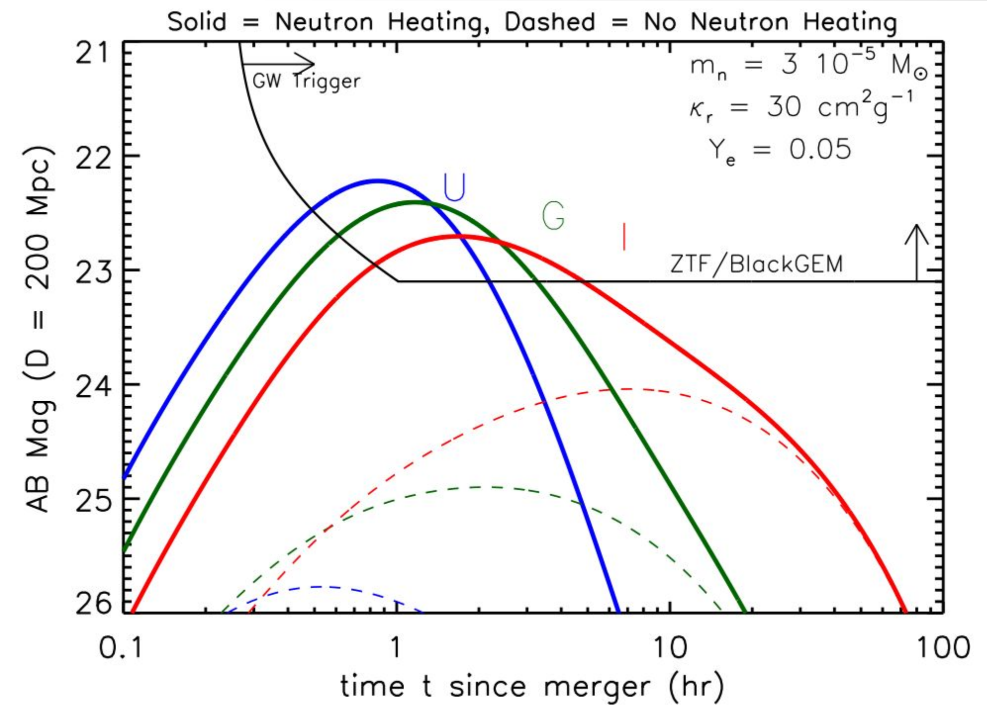
UV Precursor

Ejecta heated by free neutron decay

Peaks in the ultraviolet

On a timescale of hours after the merger



Metzger et al. 2015

Study Motivation

Disagreement on free neutron ejecta mass

For an equal mass 1.35 $M_\odot$ - 1.35 $M_\odot$ BNS merger

Smoothed Particle Hydrodynamics (SPH):

$M_{fn} \sim 10^{-4}\ M_\odot$ (Bauswein et al. 2013, Metzger et al. 2015)

Grid-Based:

$M_{fn} \sim 10^{-6}\ M_\odot$ (Radice et al. 2018b)

Study Motivation

Disagreement on free neutron ejecta mass

For an e

Paper	Method	Neutrinos
Bauswein et al. 2013	SPH	No
Radice et al. 2018b	Grid	Leakage / M0

Smooth

M_{fn} ... $_{\odot}$ (

Grid-Based:

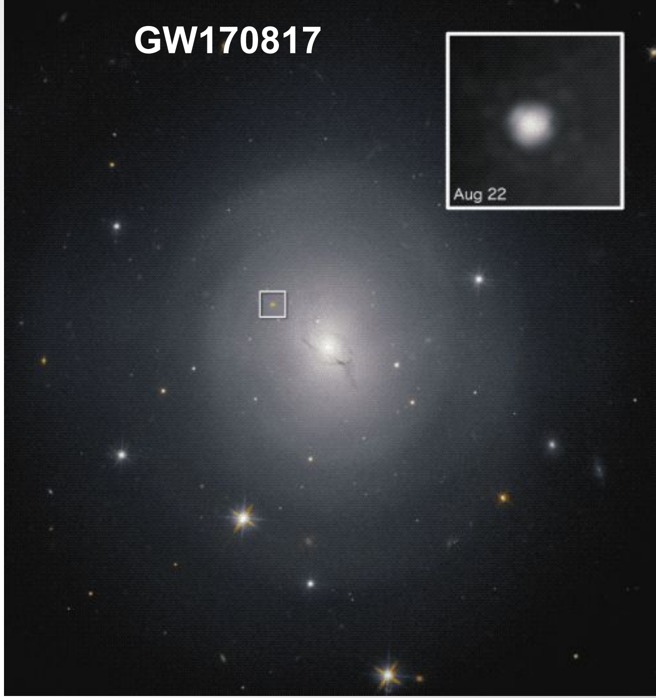
$M_{fn} \sim 10^{-6}\ M_{\odot}$ (Radice et al. 2018b)

Study Motivation

Amount of **mass ejected** impacts **detectability** of precursor

We test whether **grid-based simulations** are simply **under-resolving** this **ejecta**

We also want to estimate whether this UV precursor is realistically observable by Ultrasat



Hubble Space Telescope, NASA and ESA - https://www.nasa.gov/press-release/nasa-missions-catch-first-light-from-a-gravitational-wave-event

Resolve surface layers (< 10 m cell size; Kyutoku et al. 2014)

Previous 3D Simulations:

Radice et al. (2018b) 123 m

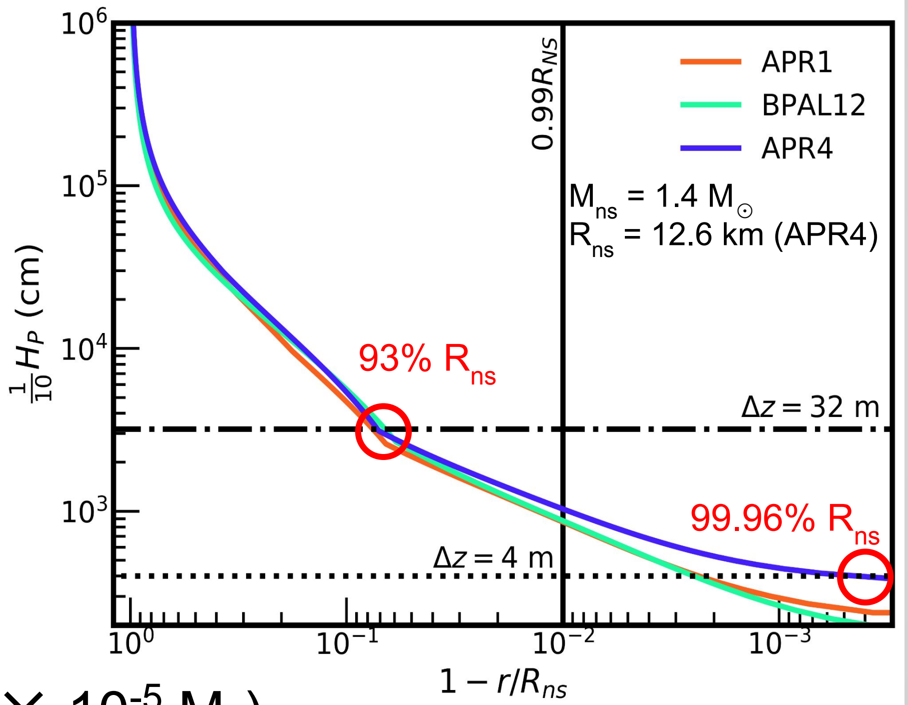
Kiuchi et al. (2017)* 63-86 m

Kiuchi et al. (2018)* 12.5 m

Numerical Experiment (2D):

Baseline Resolution: 32m

Highest Resolution: 4m ($m_{exterior} < 4 \times 10^{-5}\ M_\odot$)



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*Does not track free neutron ejecta

Axisymmetric Merger Simulation

2D Hydrodynamics

Newtonian self-gravity

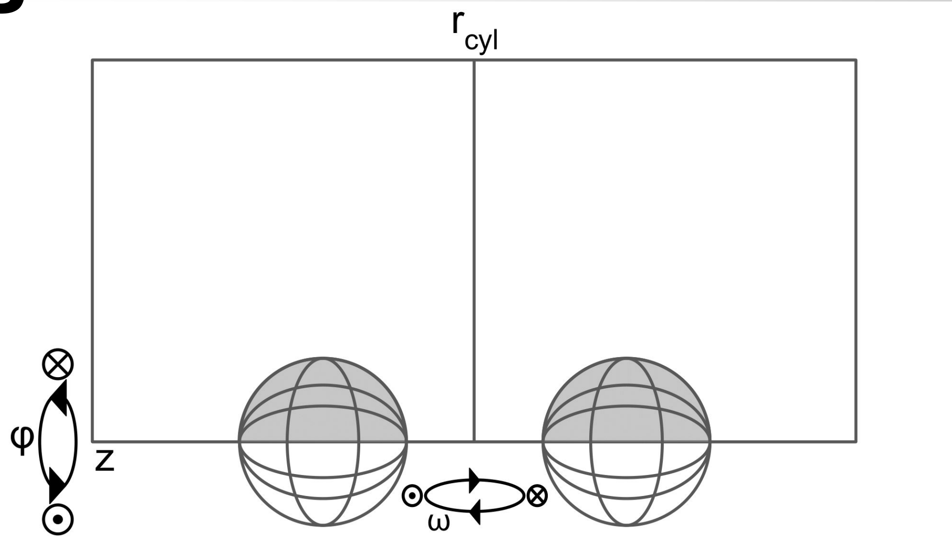
piecewise polytropic EOS

- approximate thermal effects

corotational frame

- inertial forces

Approximate gravitational wave inspiral



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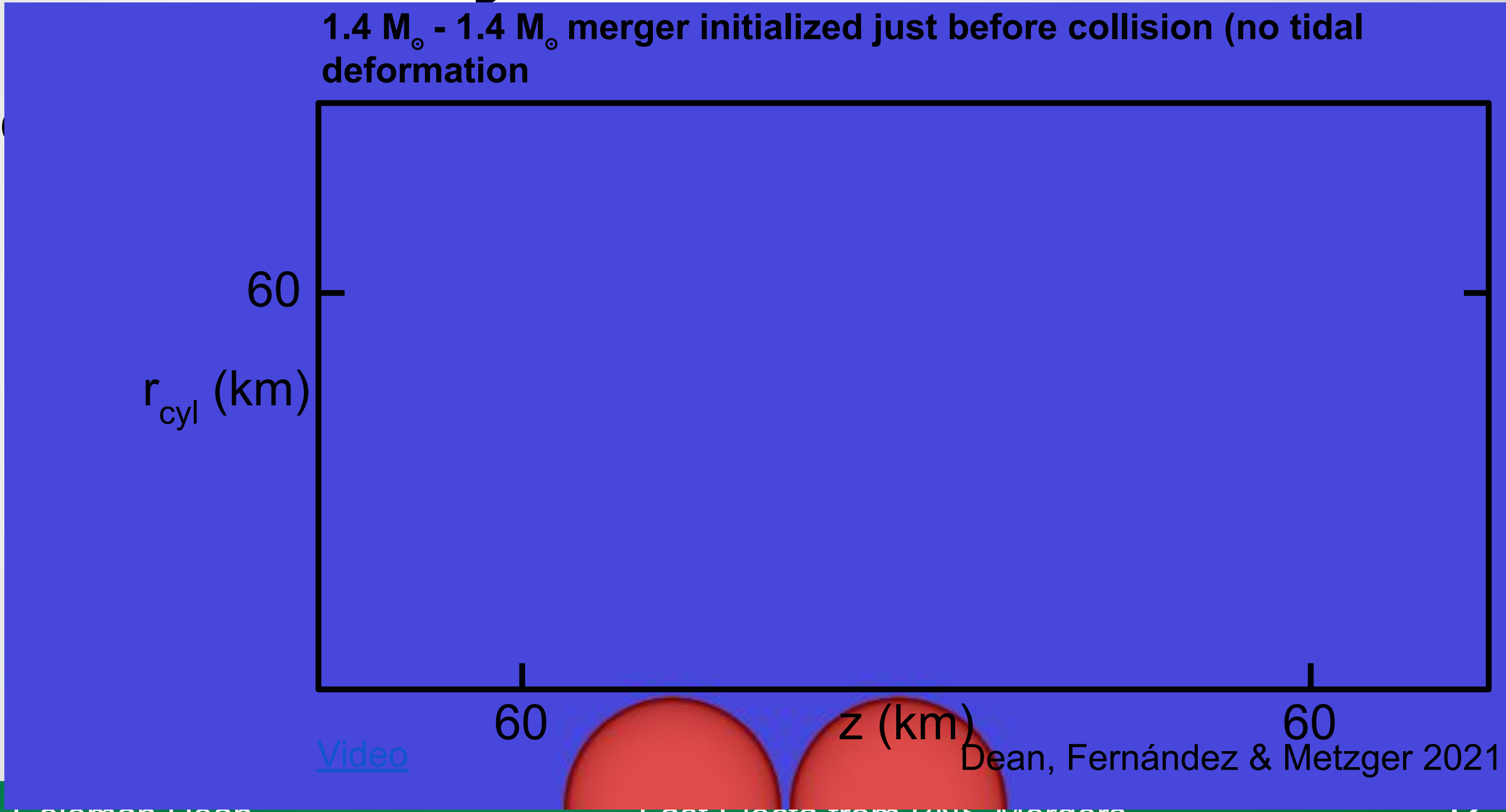
Resolution Study

Vary Res

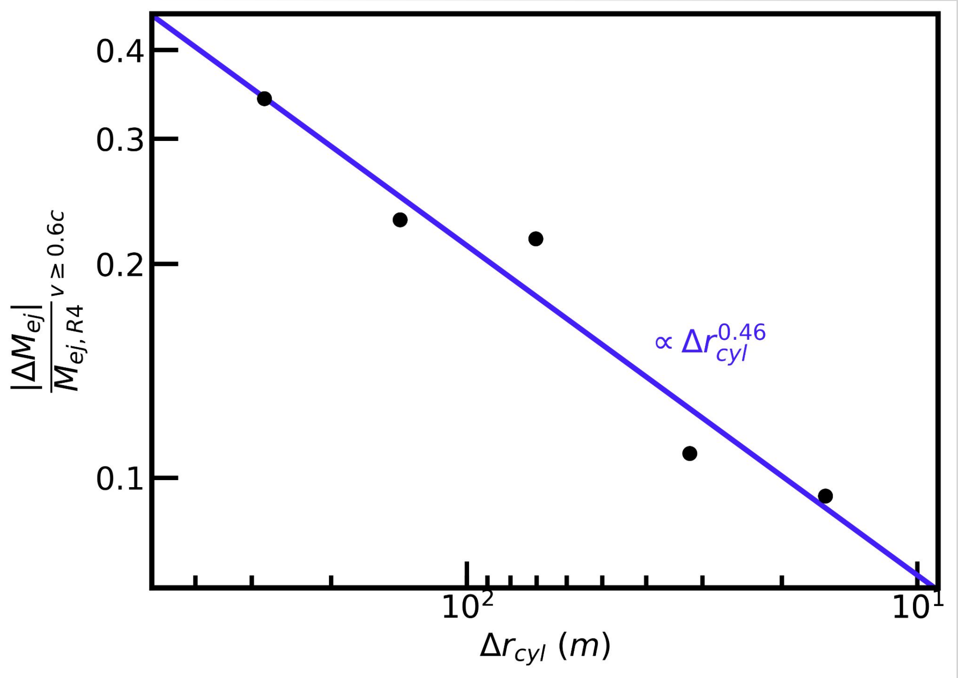
- 281m
- 141m
- 70m
- 32m
- 16m
- 4m



Fast Ejecta Mass Convergence

M_{fn} converged to within 10% by ~20 m resolution

Fast ejecta varies by a factor of ~2 in mass over a resolution change of a factor ~140



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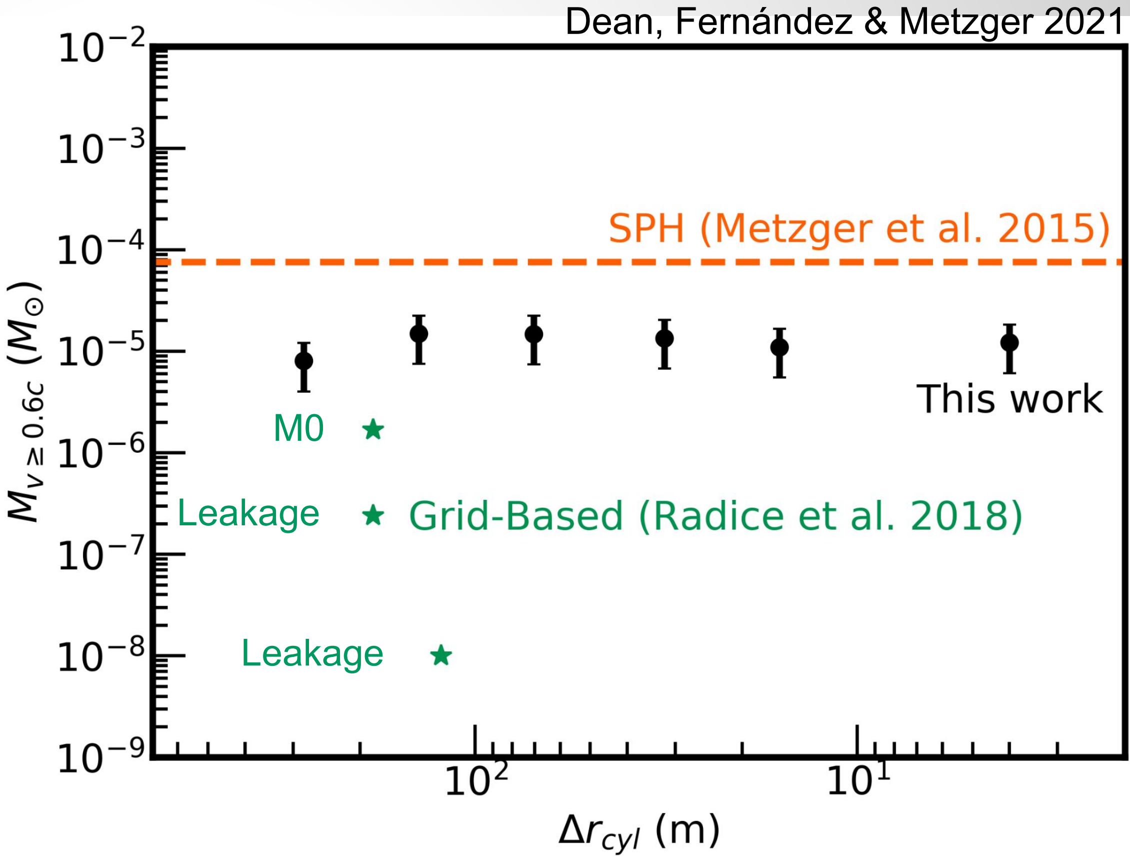
Fast Ejecta Mass Convergence

No strong resolution dependence



Parameter Space Exploration

Trends in **compactness** and **total mass** follow previously measured trends

Model breaks down for asymmetric binaries

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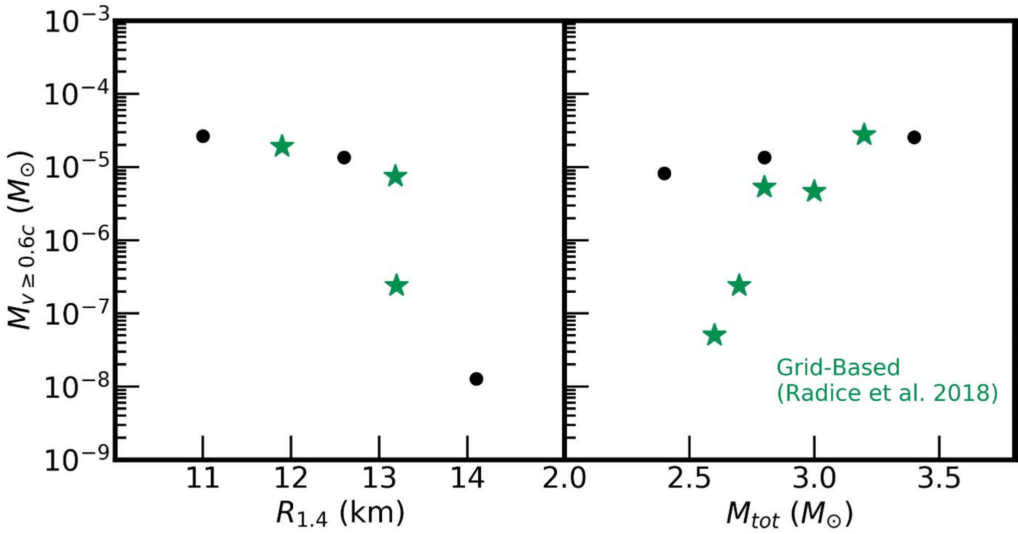

Eccentric BNS Mergers

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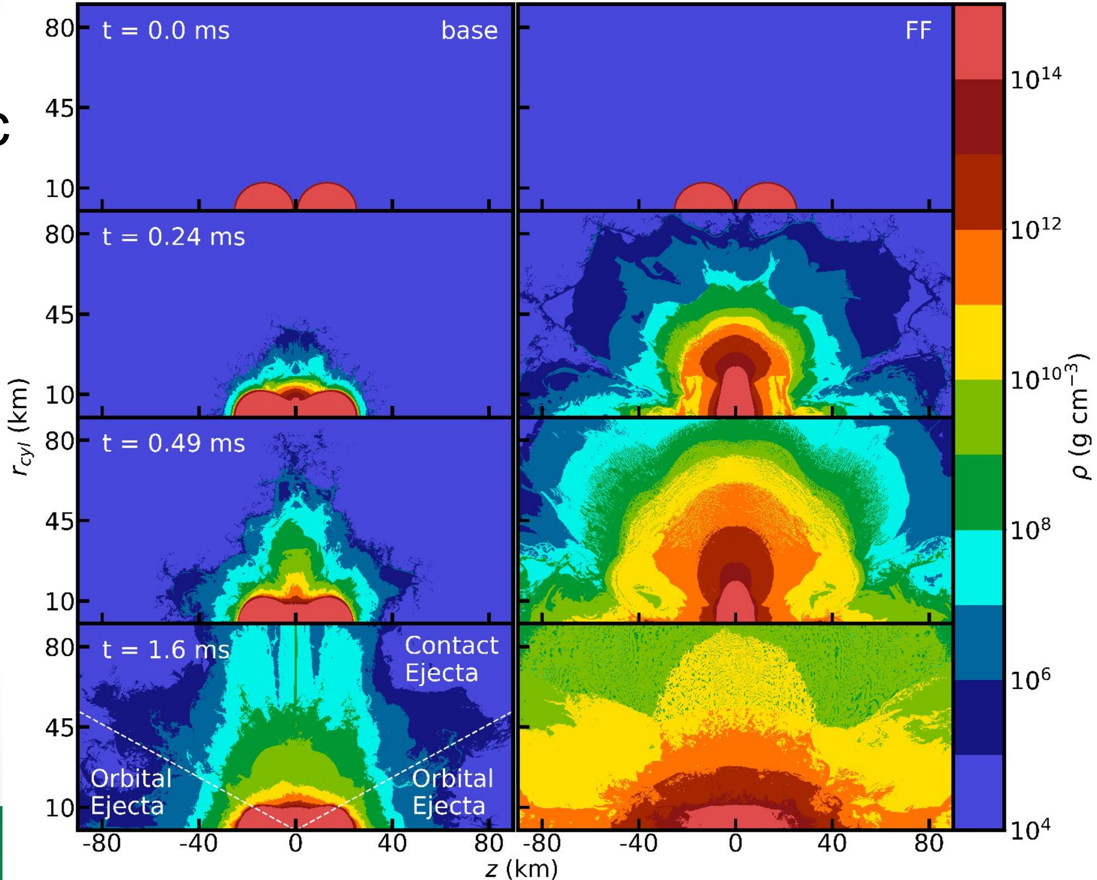
Free fall speeds (eccentric mergers)

Produce M_{ej}~10^{-2} $M_{\odot}$ (~1000x M_{ej} from GW inspiral merger speeds)

Distinct Kilonova emission



Detectability

$M_{fn} \sim 10^{-5}\ M_{\odot}$

Peak in the U band

AB Magnitude ~23 (Analytic fit from Metzger et al. 2015)

Ultrasat (Sagiv et al. 2014) 5σ limiting magnitude of 23 for a source at 200 Mpc (1 hour integration)

Detectability

In principle detectable for mergers < 200 Mpc away

GW170817 was 40 Mpc away

First EM observation: ~11 hours after merger

Other Proposed Fast Ejecta Sources

Neutrino-driven outflows (Metzger et al. 2018; Ciolfi & Kalinani 2020)

Outflows from accretion disks w/ strong initial poloidal fields (Fernández et al. 2019)

Cocoon-jet interactions (Gottlieb & Loeb 2020)

Ablation of stellar material by neutrinos (Belborodov et al. 2020)

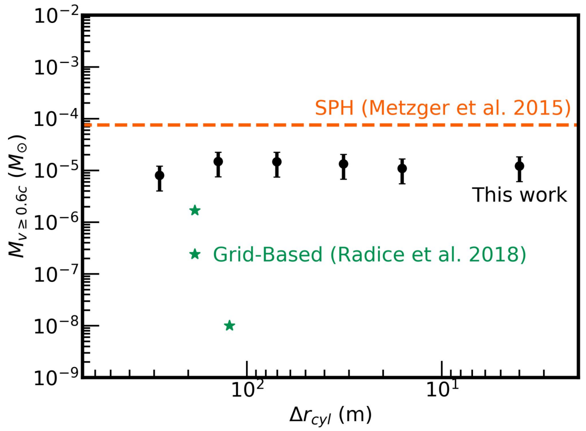
Conclusion

Resolution unlikely to explain ejecta discrepancy (SPH vs. Grid-based)

Fast ejecta converges to within 10% at a resolution of ~20 m

Eccentric BNS mergers may result in a distinguishable kilonova from quasi-circular

UV precursor in principle detectable at $M_{fn} \sim 10^{-5} M_{\odot}$ by Ultrasat for mergers < 200 Mpc



https://www.weizmann.ac.il/ultrasat/

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