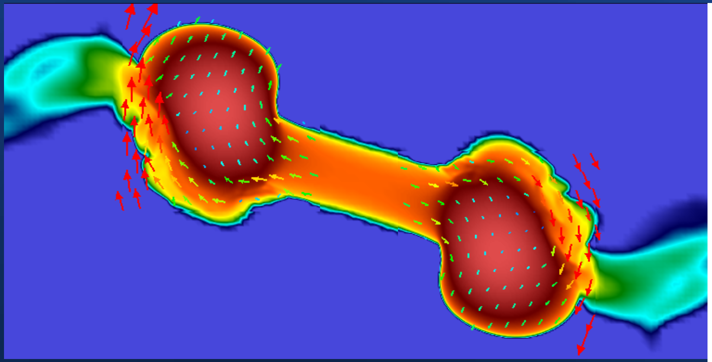
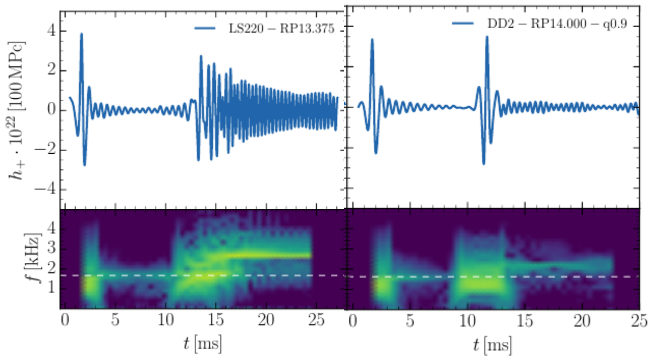
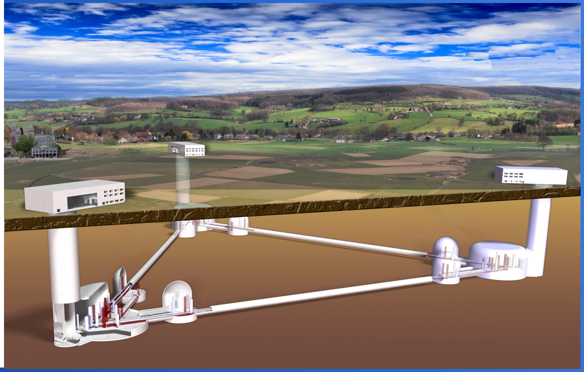
Dynamical Ejecta and nucleosynthetic yields from Eccentric Neutron Star Binaries

Roman Gold







Collaborators:
Luciano Rezzolla, Jens L. Papenfort, Shawn Rosofsky, Cecilia Chirenti, Coleman Miller

INT-JINA workshop, Seattle, WA
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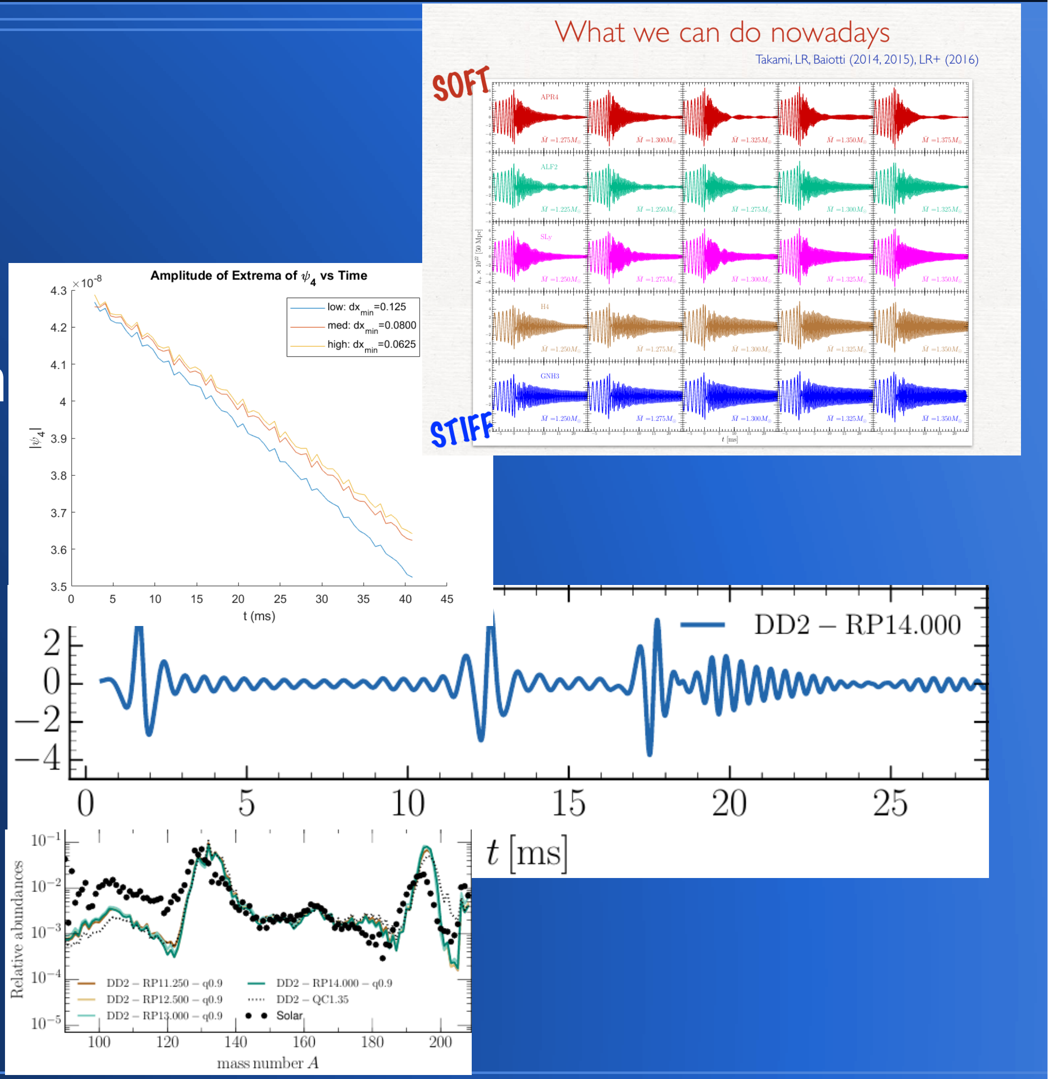
FRANKFURT AM MAIN

Introduction

- Recap: Quasi-circular binary neutron star simulations
- Universal relations & Maximum Mass of neutron stars
- Focused f-modes studies
- New features in Eccentric Binary Neutron Stars
- Dynamical ejecta & Nucleosynthesis
- Conclusions


What we can do nowadays

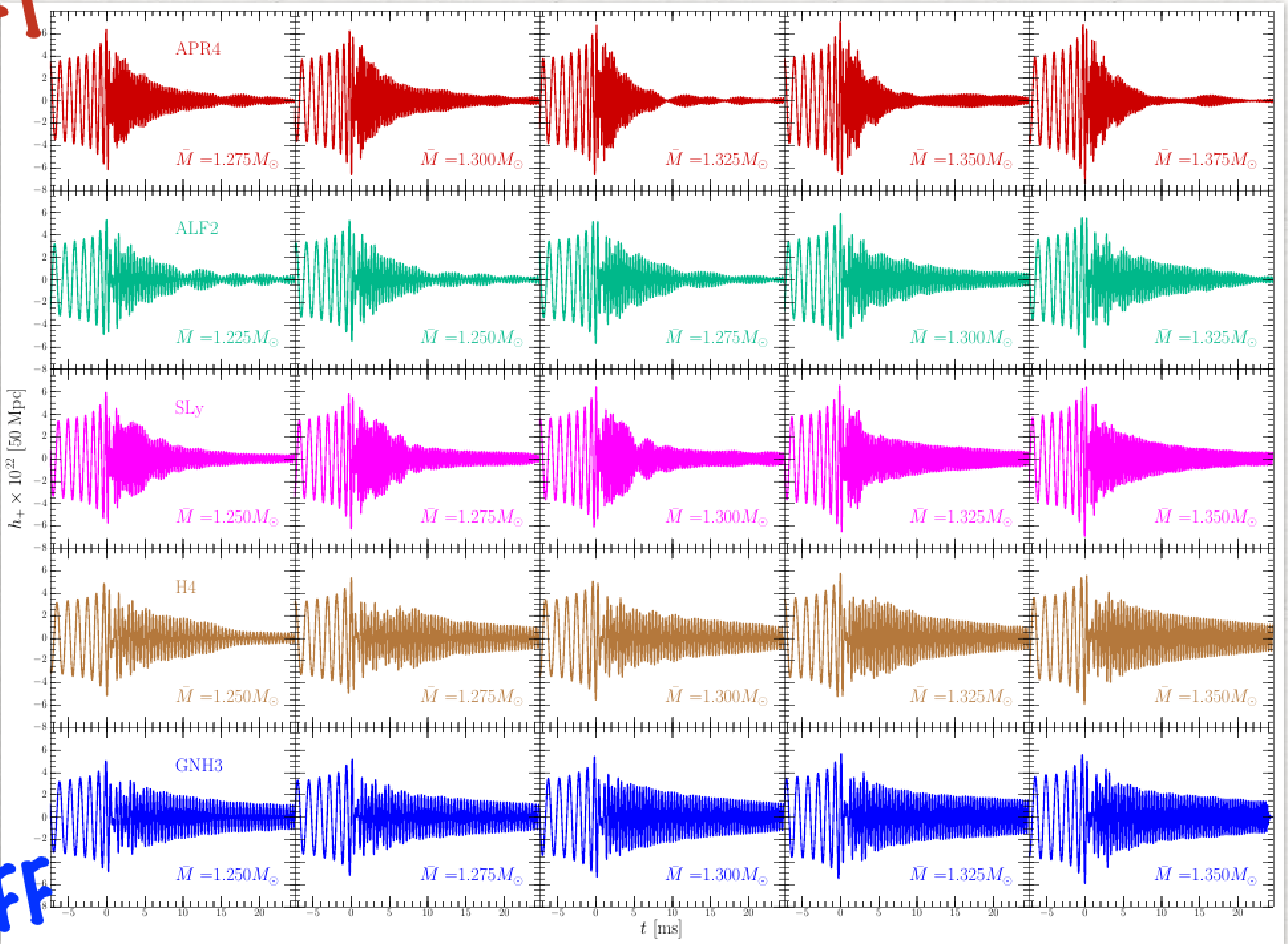
Takami, LR, Baiotti (2014, 2015), LR+ (2016)

Quasi-circular binaries

What we can do nowadays

Takami, LR, Baiotti (2014, 2015), LR+ (2016)

SOFT



STIFF

Maximum Mass of neutron stars

- The merger product of GW170817 was initially **differentially** rotating but collapsed as **uniformly** rotating object.

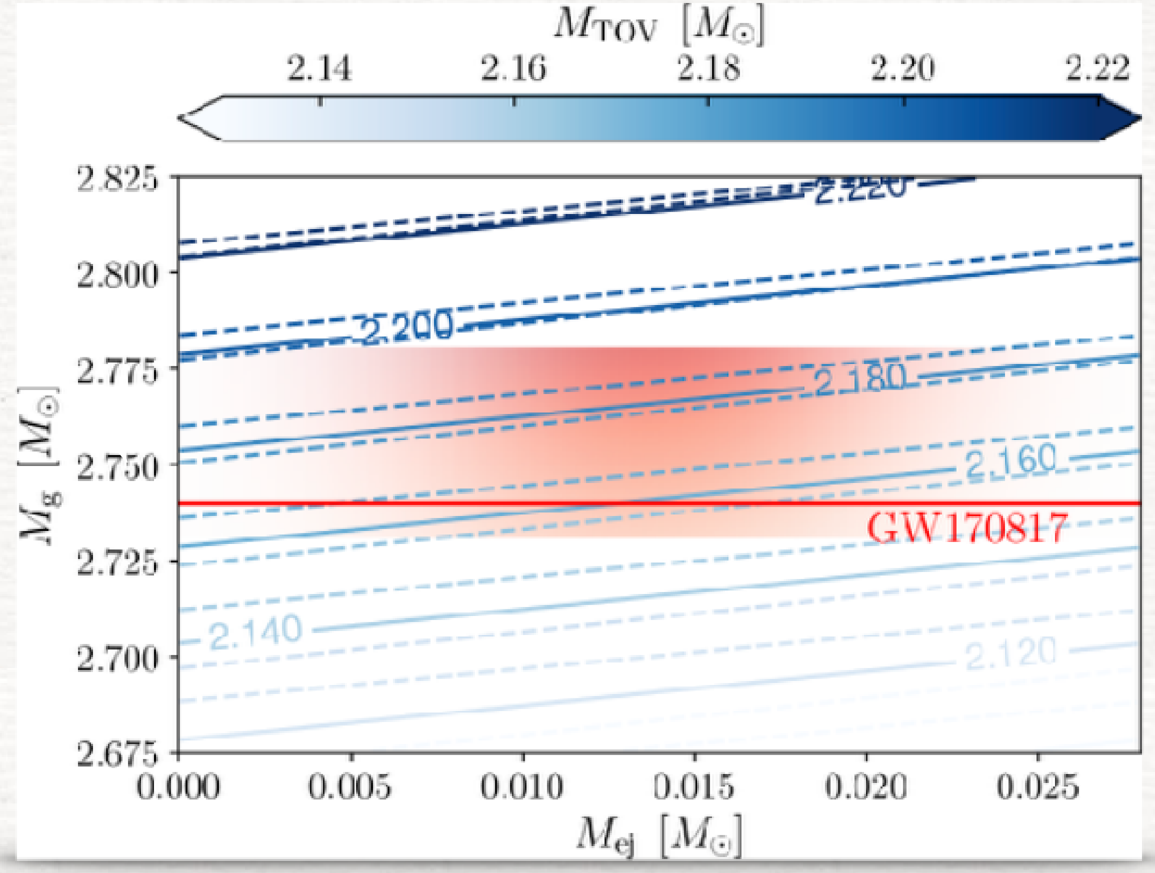
- Use measured **gravitational** mass of GW170817

$$M_1 + M_2 = 2.74^{+0.04}_{-0.01} M_\odot$$

- Use amount of ejected **rest mass** as deduced from kilonova emission

$$M_{\rm ej}^{\rm blue} = 0.014^{+0.010}_{-0.010}\, M_\odot$$

- Use **universal relations** and account errors to obtain



Rezzolla, Most, Weih 2018

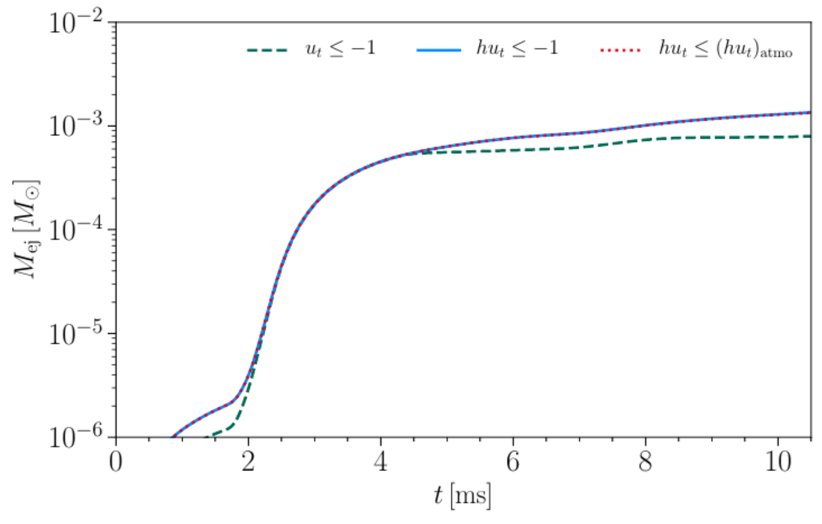
pulsar timing

$$2.01^{+0.04}_{-0.04} \leq M_{\rm TOV}/M_\odot \lesssim 2.16^{+0.17}_{-0.15}$$

universal relations and GW170817

Dynamically Ejected matter

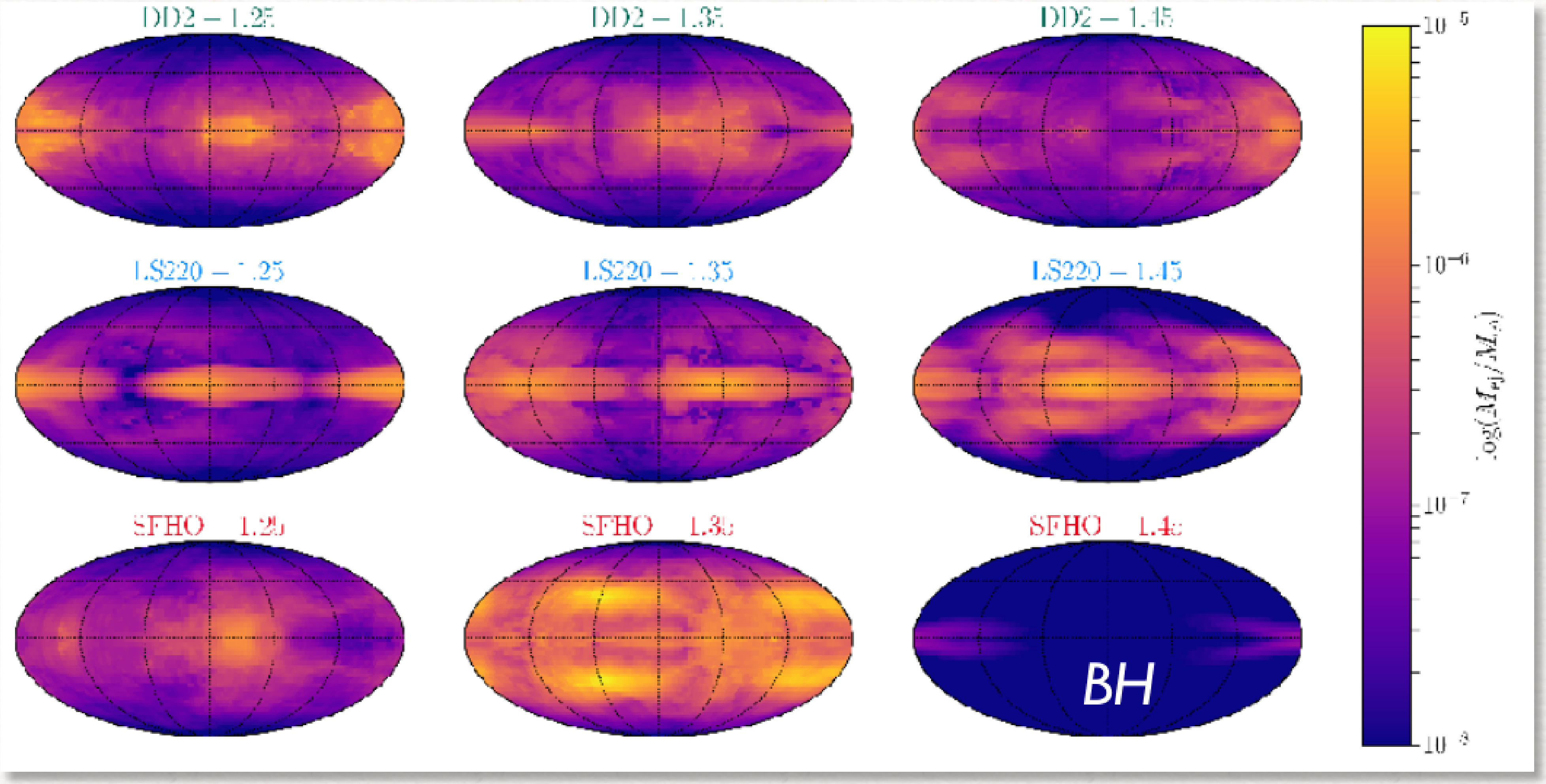
- Compute dynamically ejected (unbound) matter: u_t < -1



- Use selected tracer particles (passively advected with the flow) see [Bovard, Rezzolla 2017, arXiv:1705.07882]
- Couple to nuclear reaction network (WinNet [Winteler+ 2012,Korobkin+ 2012] /SkyNet [Lippuner+ 2017]) → Compute nucleosynthetic yields

Spatial distributions: M_{ej}

Bovard+ 17

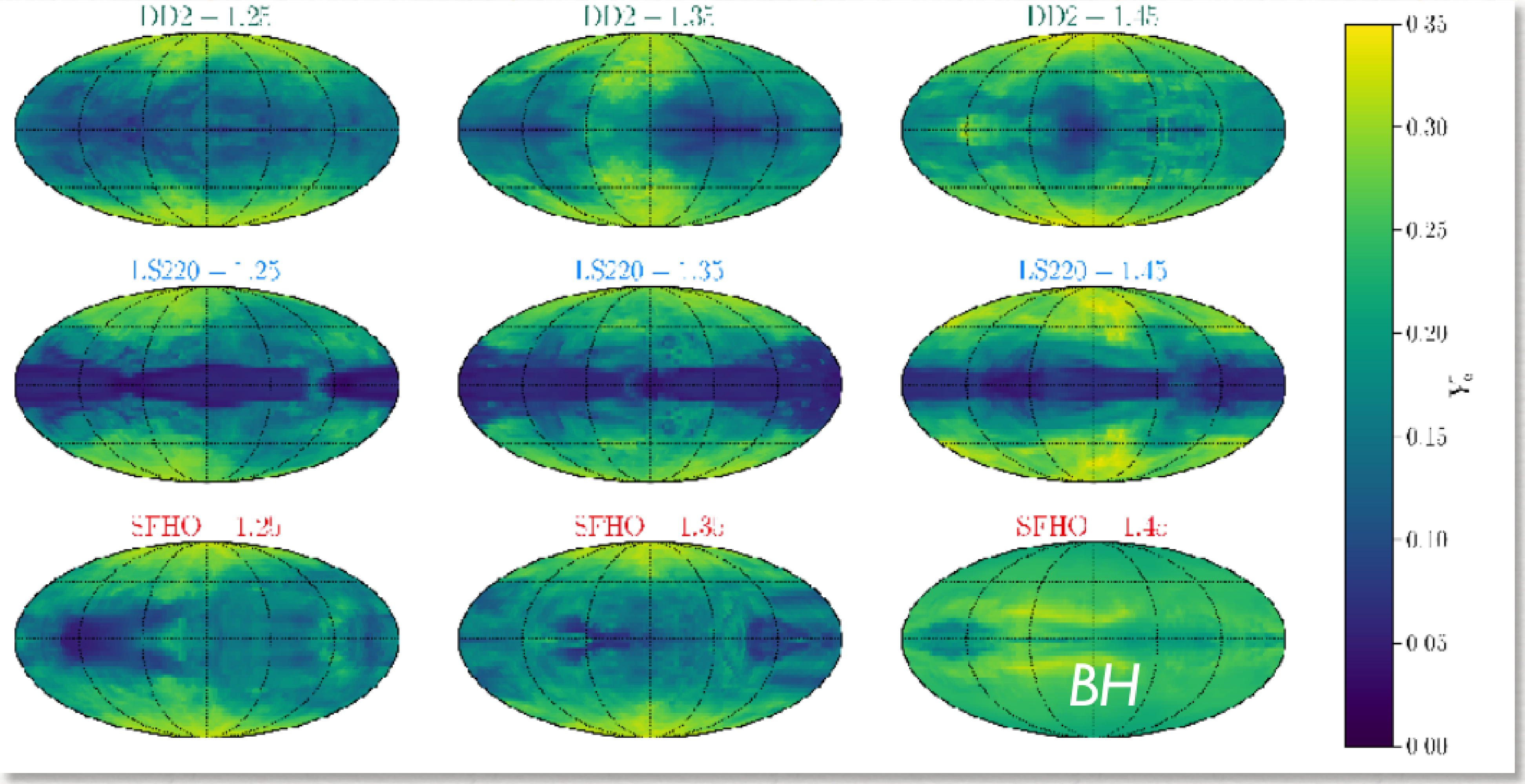


Spatial distribution of M_{ej} impacts detectability of EM counterpart:

- most of M_{ej} lost at low latitudes;
- depending on EOS/mass, contamination also in polar regions

Spatial distributions: Y_e

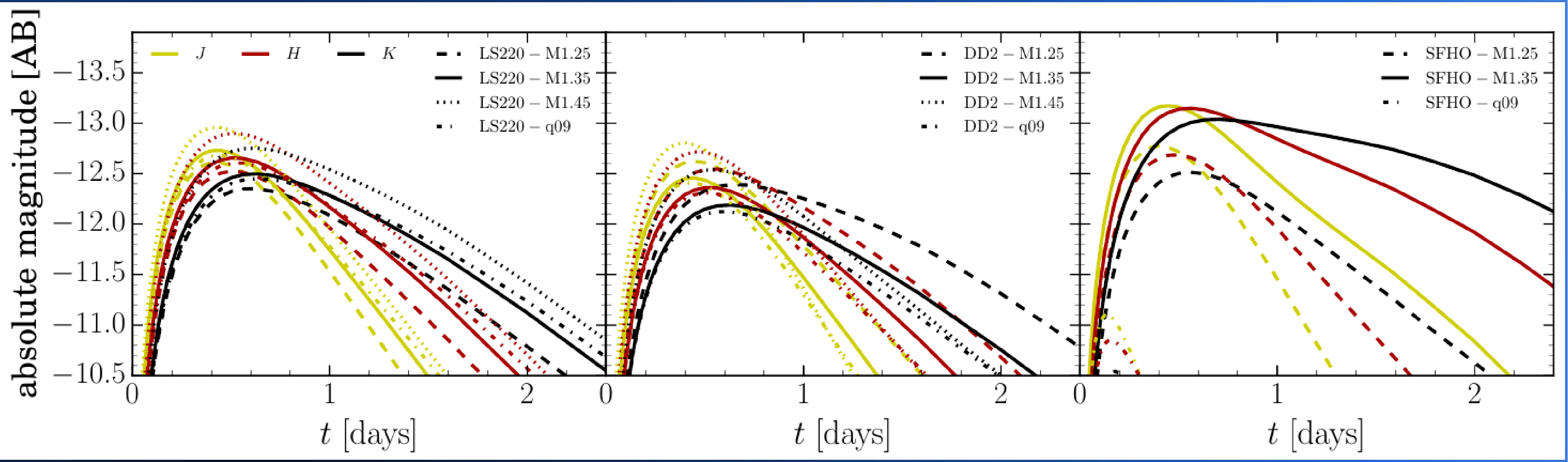
Bovard+ 17



Spatial distribution of Y_e impacts detectability of EM counterpart:

- **high Y_e** in **polar** regions: **blue** (optical) macronova
- **low Y_e** in **equatorial** regions: **red** (FIR) macronova

Kilonova light curves



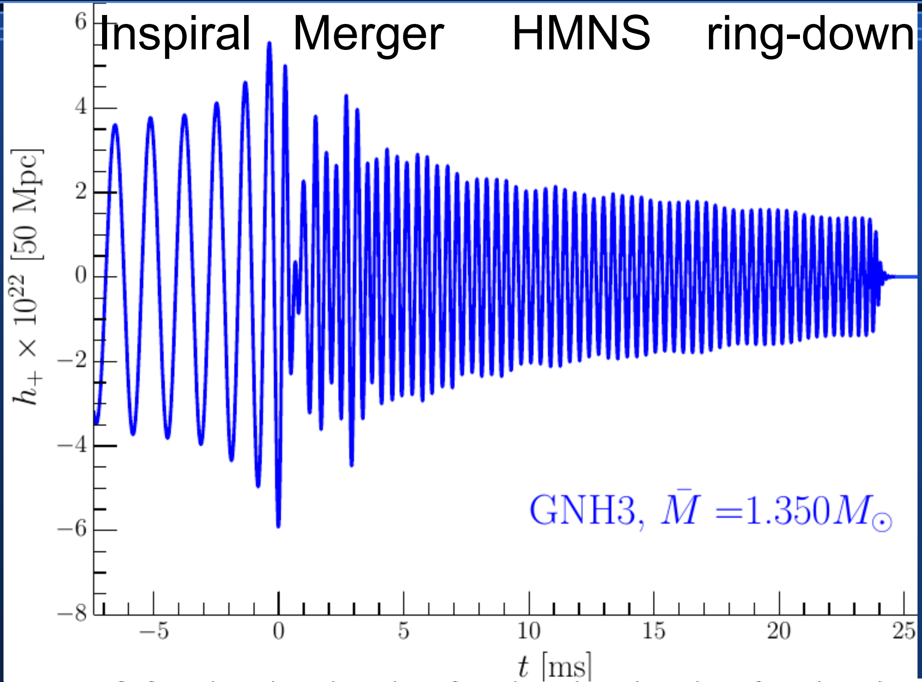
Bovard+ 2017

Eccentric binaries

Formation channels

- Circularization of eccentric binaries due to GW emission only for isolated binaries!
- Dense environments like globular clusters or star clusters in galactic cores: N-body effects
- Hill mechanism, Kozai mechanism, etc
- Dynamical captures
- Rate estimates even more uncertain than for quasi-circular population, but expect a few for 3rd generation detectors
- Rare sources: Expect detections from large distances

Binary neutron stars: GW Anatomy

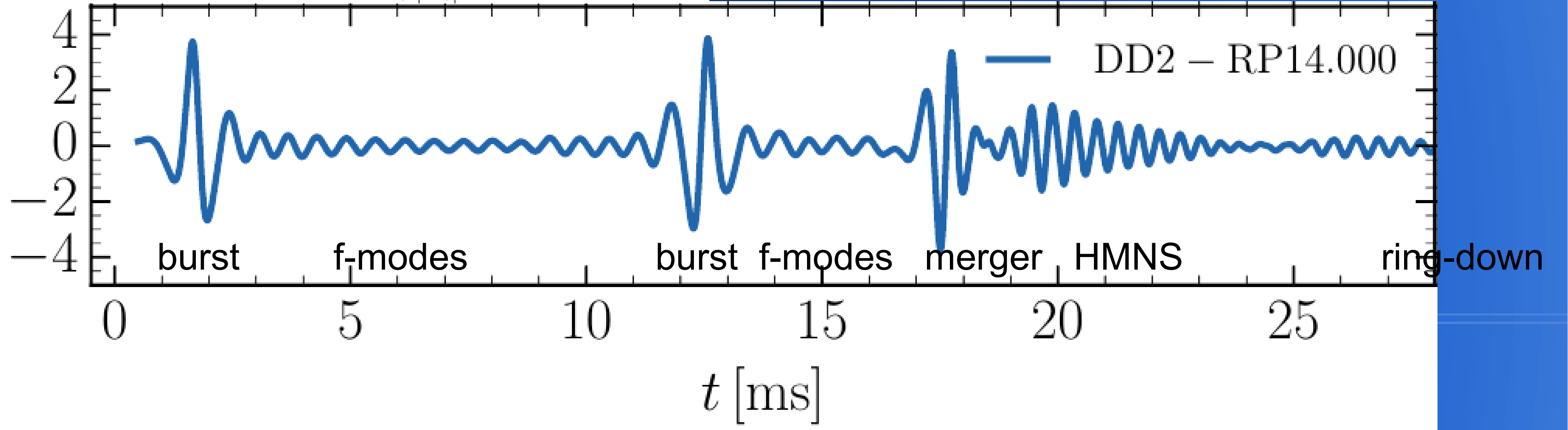


- **Quasi-circular** BNS GWs:

  Inspiral+Merger+HMNS+ring-down

- **Eccentric** BNS GWs:

  Pericenter burst + f-modes [repeatedly] + merger + HMNS + ring-down (not shown here)



Expected Detector Improvements

- Higher Laser Power
- Squeezed light
- Cryogenic
- Larger Detectors
- Better isolation (underground, new sights)

→ Sensitivity improvements at higher frequencies!

Realistic, targeted detector performances

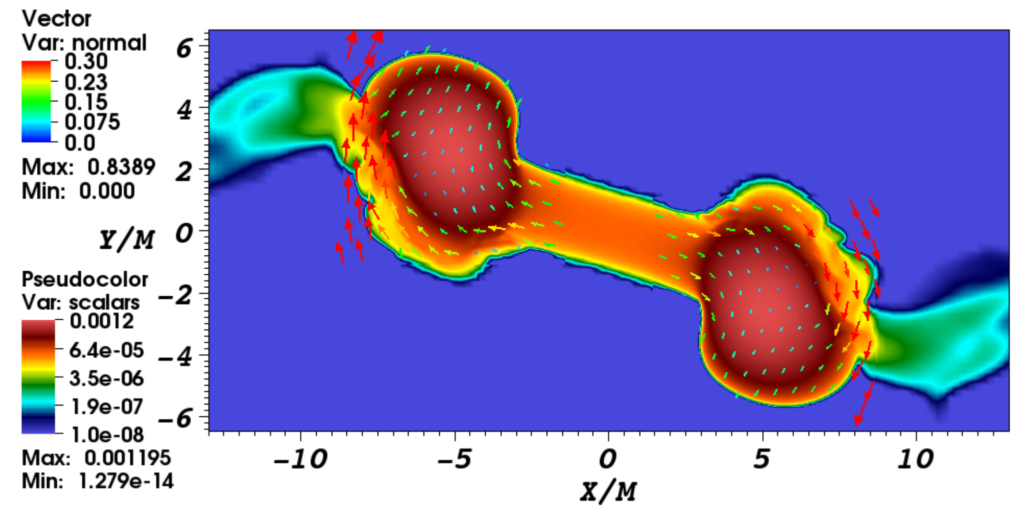
Einstein Telescope

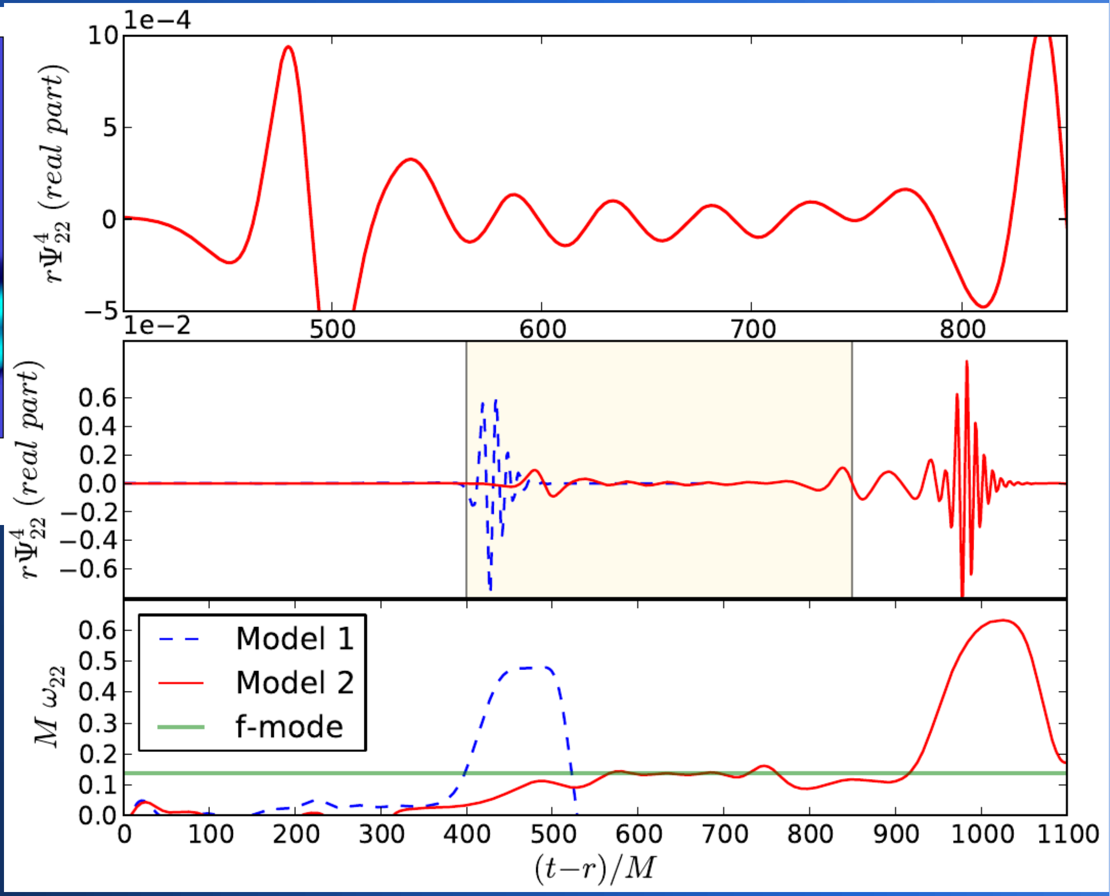
- L~10km (triangle)
- NSNS mergers out to z~3
- more star formation
- redshifted f-mode frequency ~400Hz (!)

Cosmic Explorer

- L ~ 40km
- NSNS mergers out to z~6
- redshifted f-mode frequency ~200Hz (!)

f-mode oscillations due to tidal deformation



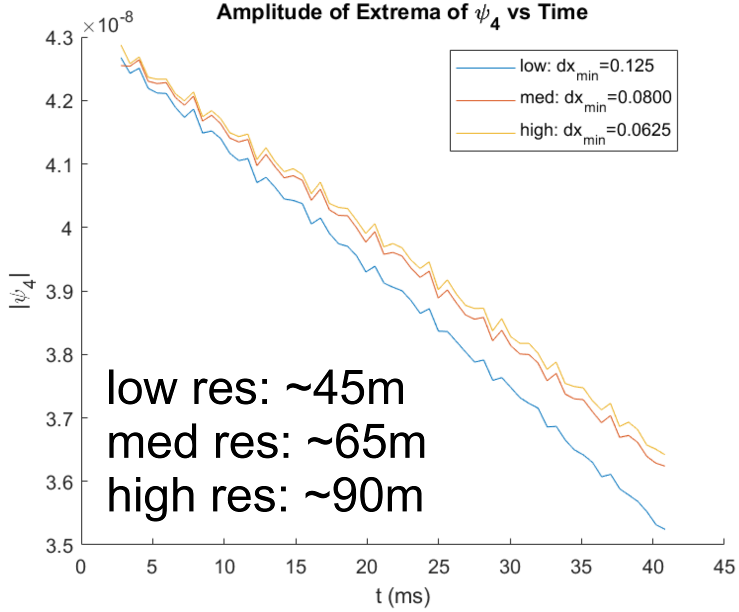


f-mode frequency & damping
depend on neutron star structure
Typical rest-frame frequencies: f~1.6kHz

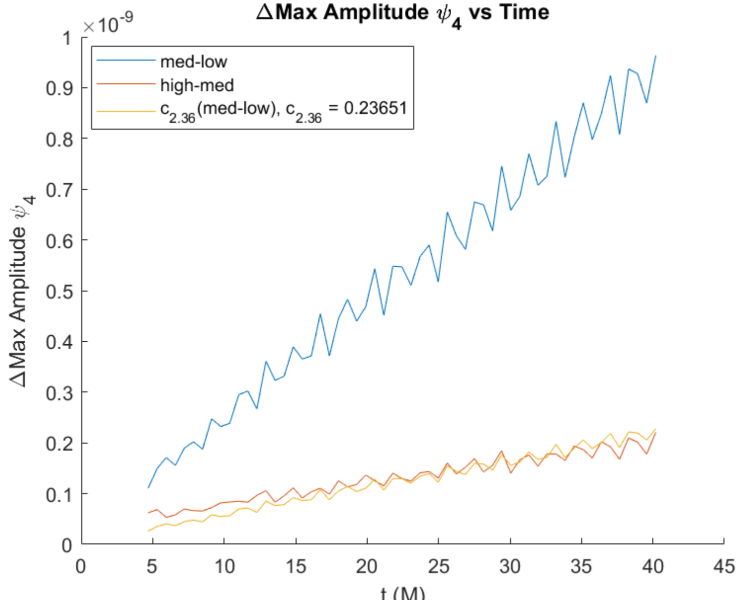
Gold+ 2012

f-mode damping in simulations

- GW emission due to f-mode oscillations drain energy
- Leads to f-modes damping, depend on NS structure
- Numerical relativity simulations include this physics, but numerical dissipation has similar effect

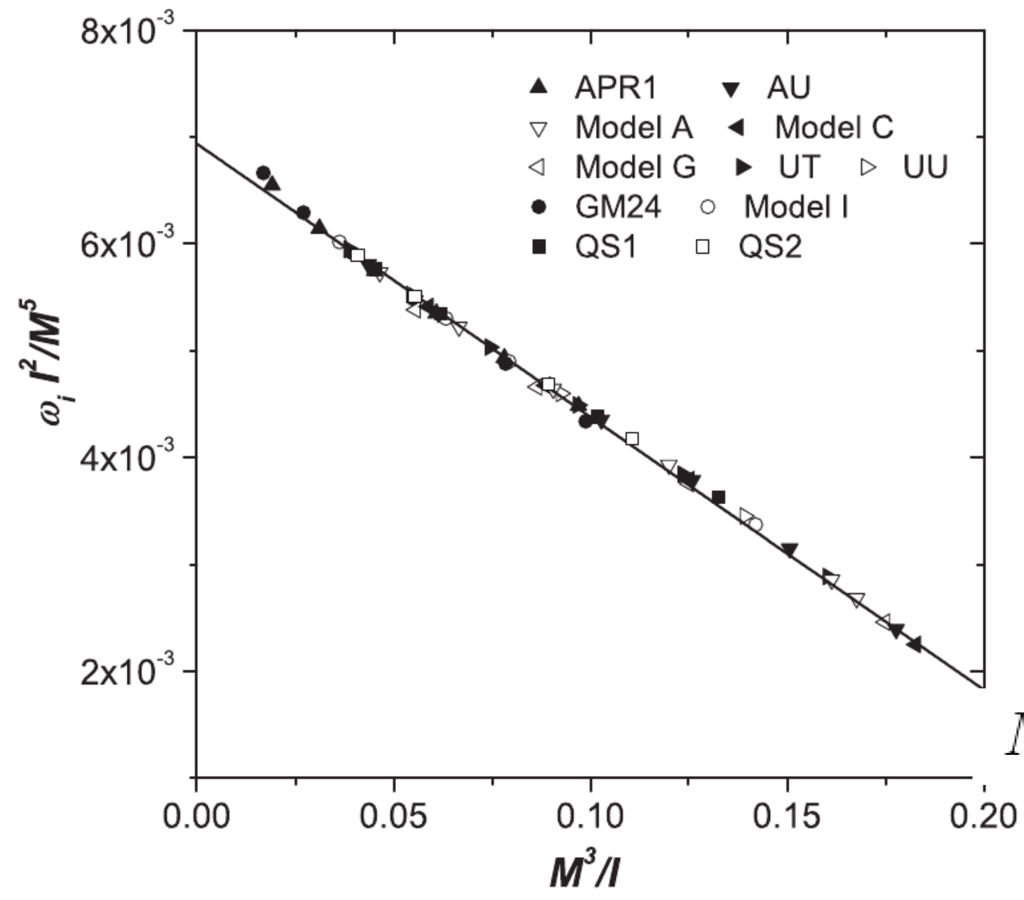


low res: ~45m
med res: ~65m
high res: ~90m



Rosofski, Gold, Chirenti, Miller [in prep.]

f-mode damping due to GW losses



- Quasi-universal relations for f-mode damping

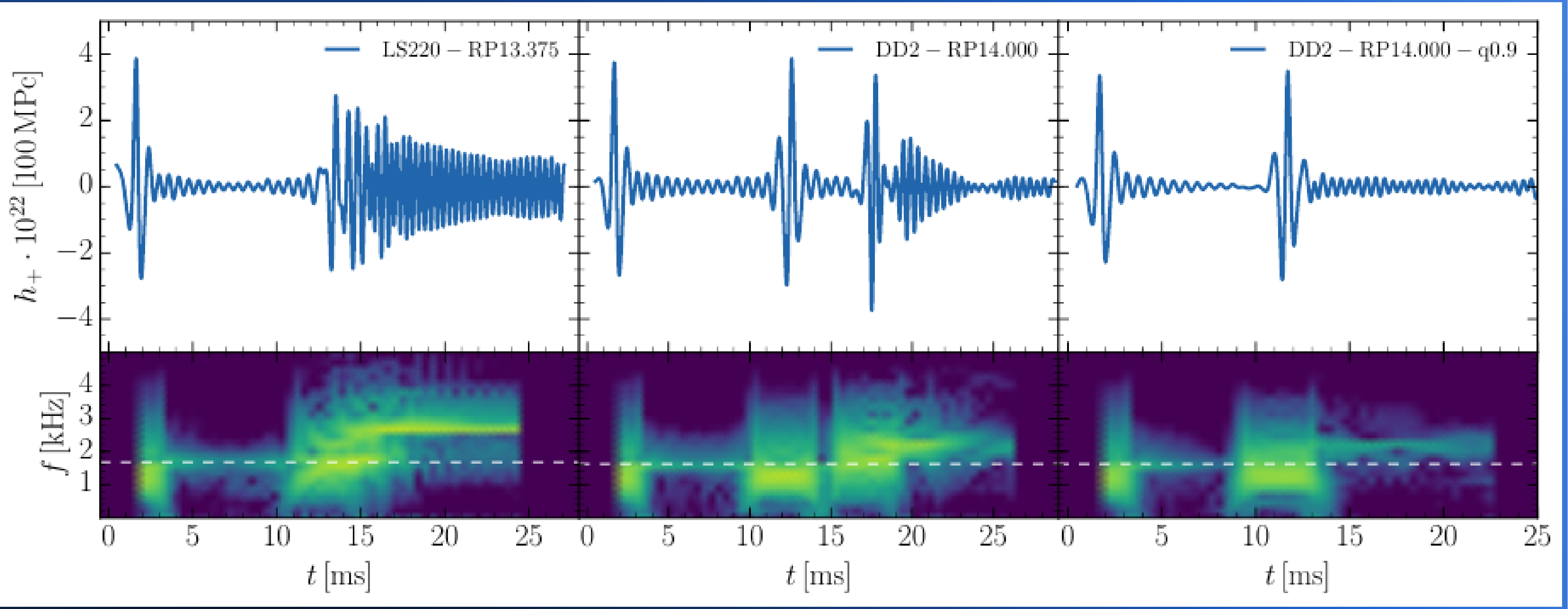
$$\eta \equiv \sqrt{M^3/I}$$

$$M\omega_{\rm r} = -0.0047 + 0.133\eta + 0.0575\eta^2$$

$$I^2\omega_{\rm i}/M^5 = -0.00694 + 0.0256\eta^2$$

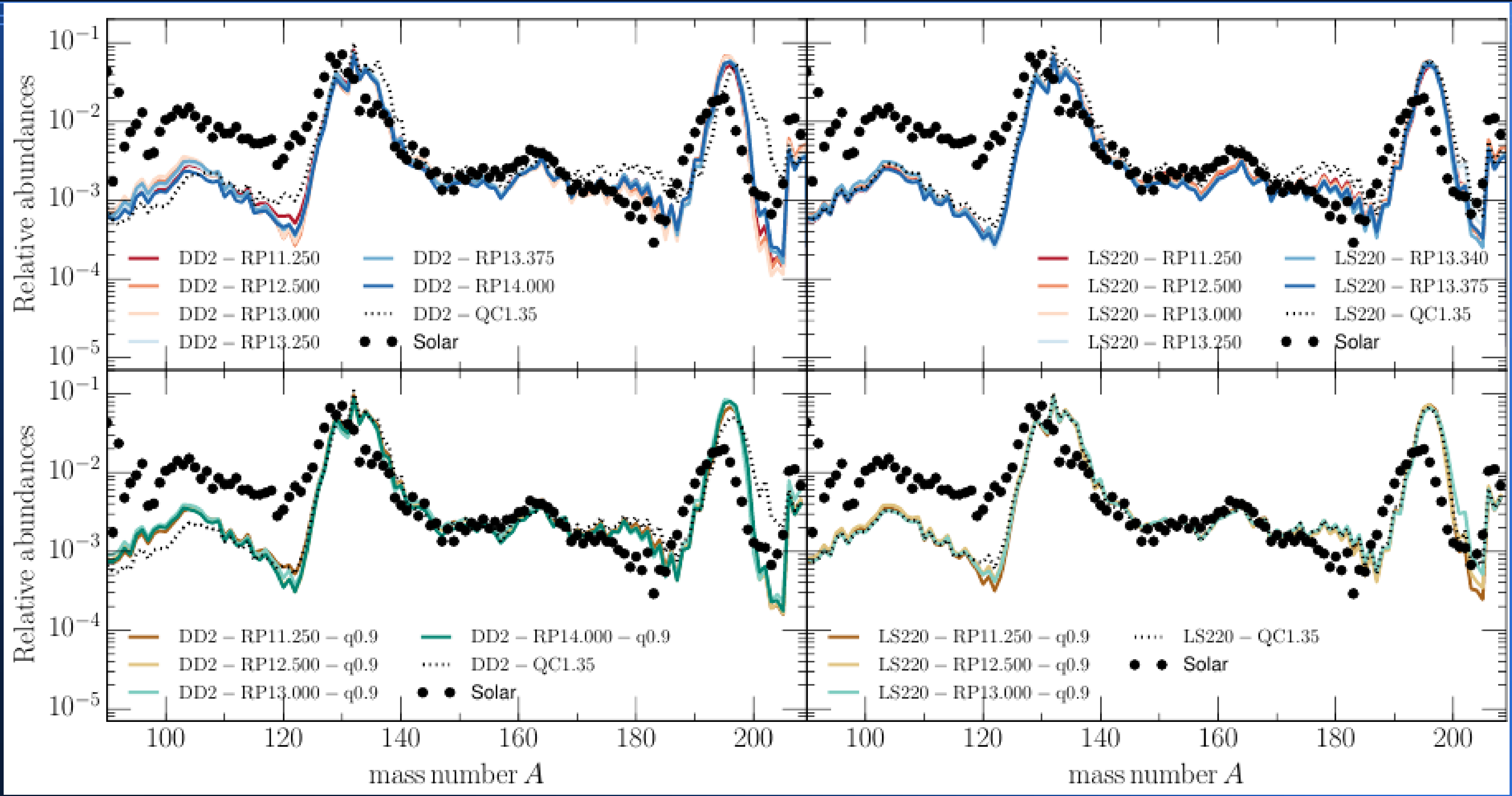
Lau+ 2010, Chirenti+ 2015

Newest models of dynamical capture scenario: GWs + spectrograms



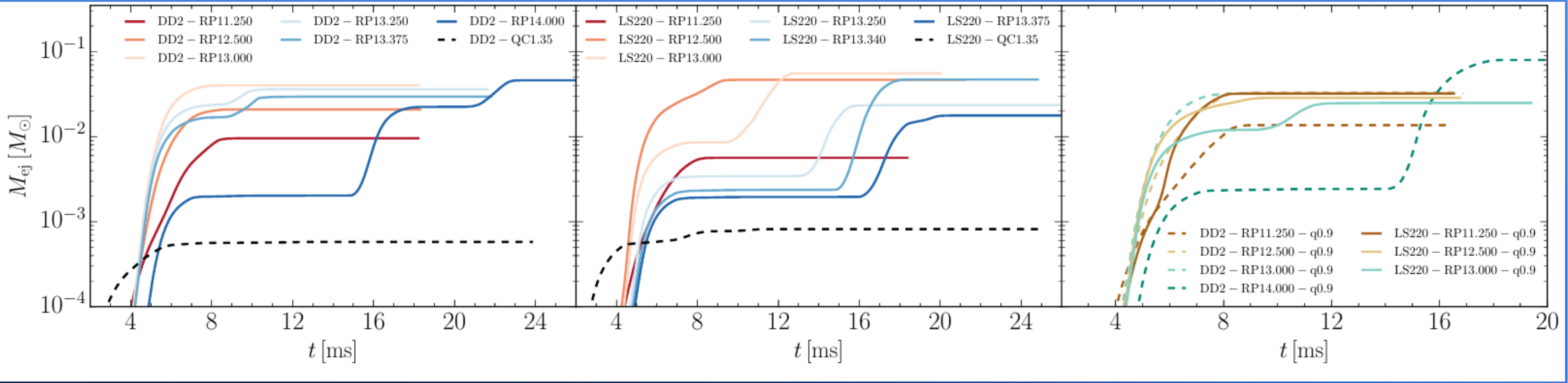
Papenfort, Gold, Rezzolla [in prep.]

Nucleosynthetic yields of eccentric binary neutron star mergers



Papenfort, Gold, Rezzolla [in prep.]

Ejected mass in eccentric case



- Much more dynamically ejected mass
- Ejected mass during one pericenter alone dwarfs entire quasi-circular inspiral+merger

Conclusions

- Quasi-circular binary neutron stars: Much more to learn, especially as detectors push for merger & post-merger signals
- Eccentric binary neutron stars: ***much richer info*** in GW than for quasi-circular systems , great for parameter estimation
- NS oscillations due to tidal interactions in eccentric binaries act as sources of GWs and constrain neutron star structure
- Numerous but common sources (quasi-circular binaries) to pushing science from special/but rare events that harbor more information: Strike the right balance!