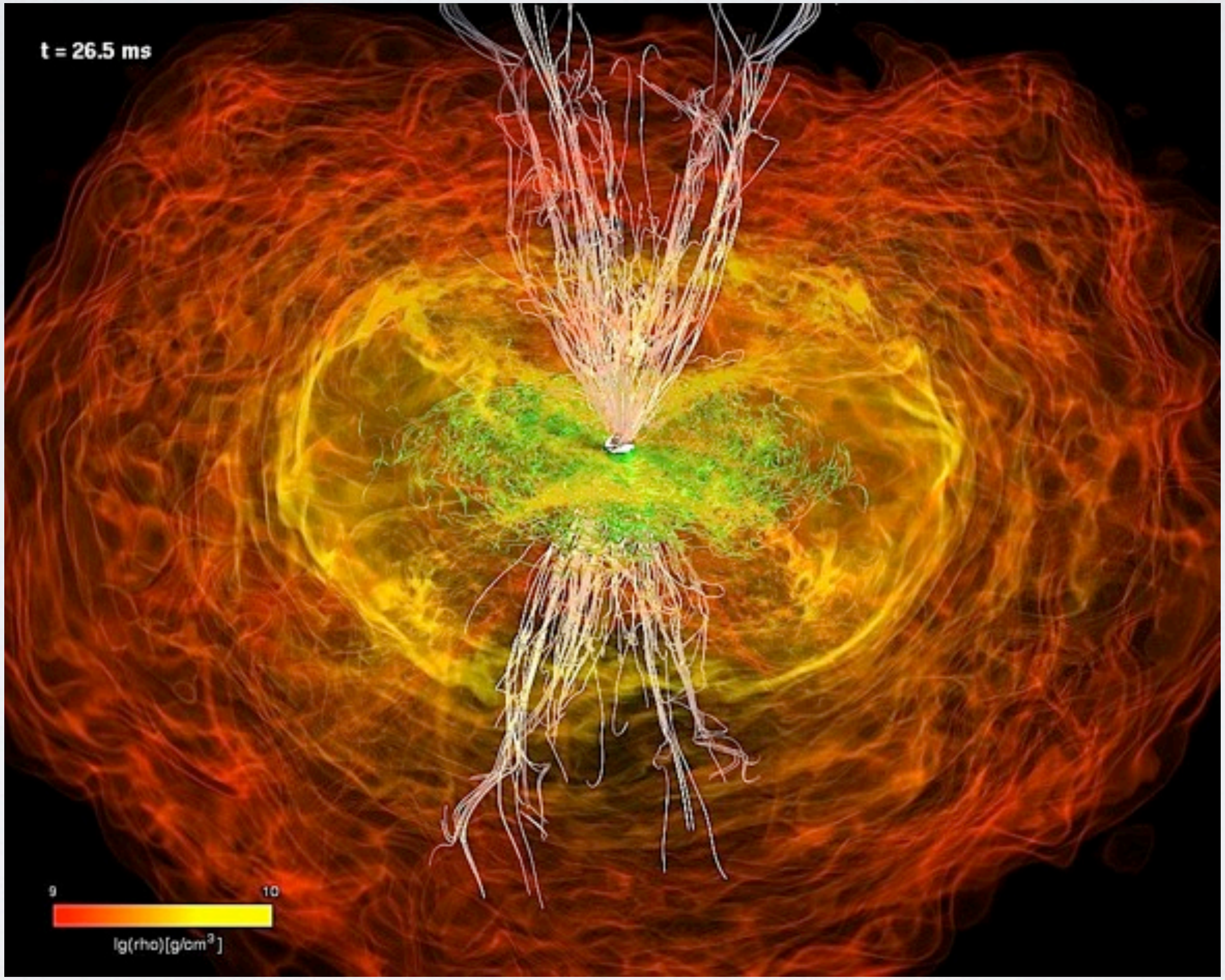
STATUS OF NUMERICAL SIMULATIONS OF NS-NS AND NS-BH MERGERS



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JILA, University of Colorado, USA

PLAN OF THE TALK

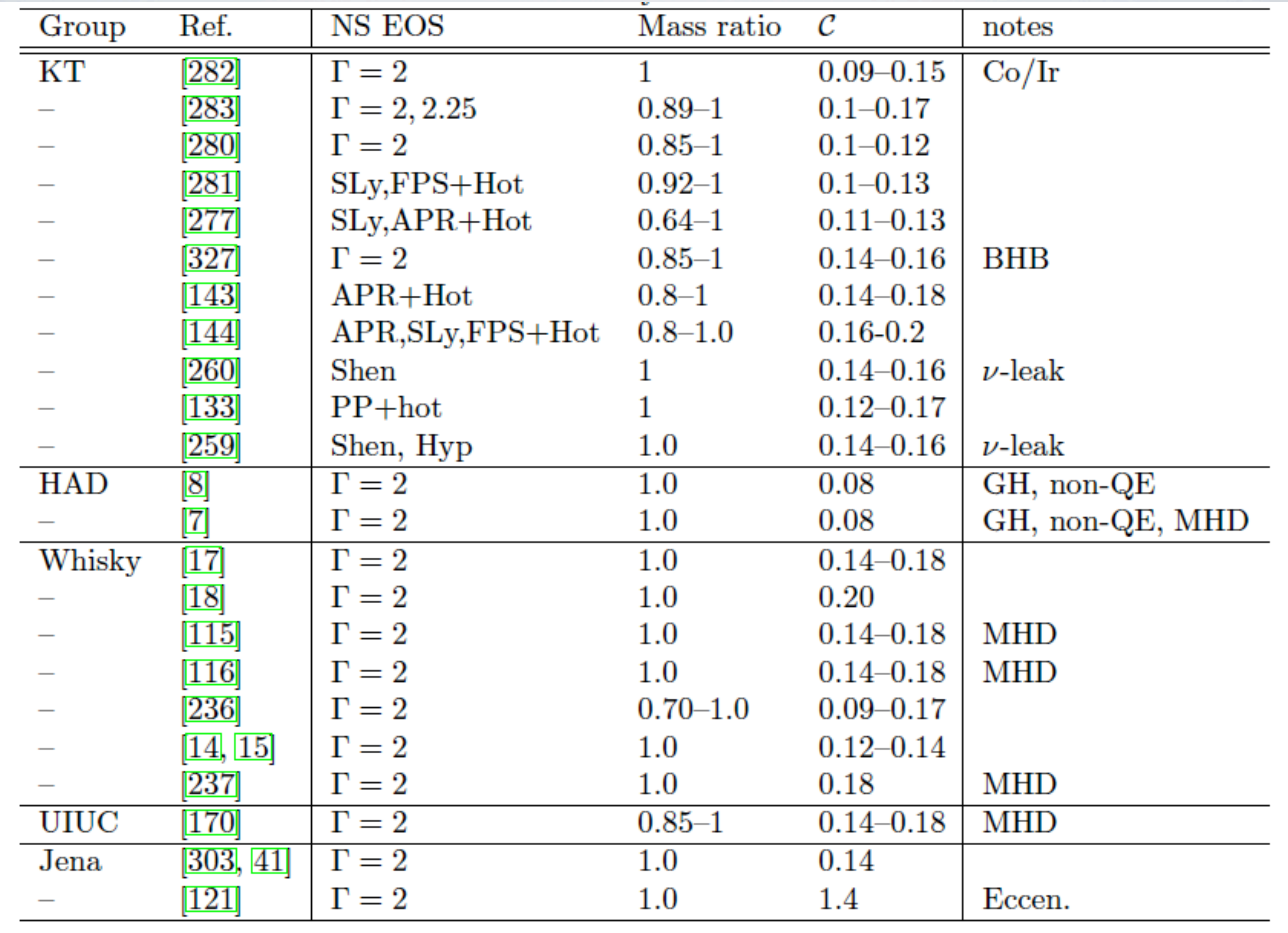
- NS-NS binaries
  - GWs from the inspiral and EOS effects
  - GWs after the merger (EOS, magnetic fields, neutrinos)

- NS-BH binaries
  - GWs

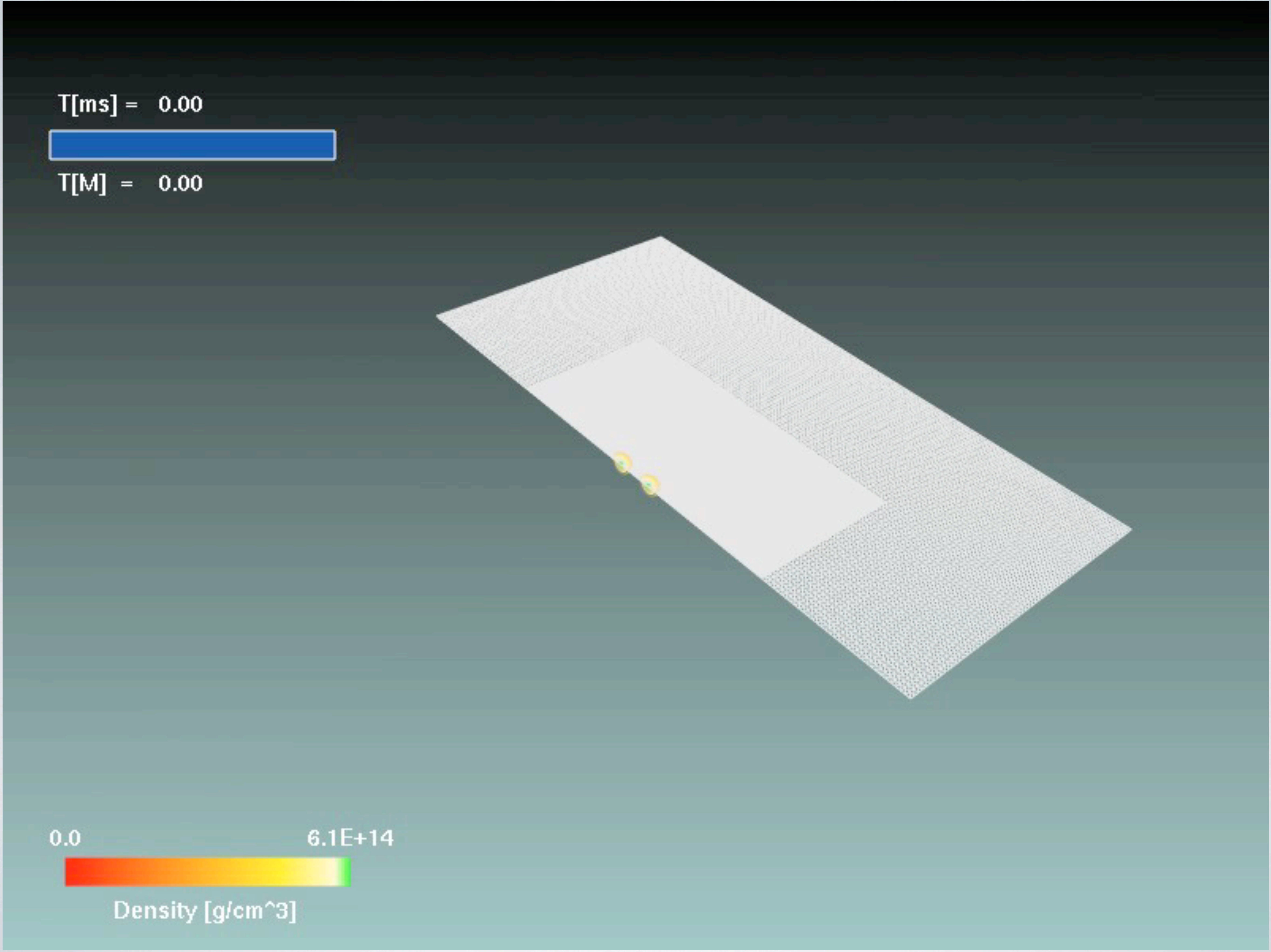
- Connection with GRB and EM counterparts?

GR BNS SIMULATIONS: STATE OF THE ART

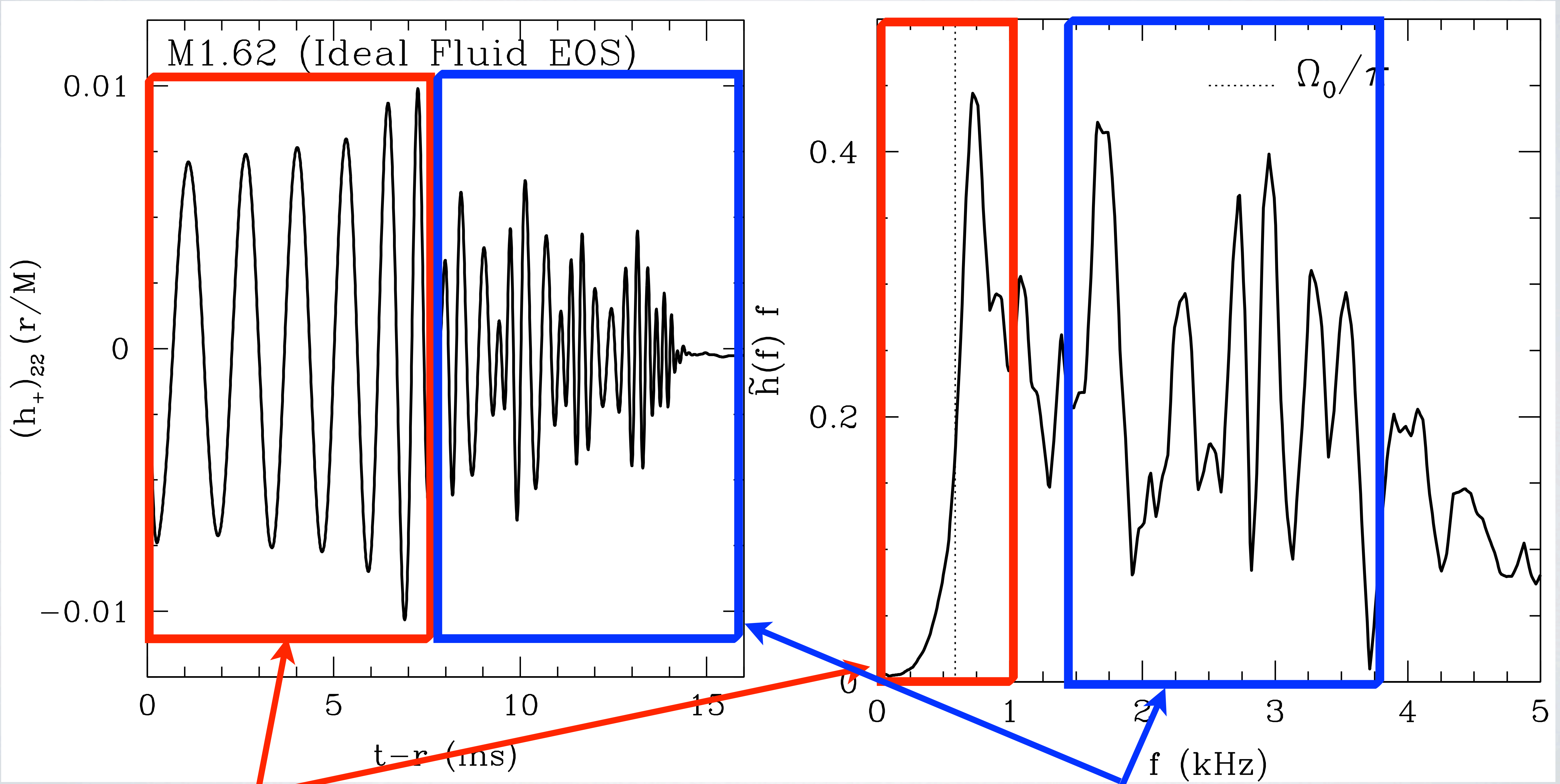
(table taken from Faber & Rasio 2012, arXiv:1204.3858)



Group	Ref.	NS EOS	Mass ratio	$\mathcal{C}$	notes
KT	[282]	$\Gamma = 2$	1	0.09–0.15	Co/Ir
–	[283]	$\Gamma = 2, 2.25$	0.89–1	0.1–0.17	
–	[280]	$\Gamma = 2$	0.85–1	0.1–0.12	
–	[281]	SLy,FPS+Hot	0.92–1	0.1–0.13	
–	[277]	SLy,APR+Hot	0.64–1	0.11–0.13	
–	[327]	$\Gamma = 2$	0.85–1	0.14–0.16	BHB
–	[143]	APR+Hot	0.8–1	0.14–0.18	
–	[144]	APR,SLy,FPS+Hot	0.8–1.0	0.16-0.2	
–	[260]	Shen	1	0.14–0.16	ν-leak
–	[133]	PP+hot	1	0.12–0.17	
–	[259]	Shen, Hyp	1.0	0.14–0.16	ν-leak
HAD	[8]	$\Gamma = 2$	1.0	0.08	GH, non-QE
–	[7]	$\Gamma = 2$	1.0	0.08	GH, non-QE, MHD
Whisky	[17]	$\Gamma = 2$	1.0	0.14–0.18	
–	[18]	$\Gamma = 2$	1.0	0.20	
–	[115]	$\Gamma = 2$	1.0	0.14–0.18	MHD
–	[116]	$\Gamma = 2$	1.0	0.14–0.18	MHD
–	[236]	$\Gamma = 2$	0.70–1.0	0.09–0.17	
–	[14, 15]	$\Gamma = 2$	1.0	0.12–0.14	
–	[237]	$\Gamma = 2$	1.0	0.18	MHD
UIUC	[170]	$\Gamma = 2$	0.85–1	0.14–0.18	MHD
Jena	[303, 41]	$\Gamma = 2$	1.0	0.14	
–	[121]	$\Gamma = 2$	1.0	1.4	Eccen.


T[ms] = 0.00
T[M] = 0.00
0.0
6.1E+14
Density [g/cm^3]

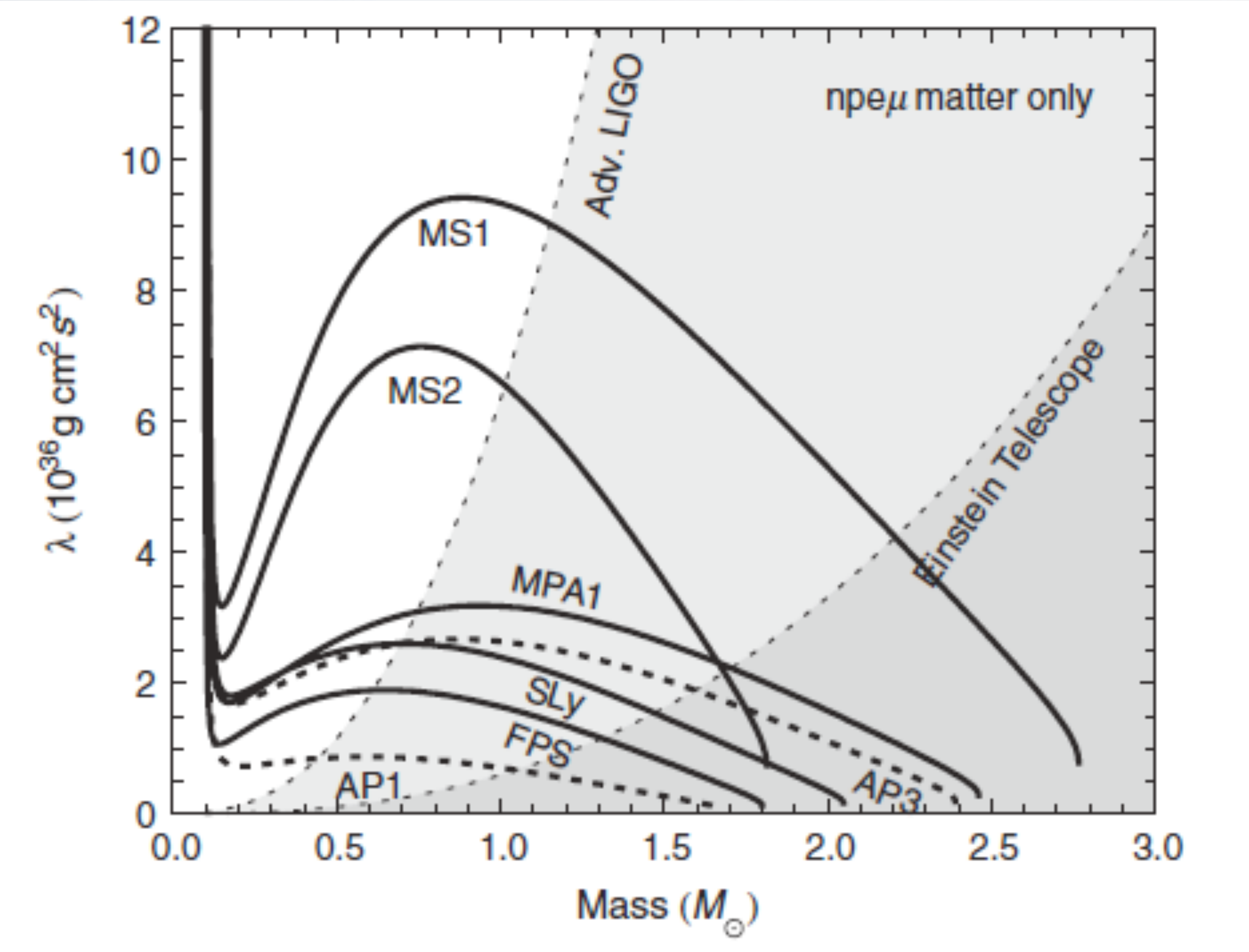
GRAVITATIONAL WAVES FROM BINARY NEUTRON STARS



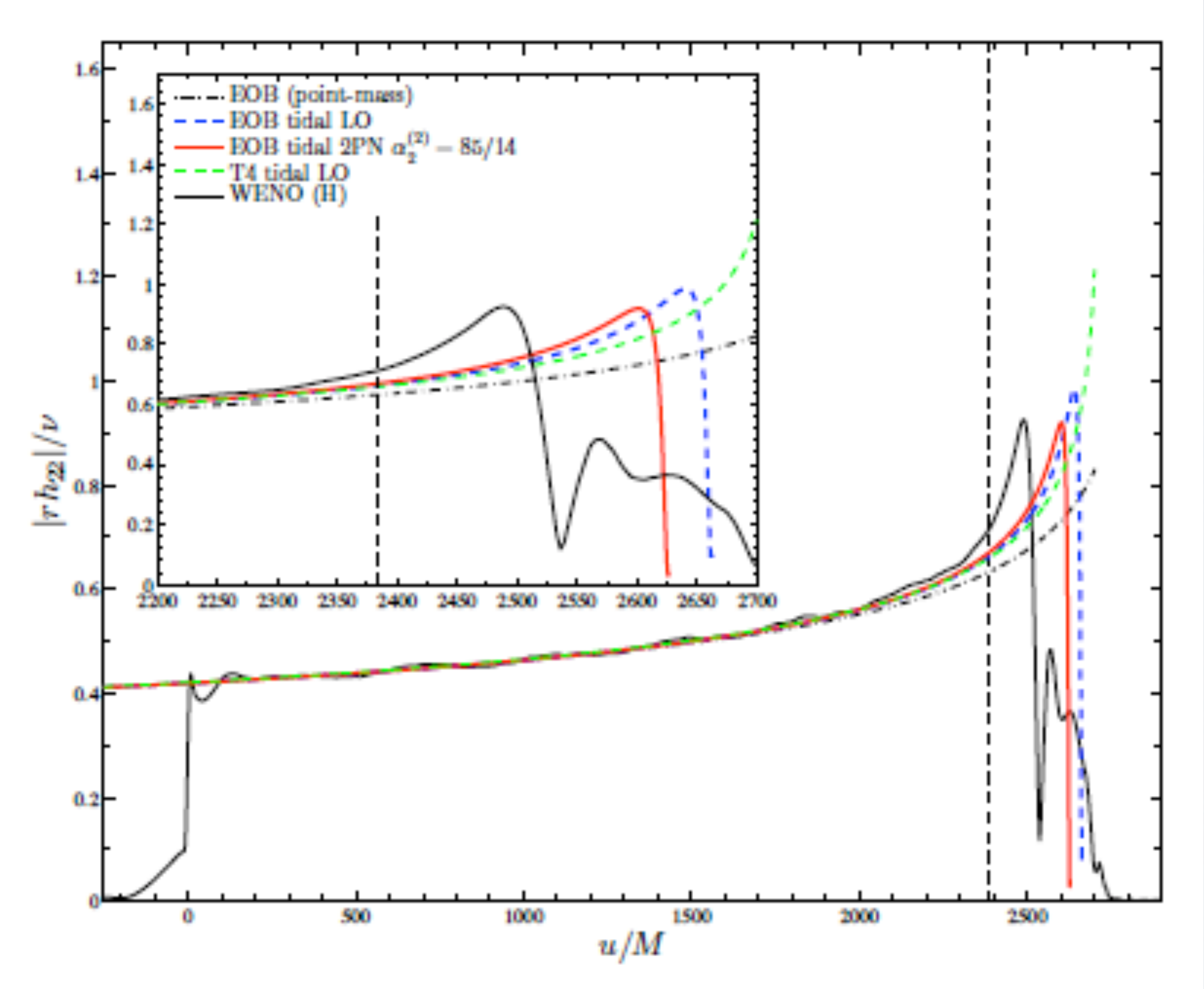
contribution from the inspiral

contribution from the HMNS

INSPIRAL GWS

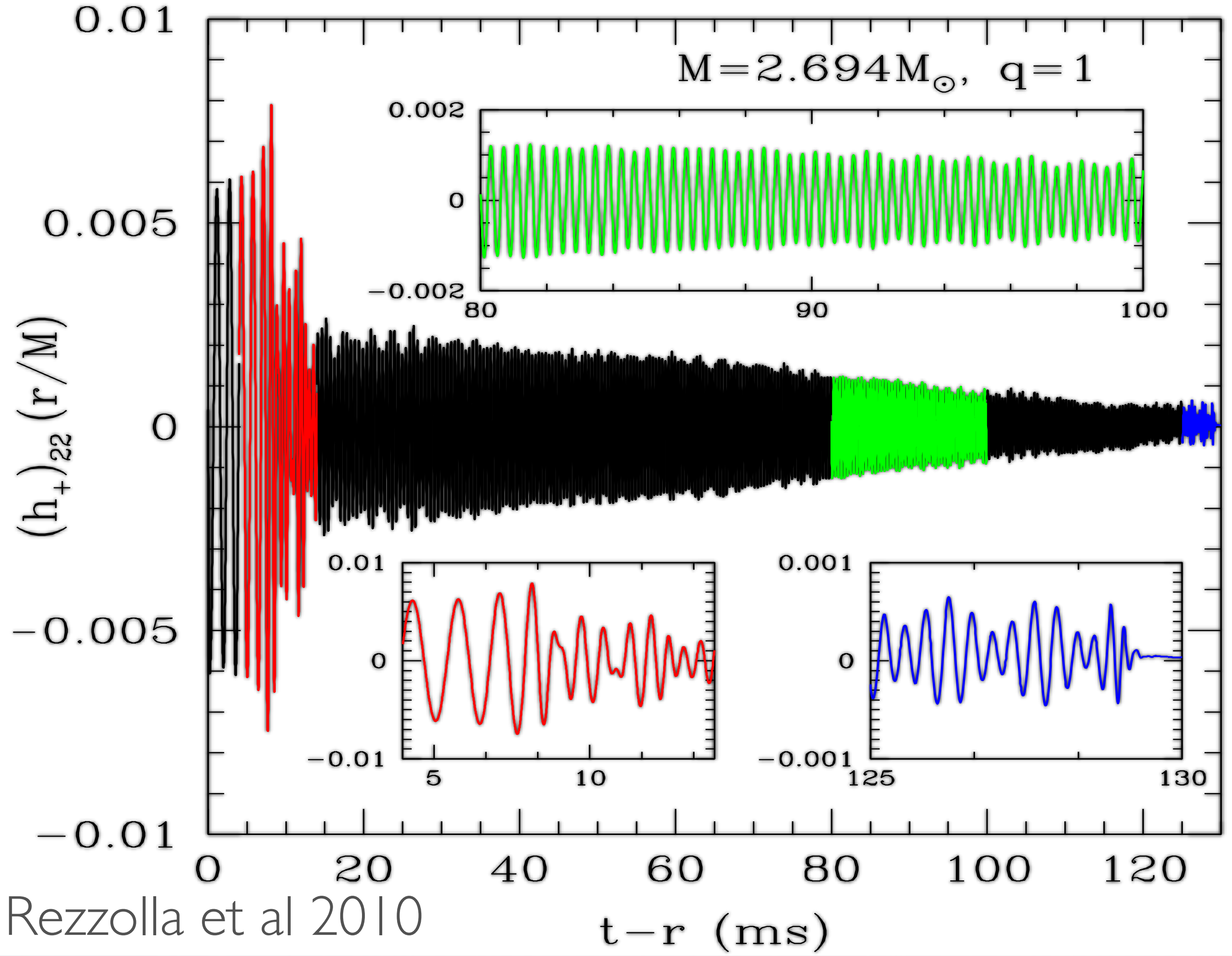


Read et al 2009, Hinderer et al 2010: different EOS effect visible in tidal effects during inspiral. Constraint on NS radius of ~1km (if mass known)

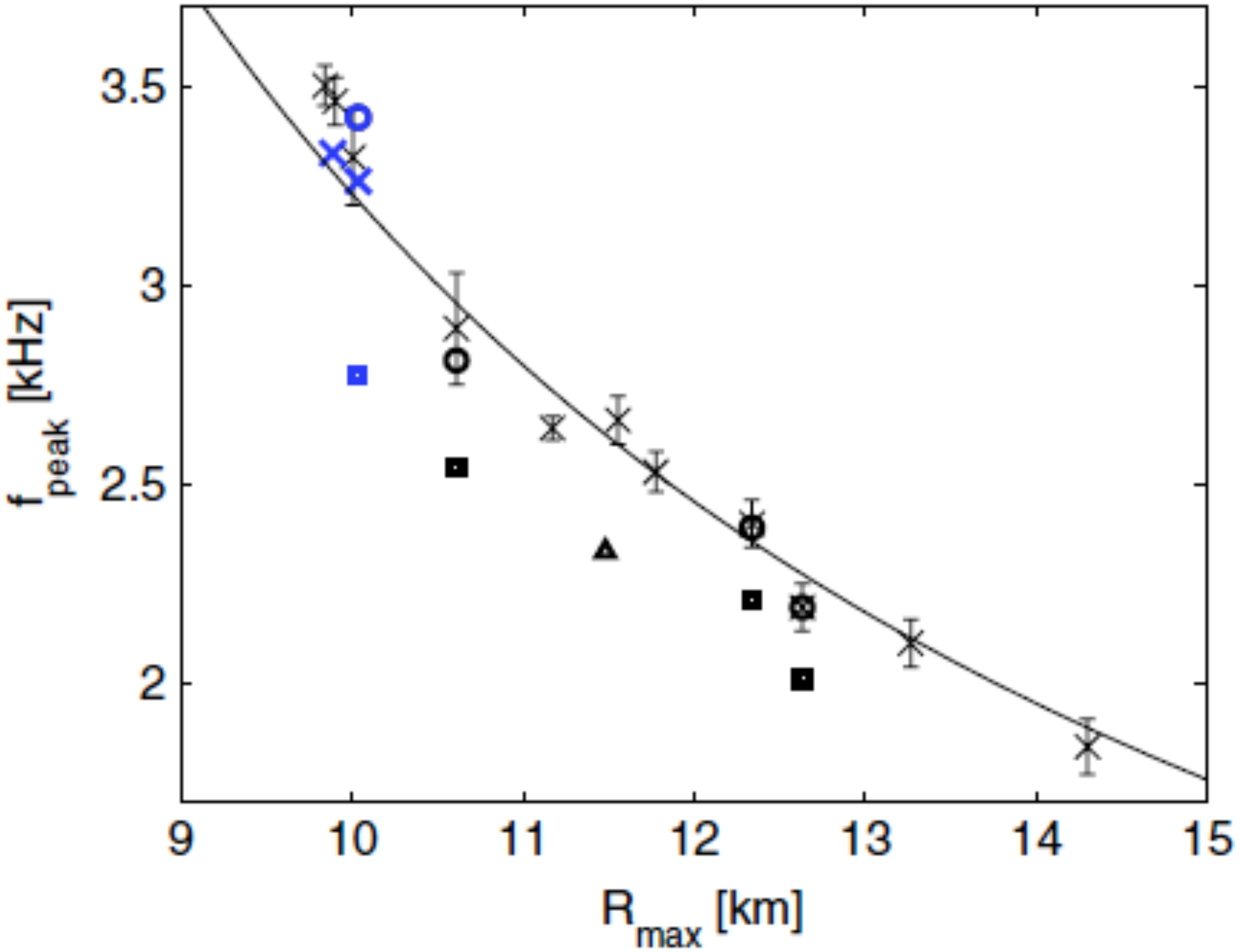


Baiotti et al 2010, Bernuzzi et al 2012: used the EOB approach to describe GW until merger.

POSTMERGER: EFFECTS OF MASS AND EOS



Rezzolla et al 2010

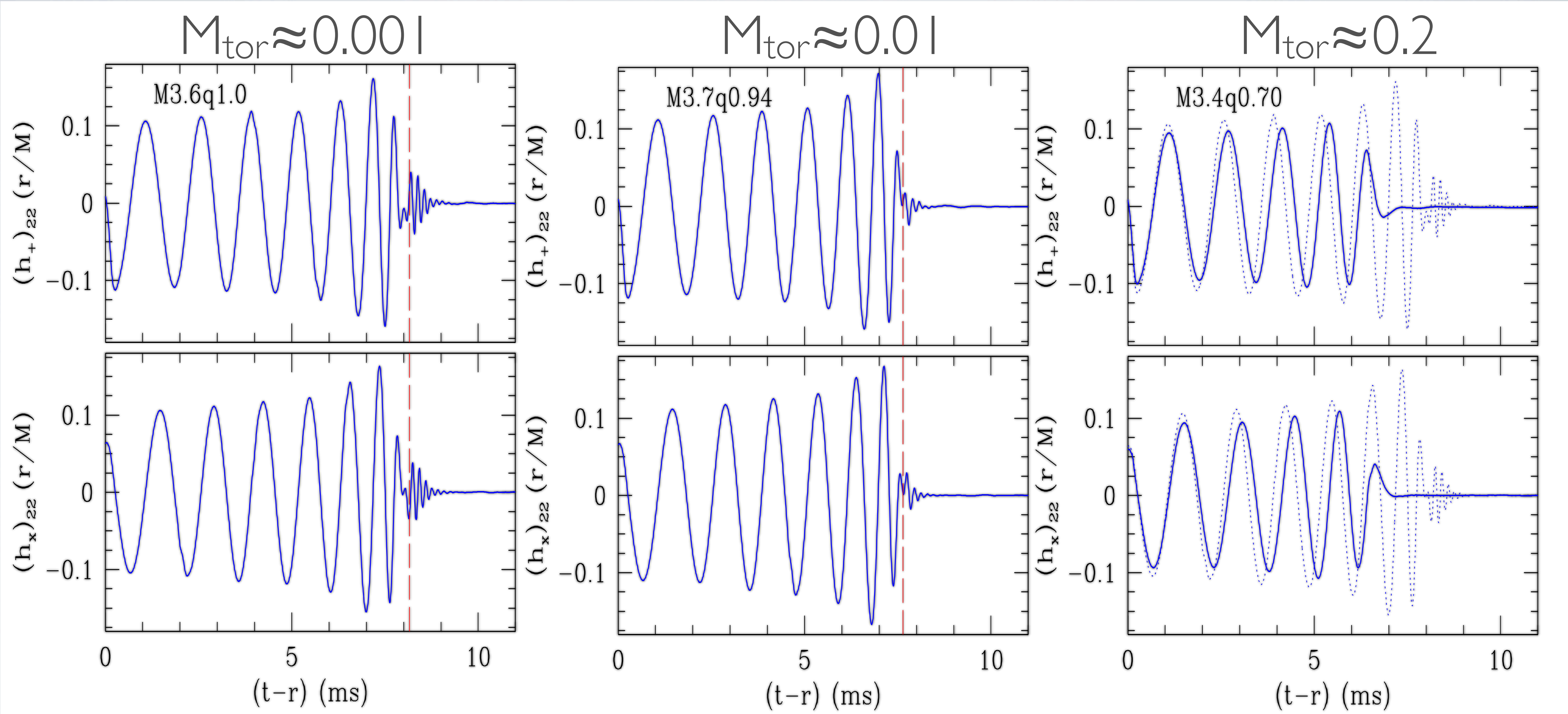


Rezzolla et al 2010: for smaller NS masses, HMNS can survive for more than 100ms.

Bauswein & Janka 2012: frequency peak in GWs emitted after merger can constrain EOS (note: Newtonian sims...)

High sensitivities at f>~1Khz required for HMNS!

POSTMERGER: EFFECTS OF MASS RATIO



Rezzolla et al 2010

Unequal-mass BNSs can produce massive tori which can effect the GWs. Larger tori suppress the QNM part of the signal.

This is an example of how GWs contain information about the possible central engine of GRBs.

POSTMERGER: NEUTRINO EFFECTS

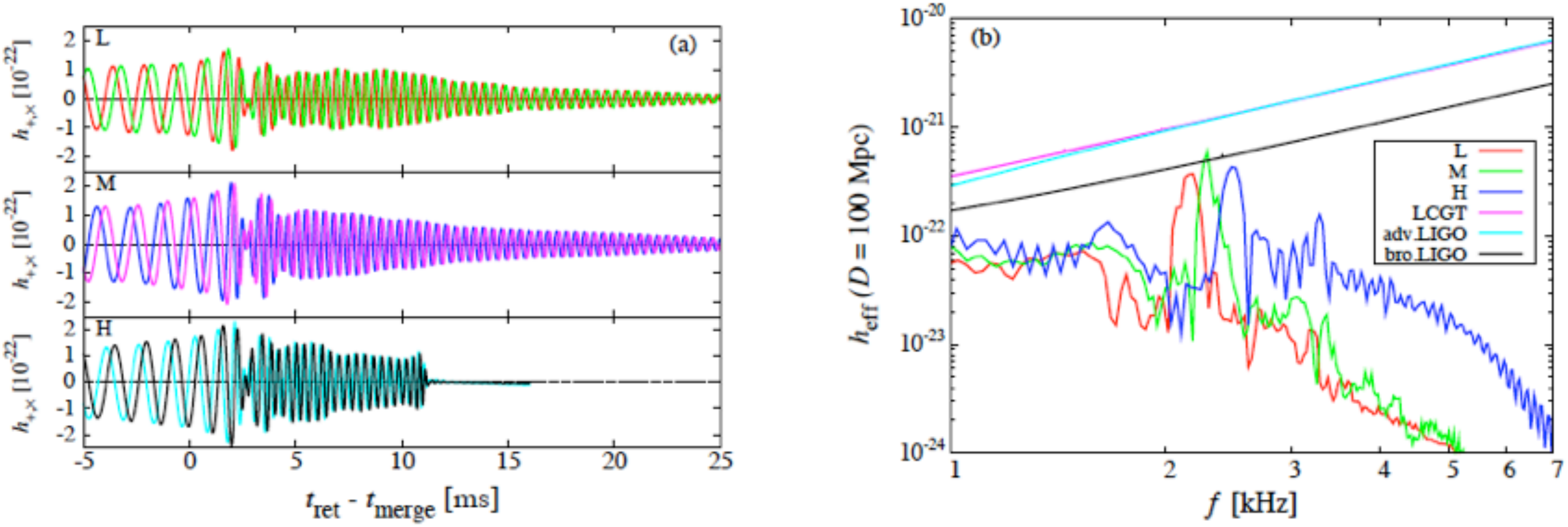


FIG. 4: (a) GWs observed along the axis perpendicular to the orbital plane for the hypothetical distance to the source $D = 100$ Mpc. (b) The effective amplitude of GWs as a function of frequency for $D = 100$ Mpc. The noise amplitudes of Advanced Laser Interferometer Gravitational wave Observatories (adv. LIGO), broadband configuration of Advanced LIGO (bro. LIGO), and Large-scale Cryogenic Gravitational wave Telescope (LCGT) are shown together.

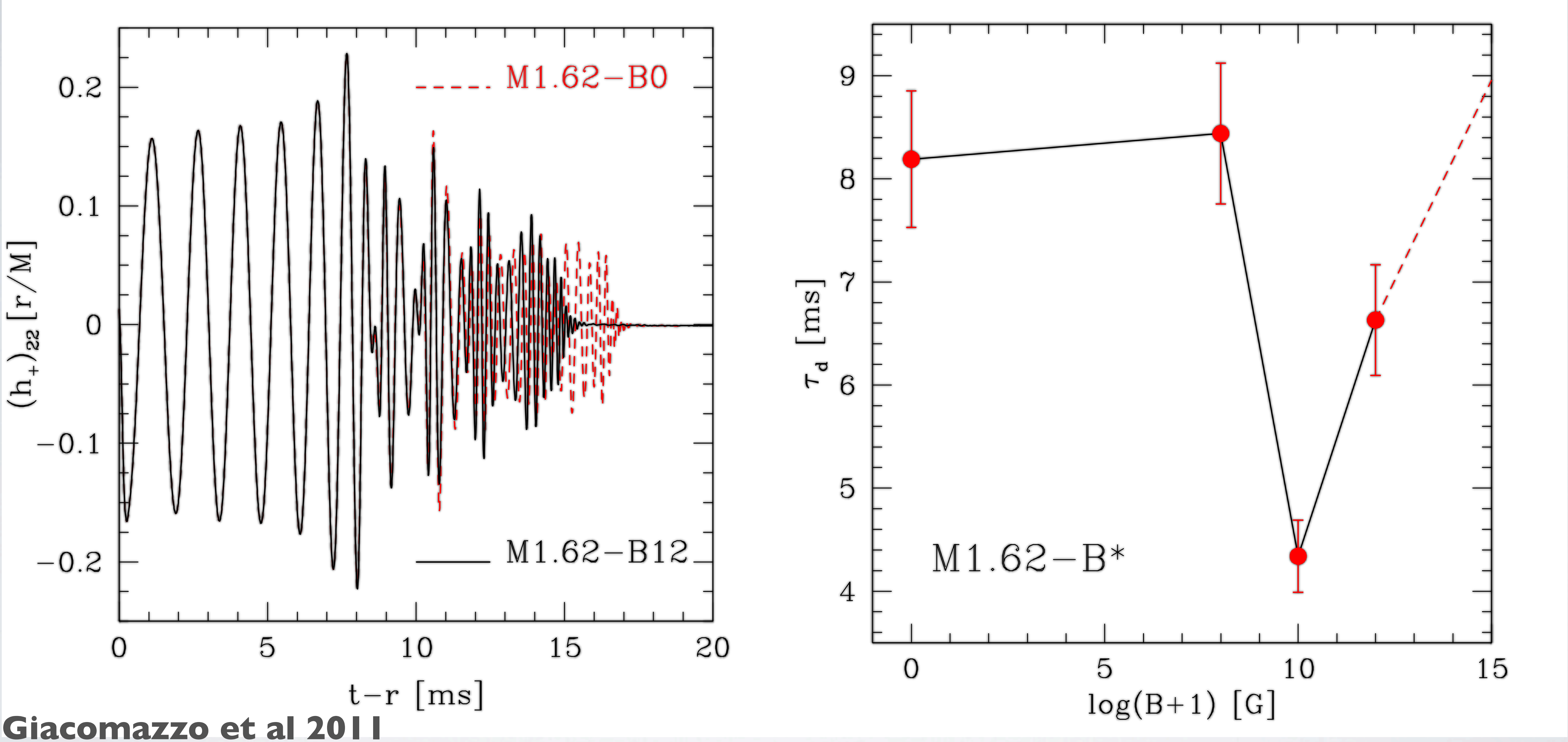
Sekiguchi et al 2011

Neutrino luminosities~1e53 erg/s

Long-living HMNS formed after the merger

Difficult to measure GWs from HMNS with Advanced LIGO

POSTMERGER: MAGNETIC FIELD EFFECTS



Giacomazzo et al 2011

The magnetic field can accelerate the collapse of the HMNS. Survival of the HMNS could be used to infer strength of the magnetic field.

GR NS-BH SIMULATIONS: STATE OF THE ART

(see Faber & Rasio 2012, arXiv:1204.3858)

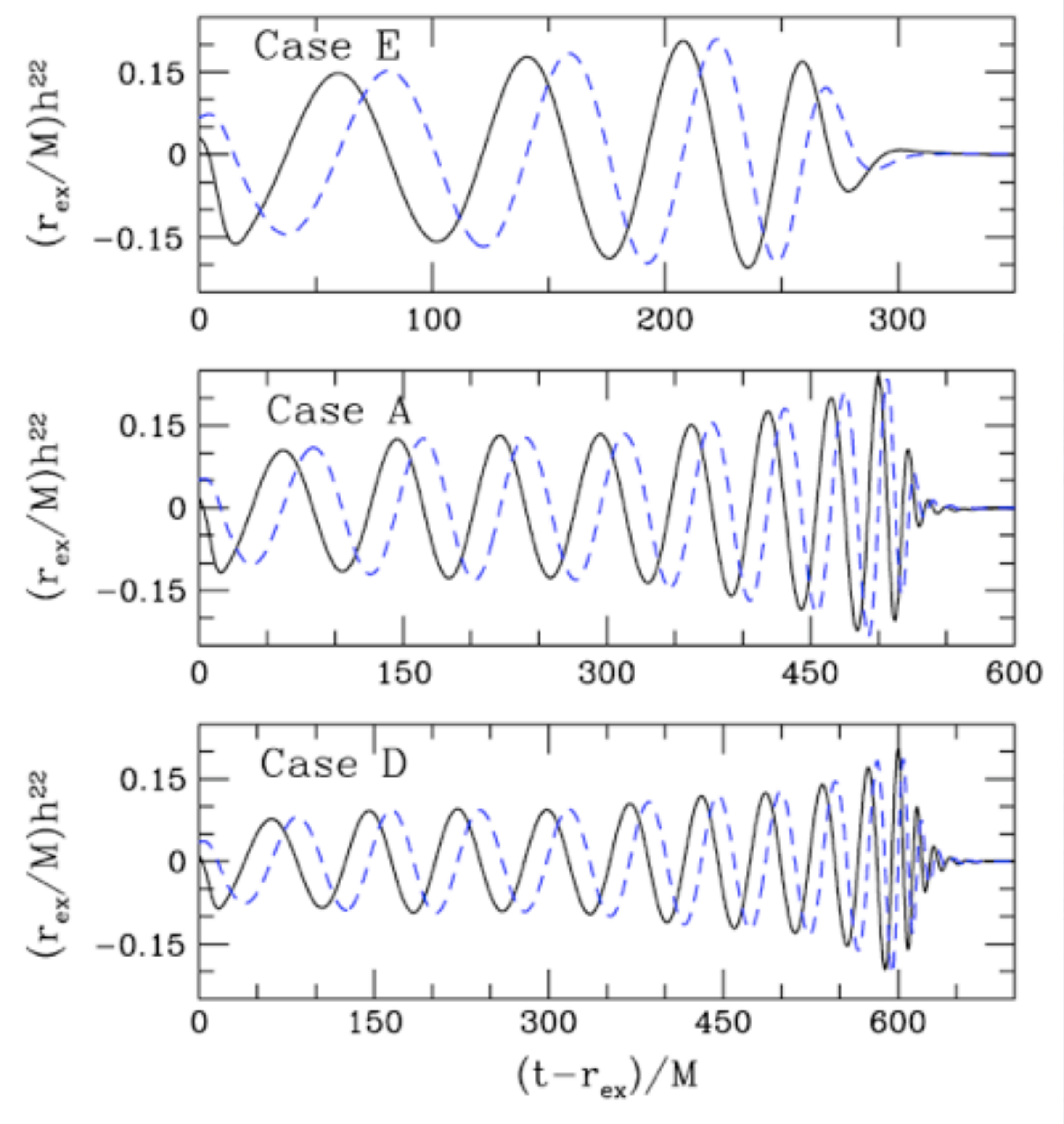
KT:q~1/2; a=0; ideal-fluid
q~1/2; a=0; ideal-fluid
q~1/3; a=0; ideal-fluid
q=1/2, 1/3, 1/4, 1/5; a=0; ideal-fluid
q=1/2, 1/3; a=0; PP EOS
q=1/2, 1/3, 1/4, 1/5; a=-0.5, 0.5, 0.75; PP EOS
HAD: q=1/5; a=0.5; ideal-fluid; MHD
Whisky: q~1; a=0; ideal-fluid; head-on collision
UIUC: q=1, 1/2, 1/3; a=0; ideal-fluid
q=1,1/3,1/5; a=-0.50, 0, 0.75; ideal-fluid
q=1/3; a=0, 0.75; ideal-fluid; MHD (1e16, 1e17G)
SXS: q=1/3; a=0.5; ideal-fluid, PP, Shen EOSs
q=1; a=0, 0.5, 0.9; ideal-fluid; misaligned BH spins
q=1/5, 1/7; a=0.5, 0.7, 0.9; ideal-fluid
Princeton: q=1/4; a=0; PP EOS; eccentric orbits

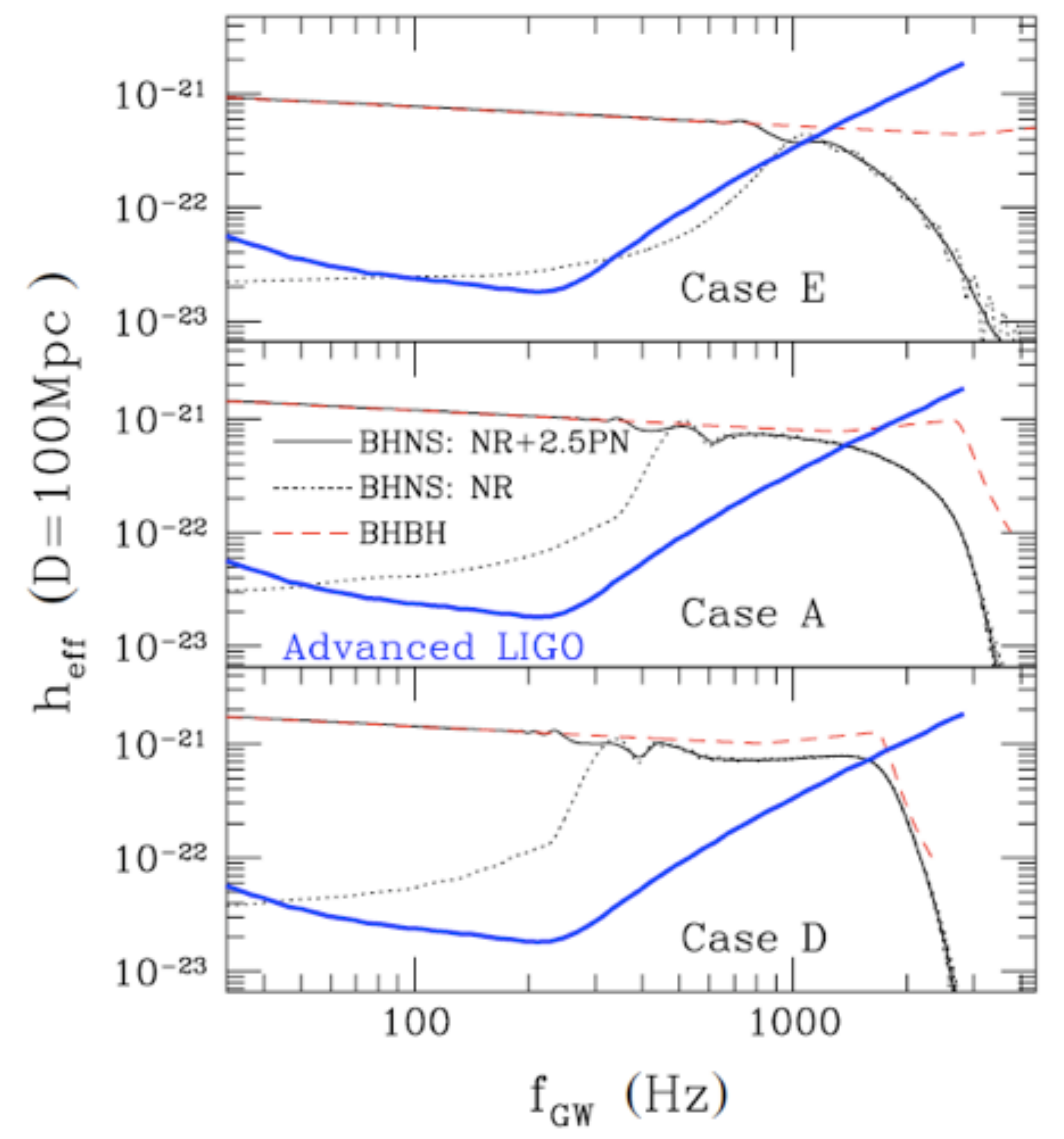
BH-NS: CLASSIFICATION OF GWS

- Shibata et al 2009 defined 3 types of GWs:
  - **type I:** NS disrupted outside ISCO. Only inspiral signal.
  - **type II:** mass transfer near ISCO. Both inspiral and merger are present in the GWs.
  - **type III:** no disruption. GWs very similar to BBH and composed by inspiral, merger and ringdown.
- Classification depends on mass-ratio and NS compactness (type III for $Q>3$, type II for $2<Q<3$, type I for $Q<2$)
- GW cutoff frequency can be used to measure mass-ratio and NS compactness (except for type III signals)

GW FROM BH-NS (NO SPIN)

Etienne et al 2009



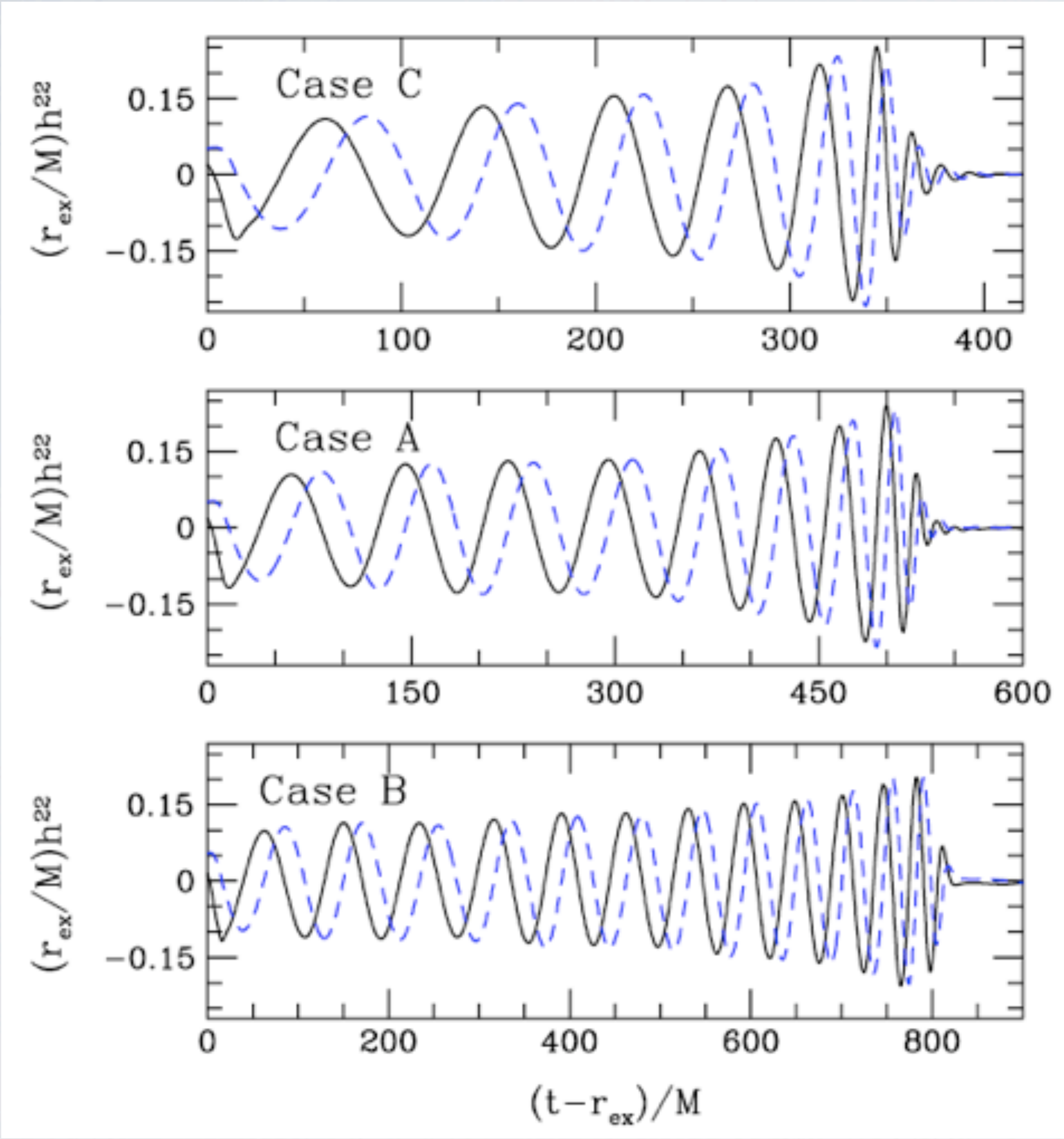


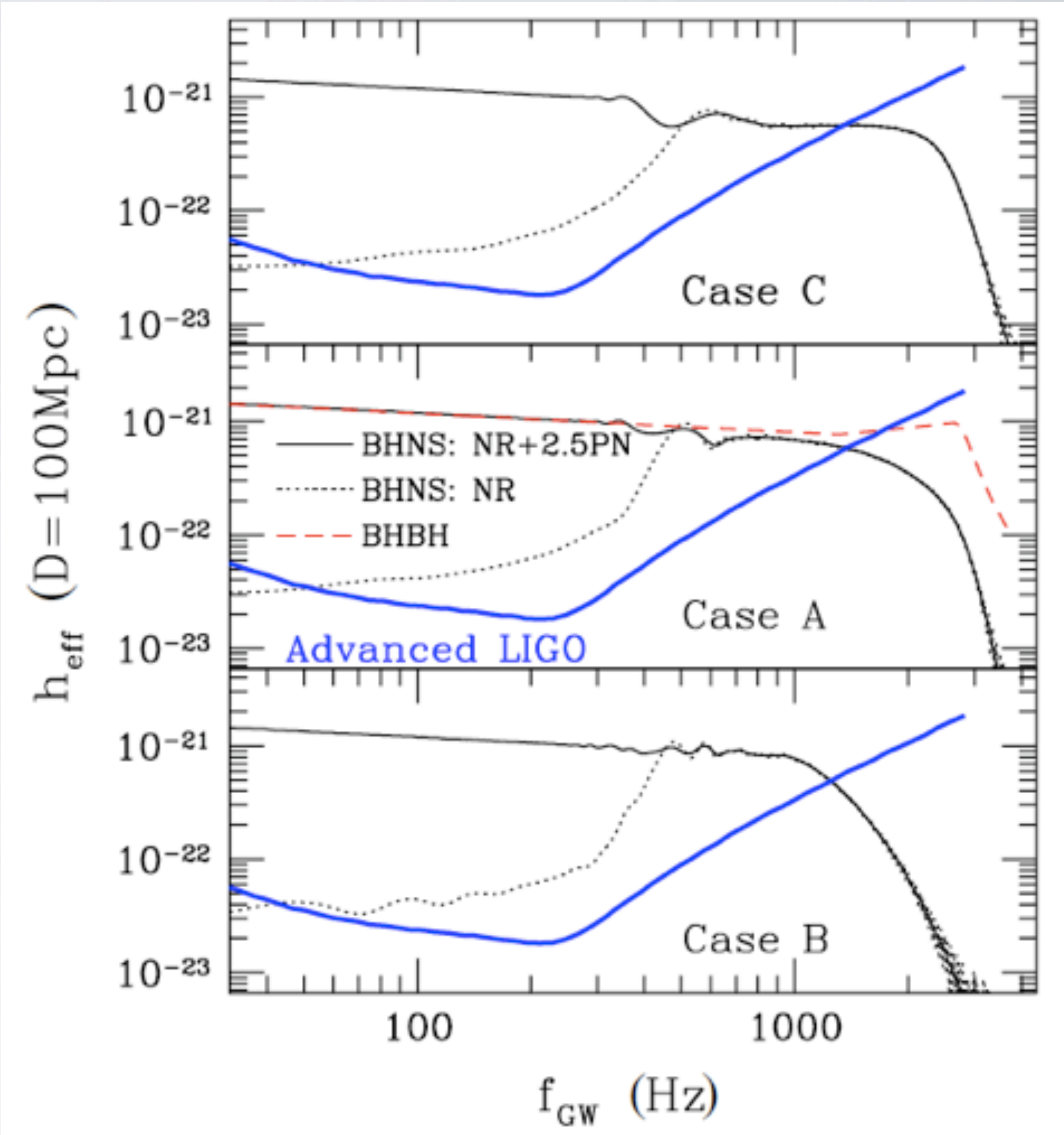
E: Q=1
A: Q=3
D: Q=5

Difficult to detect difference with BBH.
Note how when increasing Q the frequency cutoff gets close to the one for BBH.

GW FROM BH-NS: ROLE OF BH SPIN

Etienne et al 2009

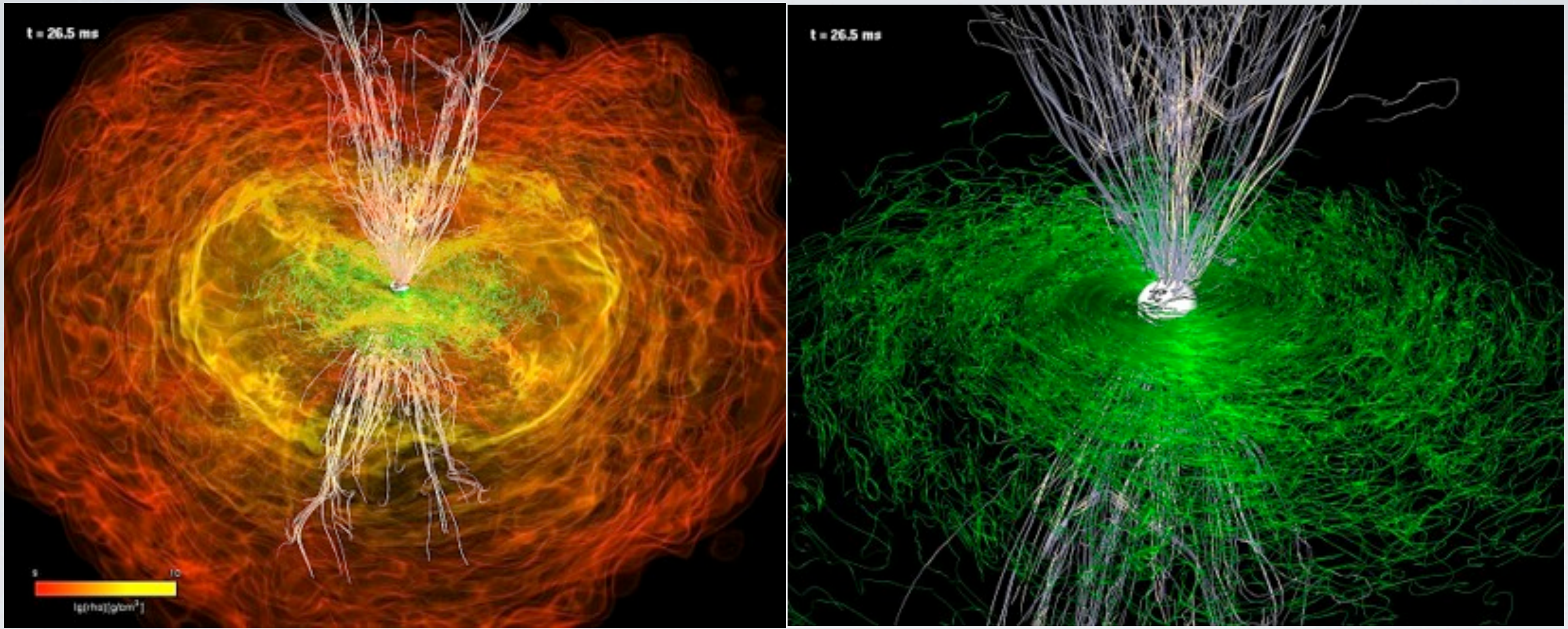




C: Q=3, a=-0.5
A: Q=3, a=0
B: Q=3, a=0.75

Ringdown signal gets smaller with higher BH spin because of larger disk formation.

GRB AS THE RESULT OF MERGERS?

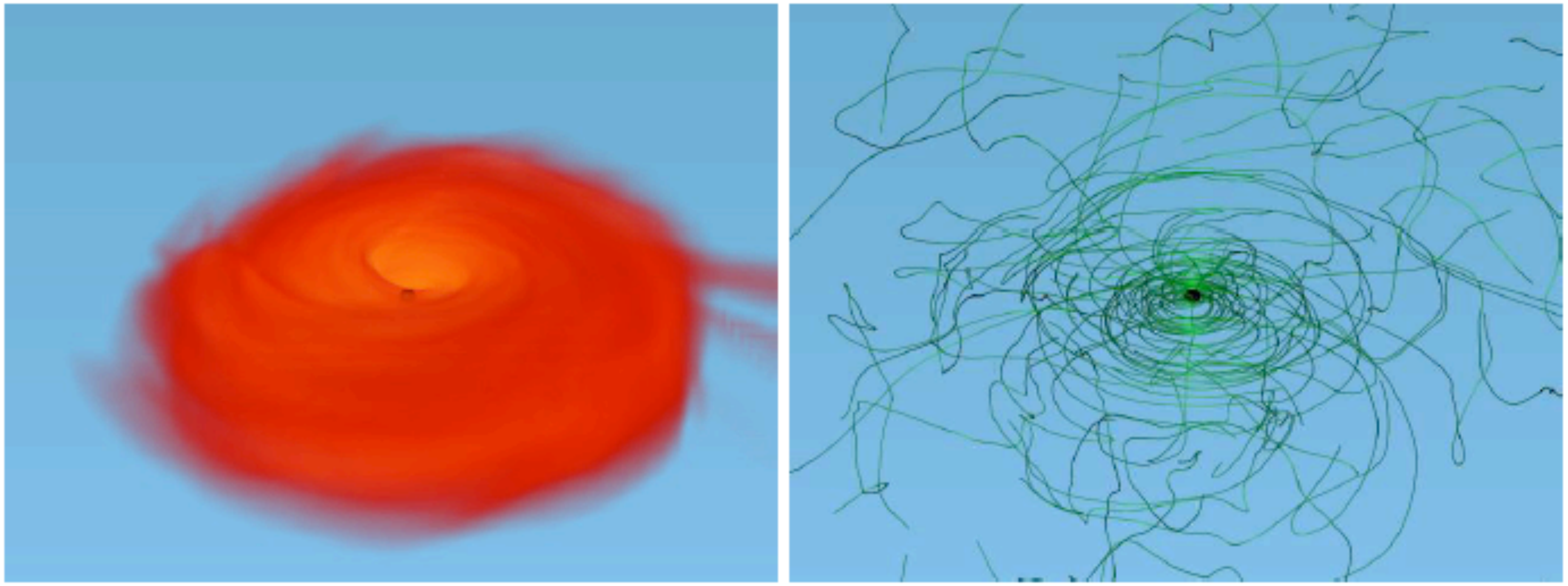


Rezzolla et al 2011

NS-NS

B~1e12G

collimated emission



Etienne et al 2012

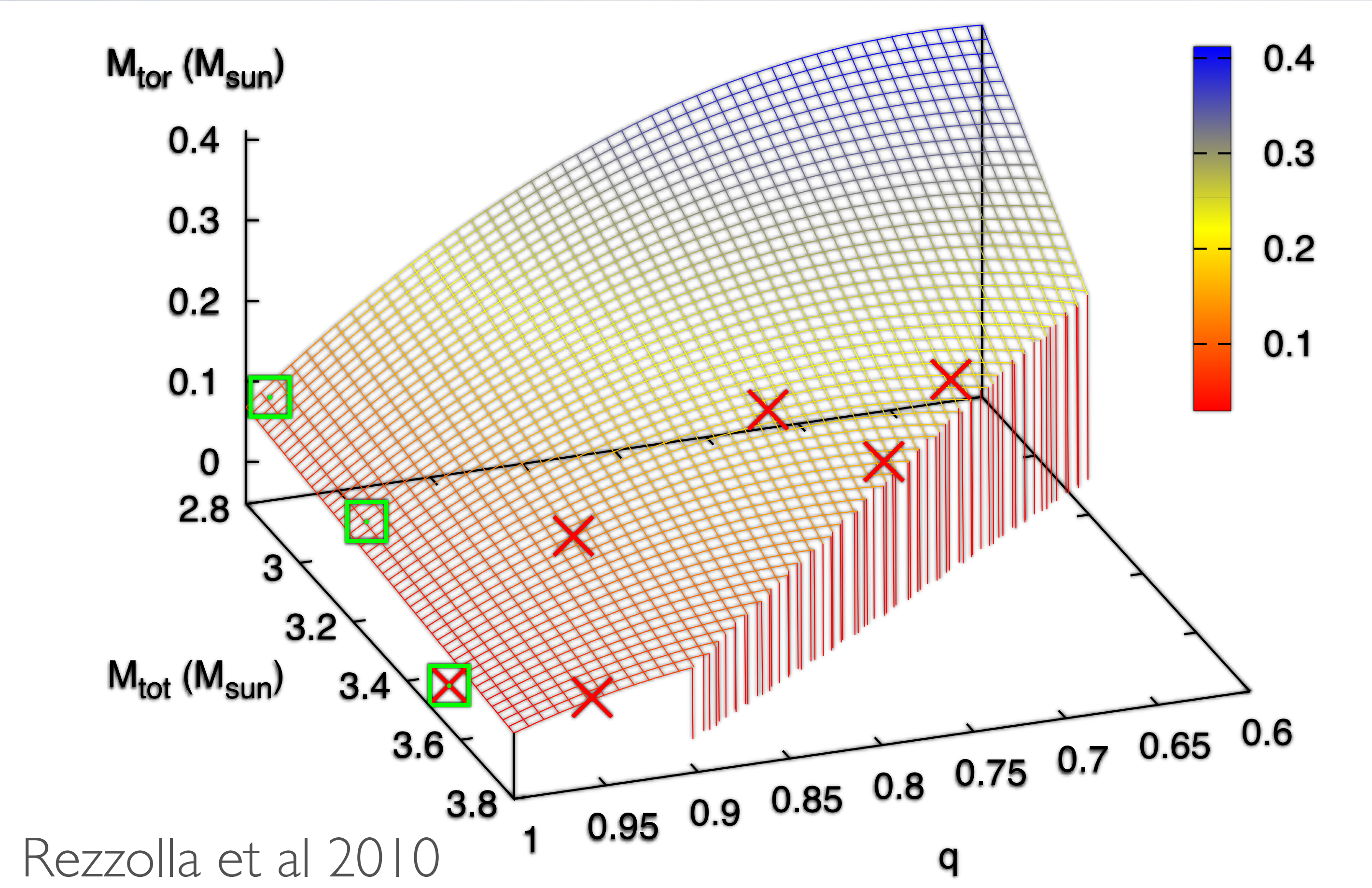
NS-BH

B~1e17G

no collimated emission

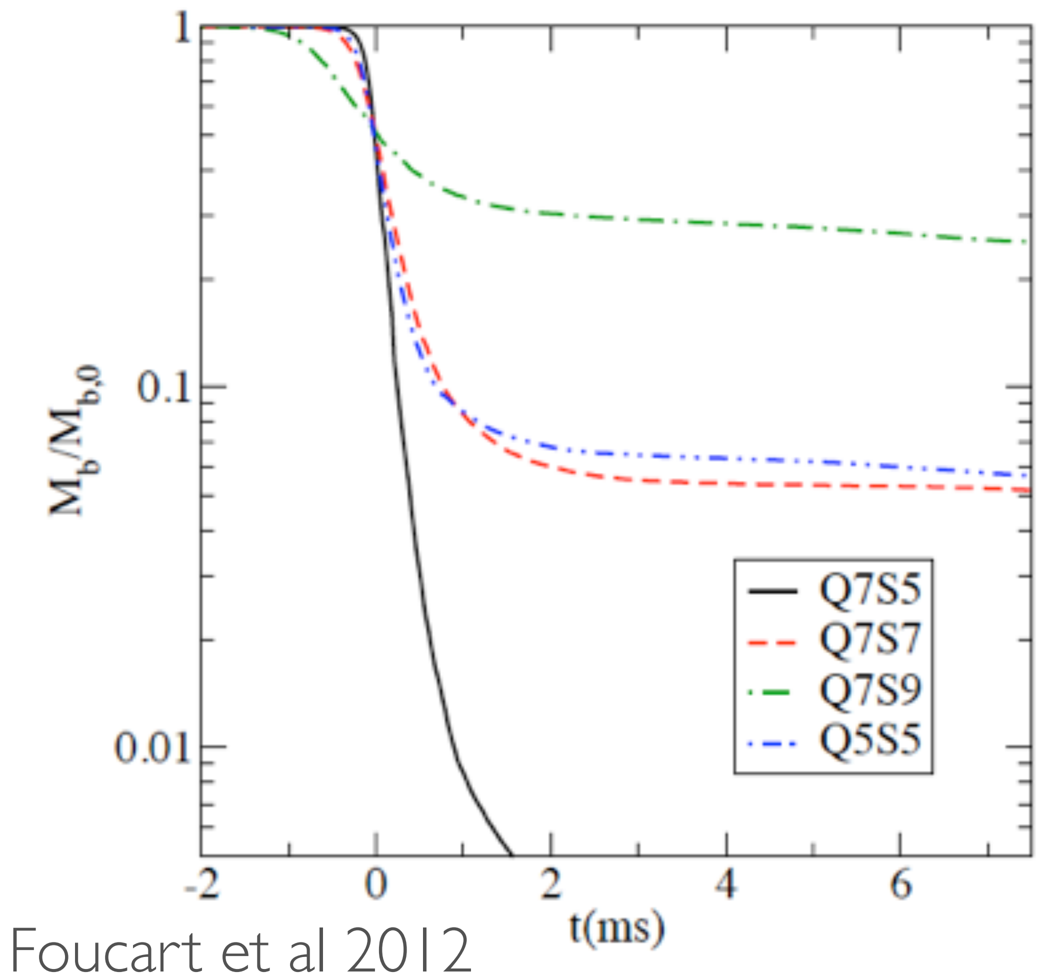
TORI MASSES FROM MERGERS

NS-NS



Rezzolla et al 2010

NS-BH



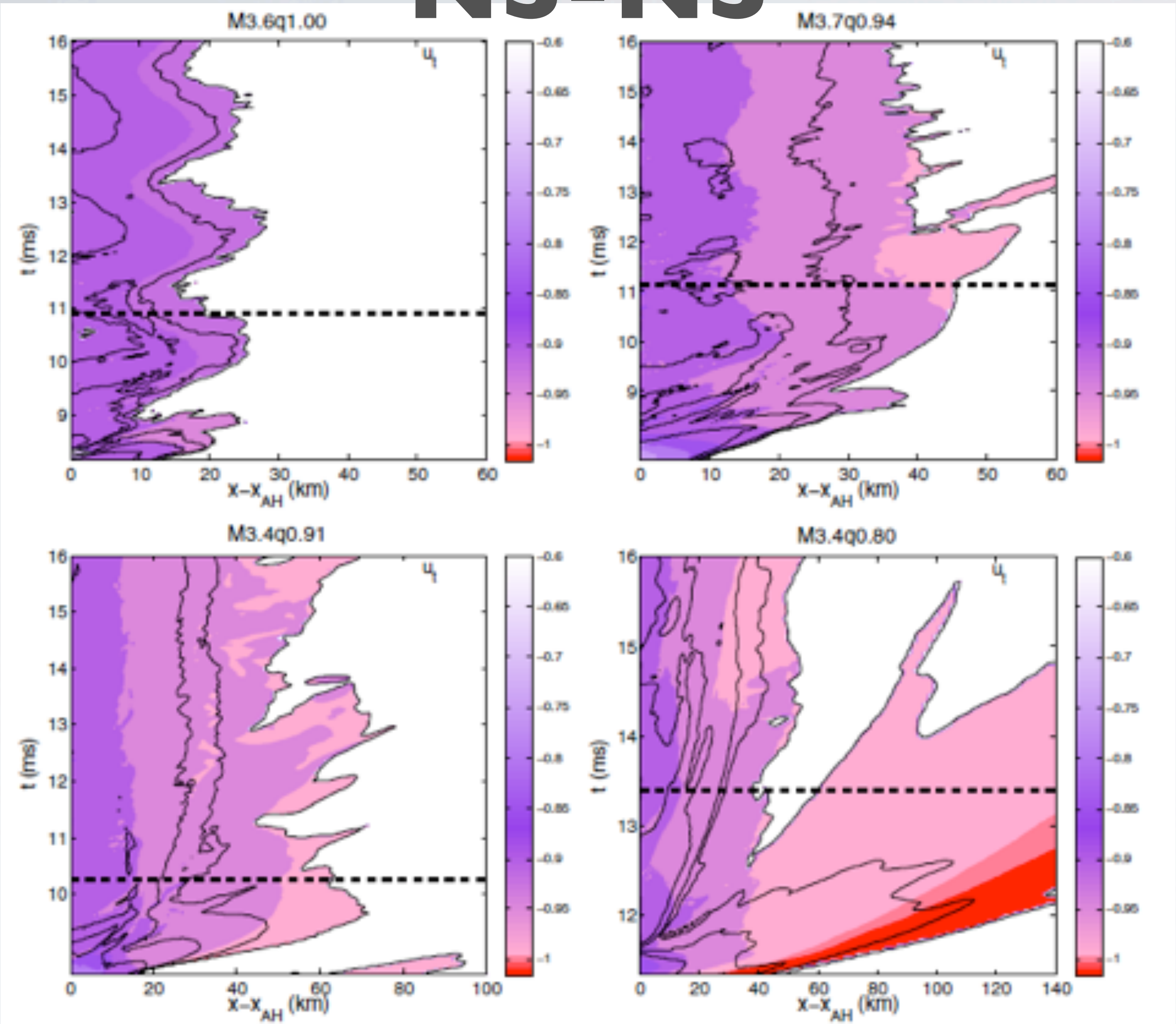
Foucart et al 2012

The torus mass increases with the mass ratio and decreases with the total mass. Possible to form tori up to ~0.3 solar masses.

Even with a 10 Msun BH it is possible to form massive disks if the BH is spinning (a~0.7).

EJECTED MATTER AND FALLBACK

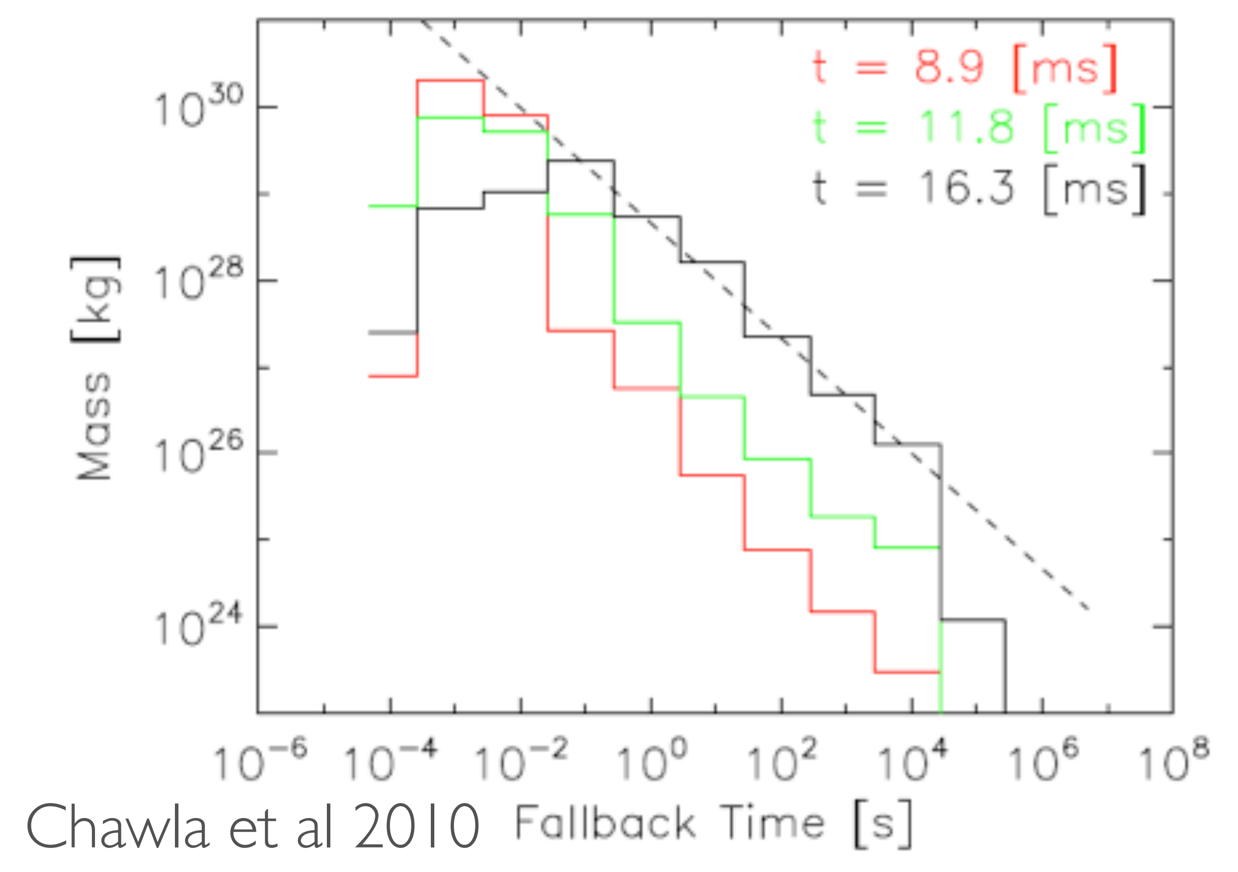
NS-NS



Rezzolla et al 2010

Negligible amount of matter is unbound (~1e-4 Msun)

NS-BH



Chawla et al 2010

99% of bound matter has fallback time of ~10s. Negligible amount of matter is unbound

Most of NS-NS and NS-BH simulations do not show significant amounts of matter ejected from the system.

COMMENTS

- Numerical relativity not really necessary for first GW detections by advanced LIGO, crucial for GW astronomy and ET

- GR **NECESSARY** to understand dynamics of matter in mergers and EM counterparts (Newtonian sims not trustable after merger)

- Qualitative agreement between different groups on what we can detect in GWs and matter dynamics

- The parameter space is HUGE so each group focused on a particular area (small overlap in initial data)

- Magnetic field effects and microphysics still largely unexplored

- More rigorous comparison between groups is needed (first attempt with Whisky/KT groups). NINJA matter?