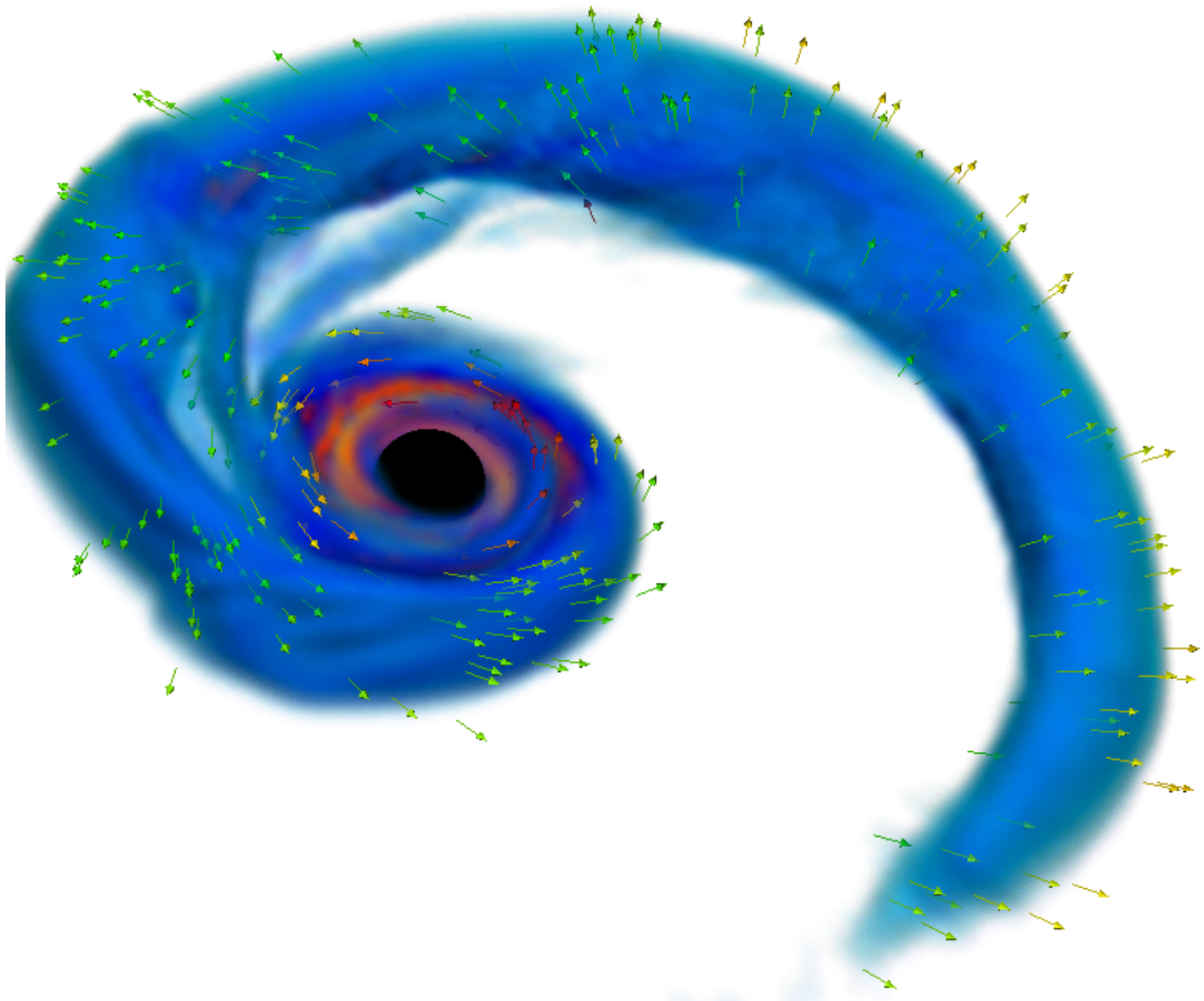
The Outcome of Neutron Star Mergers



Francois Foucart
Einstein Fellow
Lawrence Berkeley Nat. Lab.
SXS Collaboration

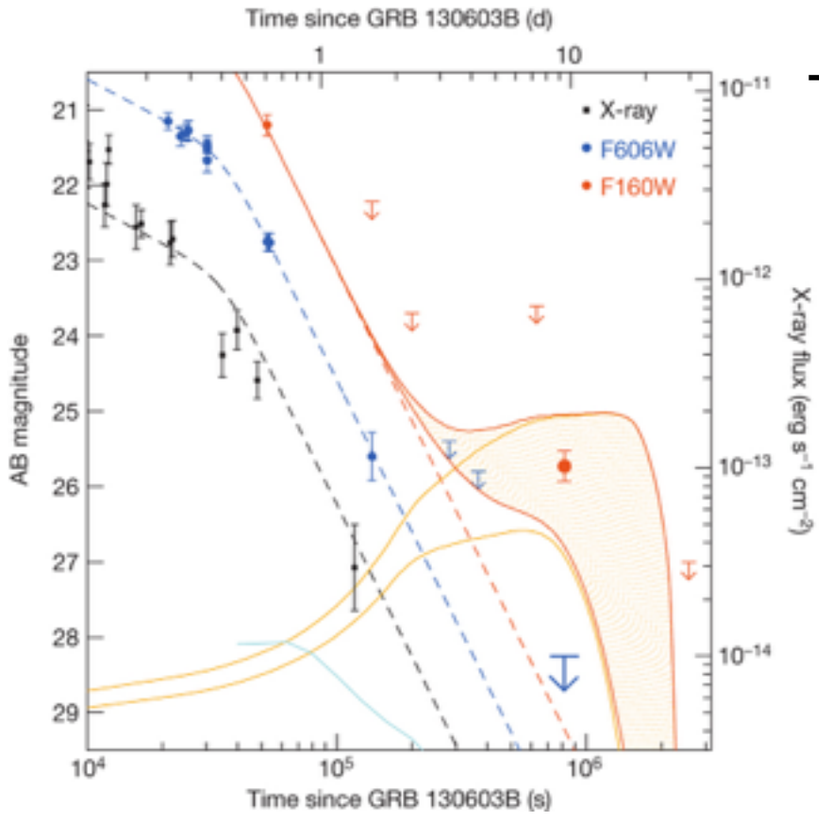
Oct 28th 2014
Einstein Symposium

Collaborators

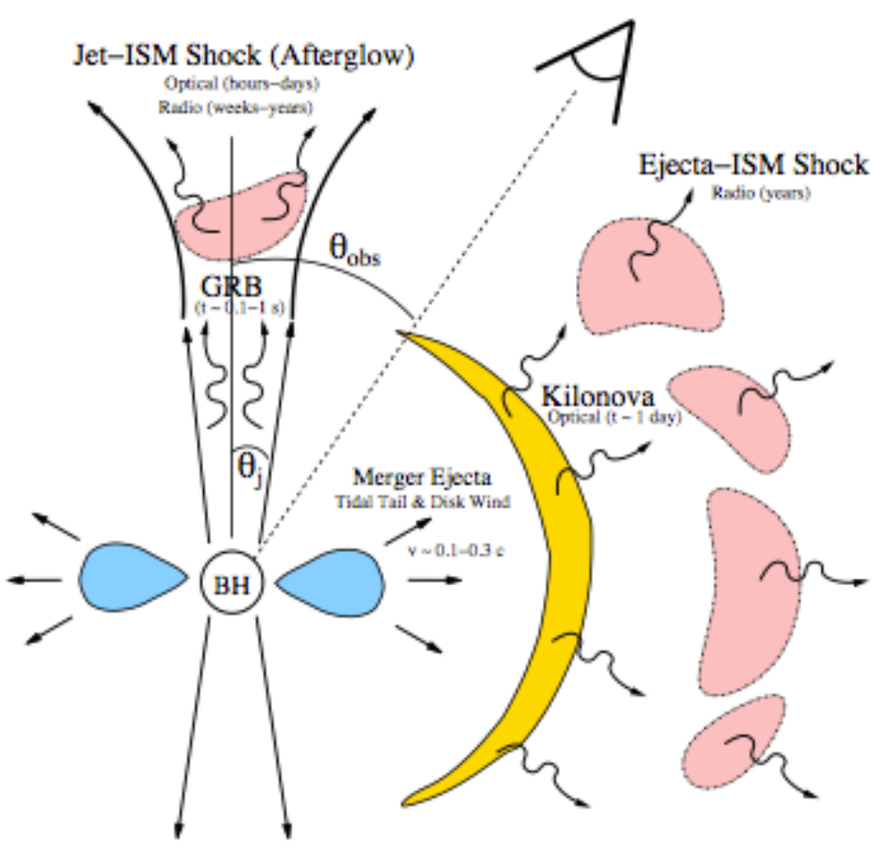
- Brett Deaton (WSU)
- Matt Duez (WSU)
- Evan O'Connor (NC State)
- Christian Ott (Caltech)
- Luke Roberts (Caltech)
- Lawrence Kidder (Cornell)
- Harald Pfeiffer (CITA)
- Bela Szilagyi (Caltech)
- Mark Scheel (Caltech)
- Curran Muhlberger (Cornell)

Observing Mergers

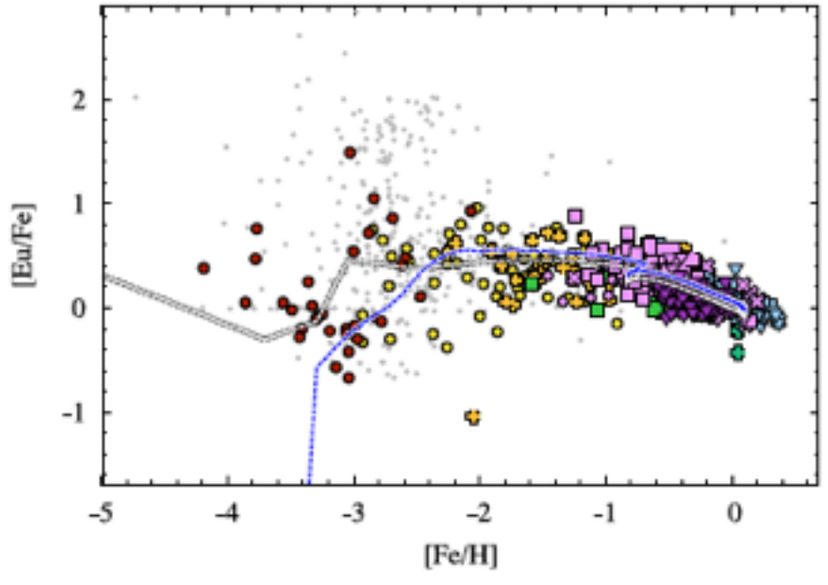
LIGO Livingston



Tanvir et al. 2013



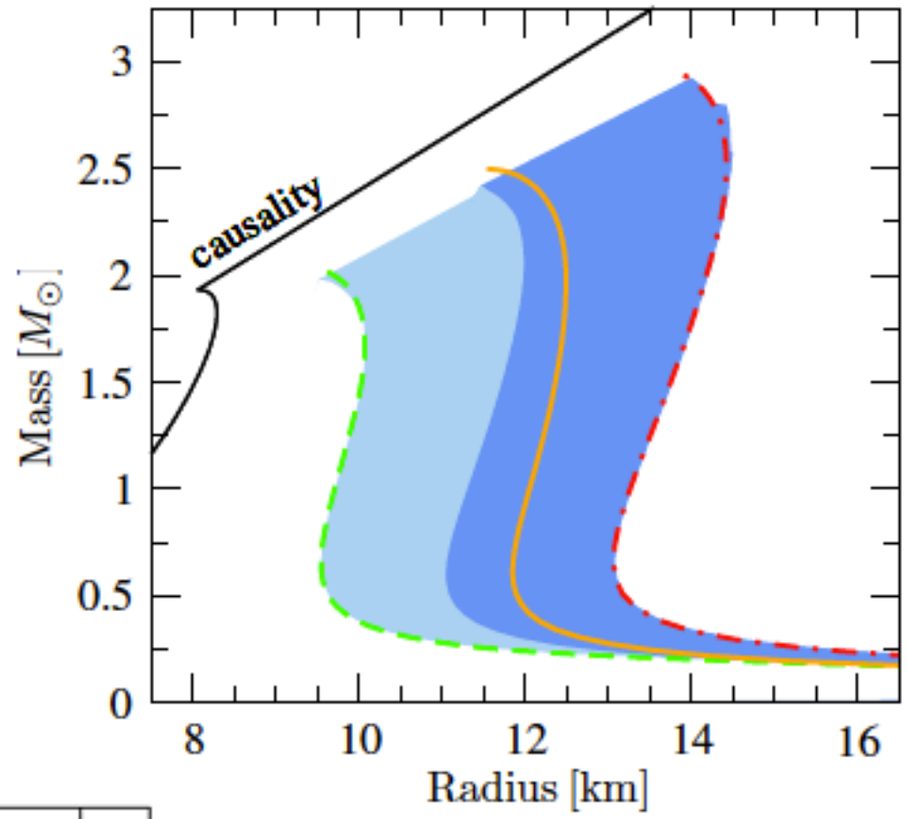
Metzger & Berger 2012



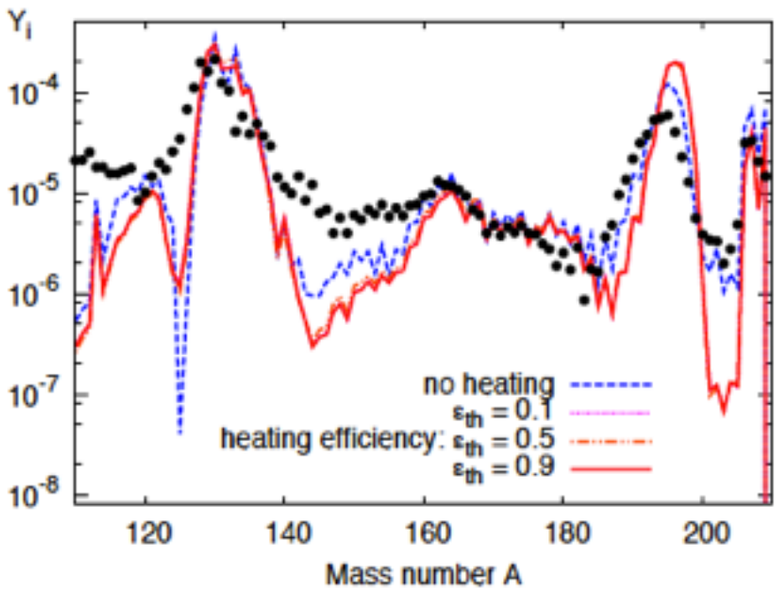
Matteucci et al. 2014

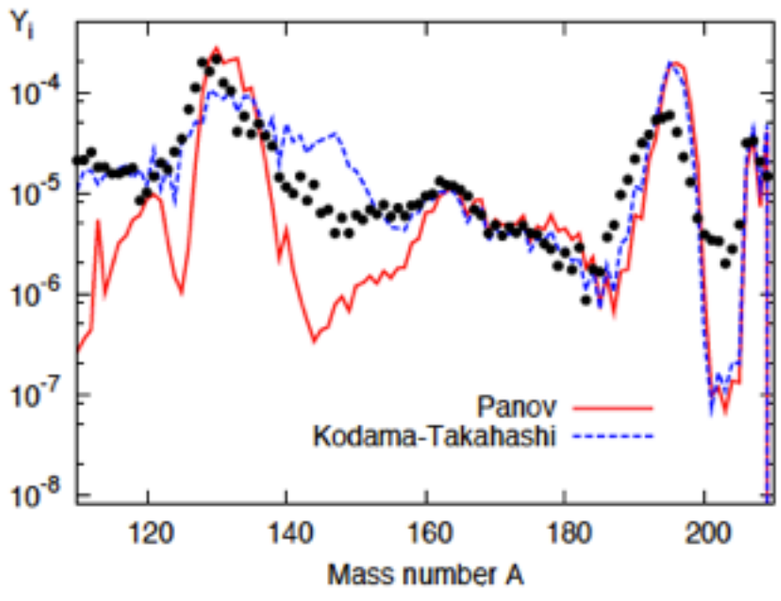
Astrophysics with Mergers

- Direct detection of GW
- Population of compact binaries
- NS equation of state
- Constraints on r-process



Hebeler et al. 2013

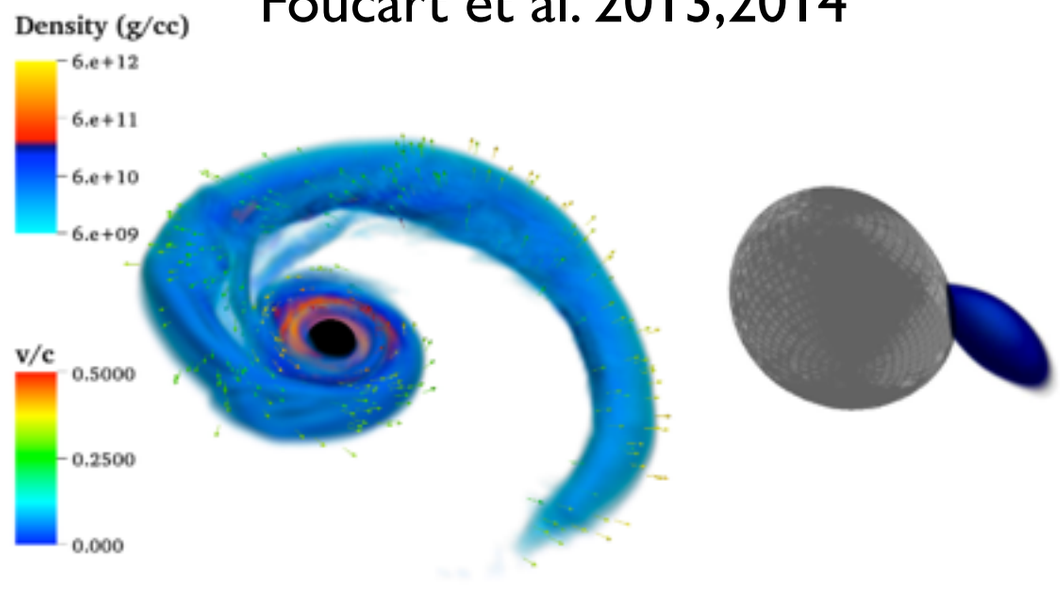




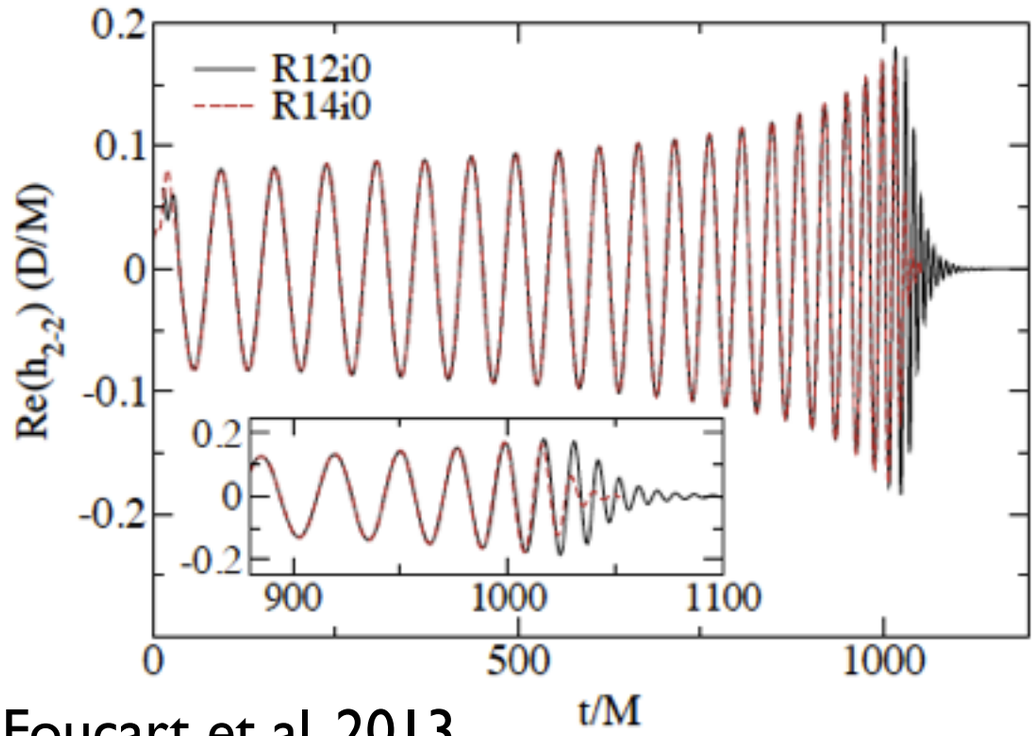
Korobkin et al. 2012

Role of GR Simulations

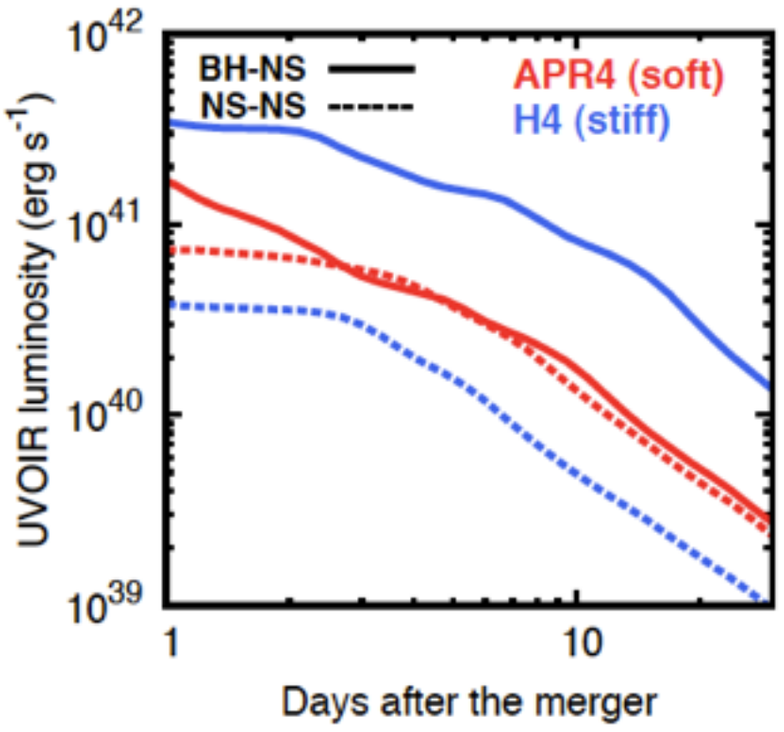
- Waveform modeling
- Characterize Merger / Remnant
- Constrain EM signals



Foucart et al. 2013,2014



Foucart et al. 2013



Tanaka et al. 2013

Important Physics

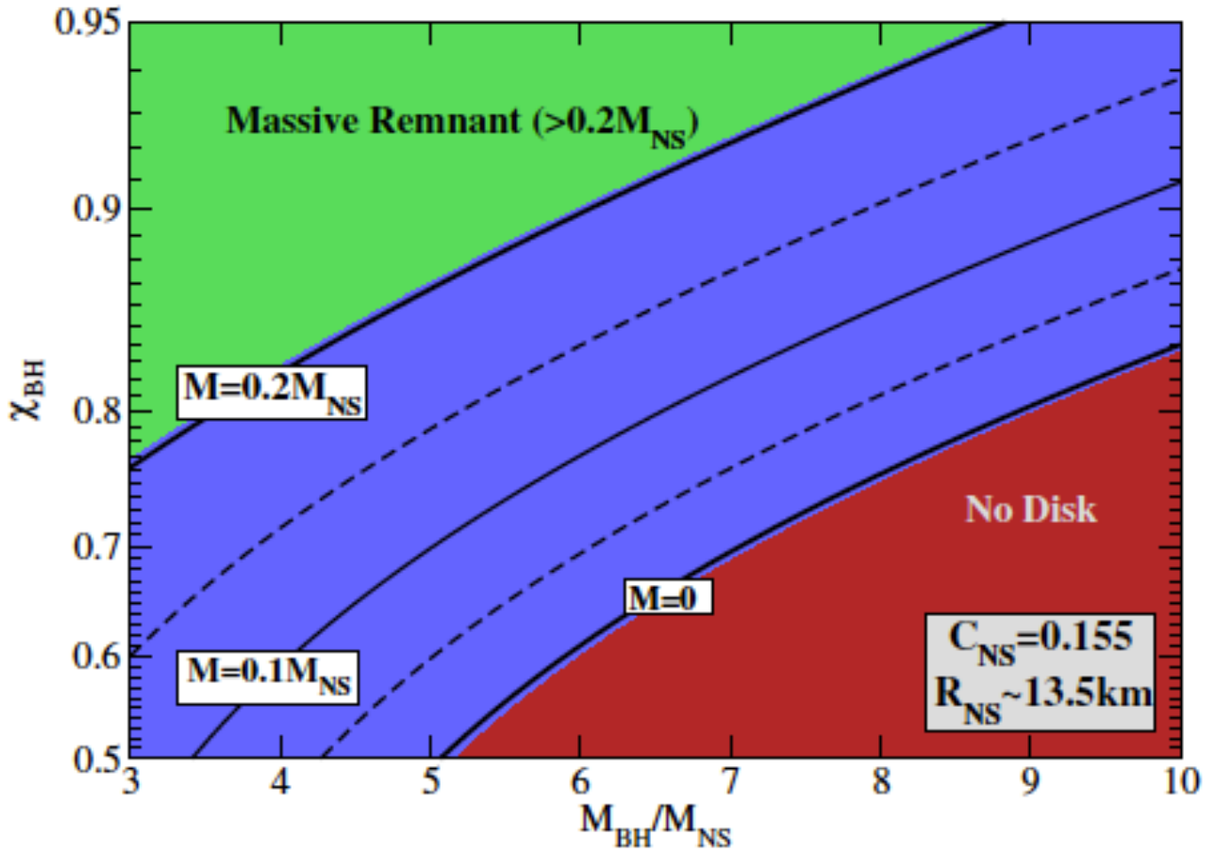
- General Relativity + Hydrodynamics
- Magnetic Fields
- Neutrino Radiation
- Equation of state of dense matter $P(\rho, T, Y_e)$
- Nuclear reactions in disk / outflows

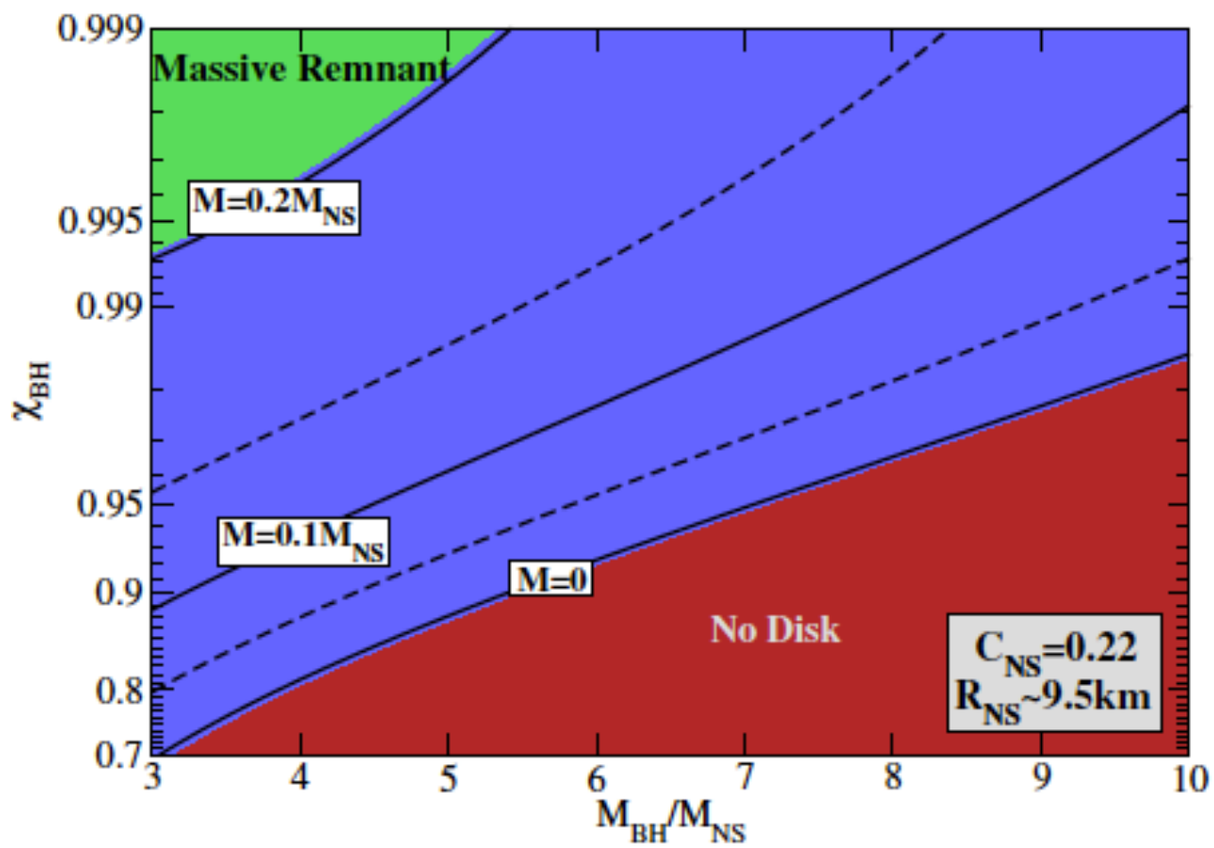
Results : BH-NS

Outcome : BH-NS

BH-NS "Disruption Line"

Foucart 2012





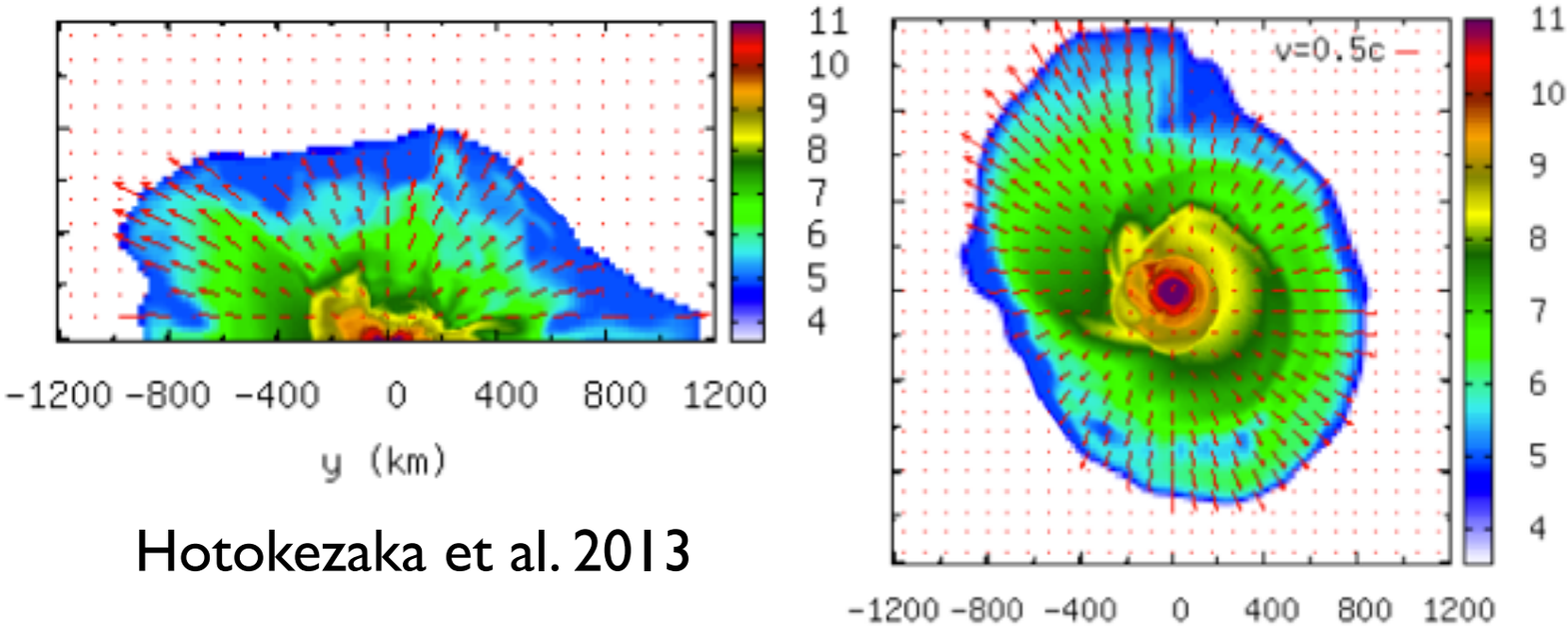
Approximate disruption condition from NR simulations:

$$C_{\rm NS} \lesssim \left(2 + 2.14 q^{2/3} \frac{R_{\rm ISCO}}{6M_{\rm BH}}\right)^{-1}$$

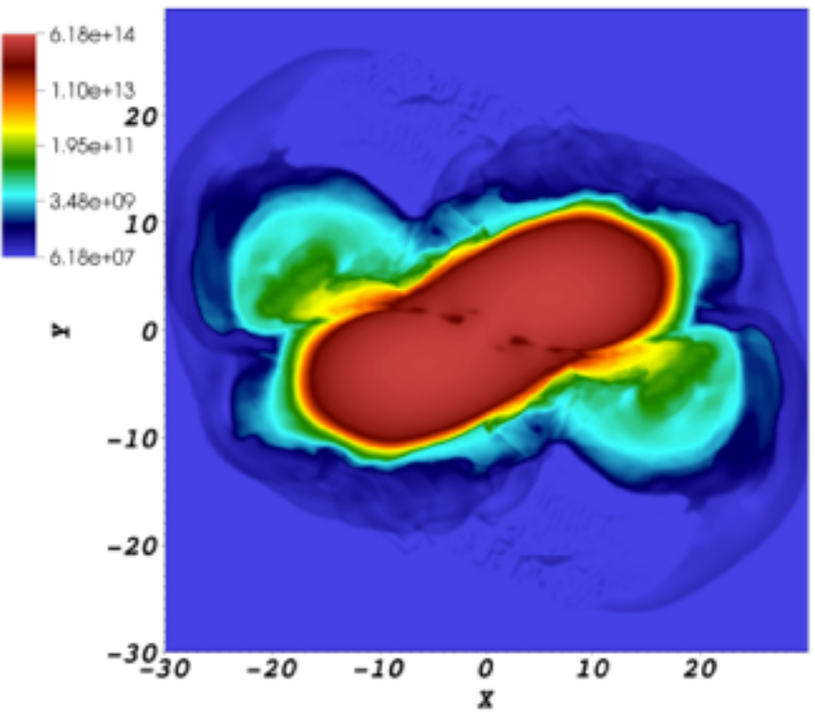
NS-NS Mergers

Post-Merger Remnant

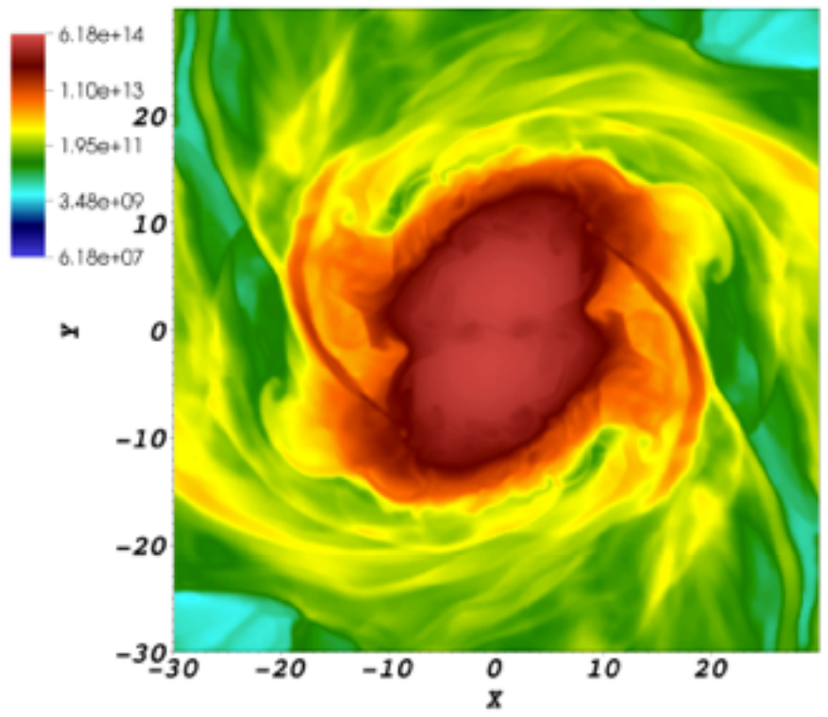
- Low mass ejecta
- Hot disk
- Massive NS remains for M_{NS}~1.2-1.4M_{sun}



Hotokezaka et al. 2013



t = 15.2 ms

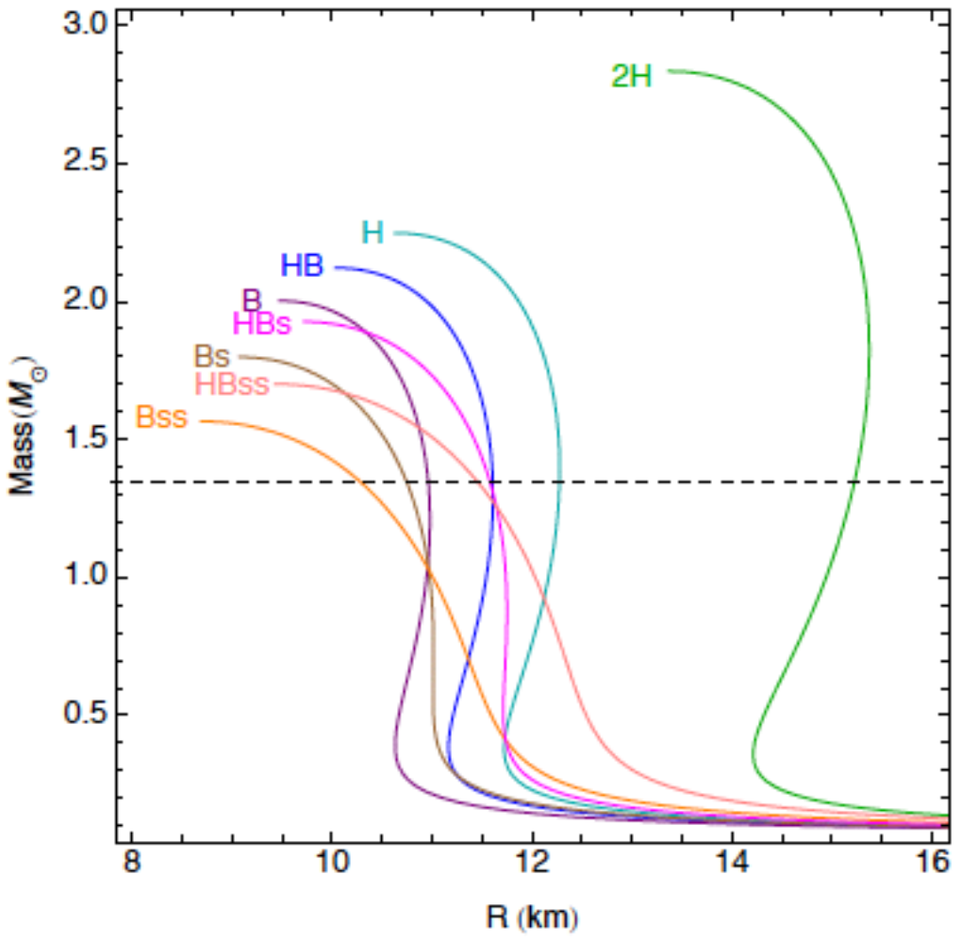


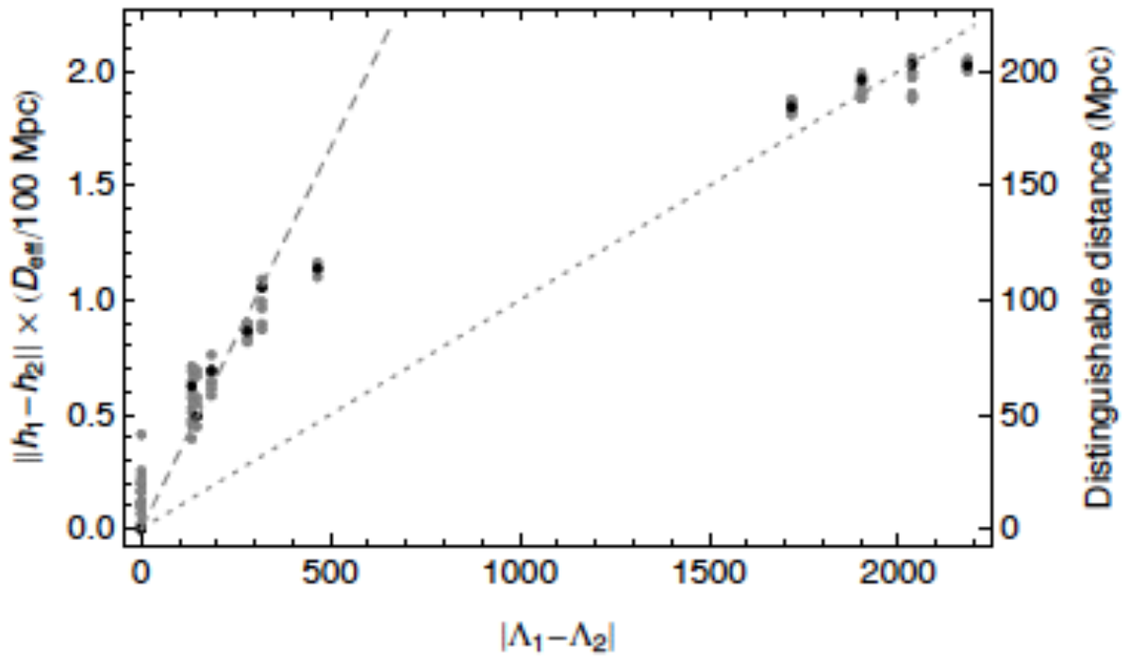
t = 18.9 ms

- Hard to resolve B-field
- Importance of contact region

Giacomazzo & Perna 2013

Grav. Waves: NS-NS





Extreme EoS effects detectable at ~200Mpc, typical at ~50-100 Mpc (Read et al. 2013)

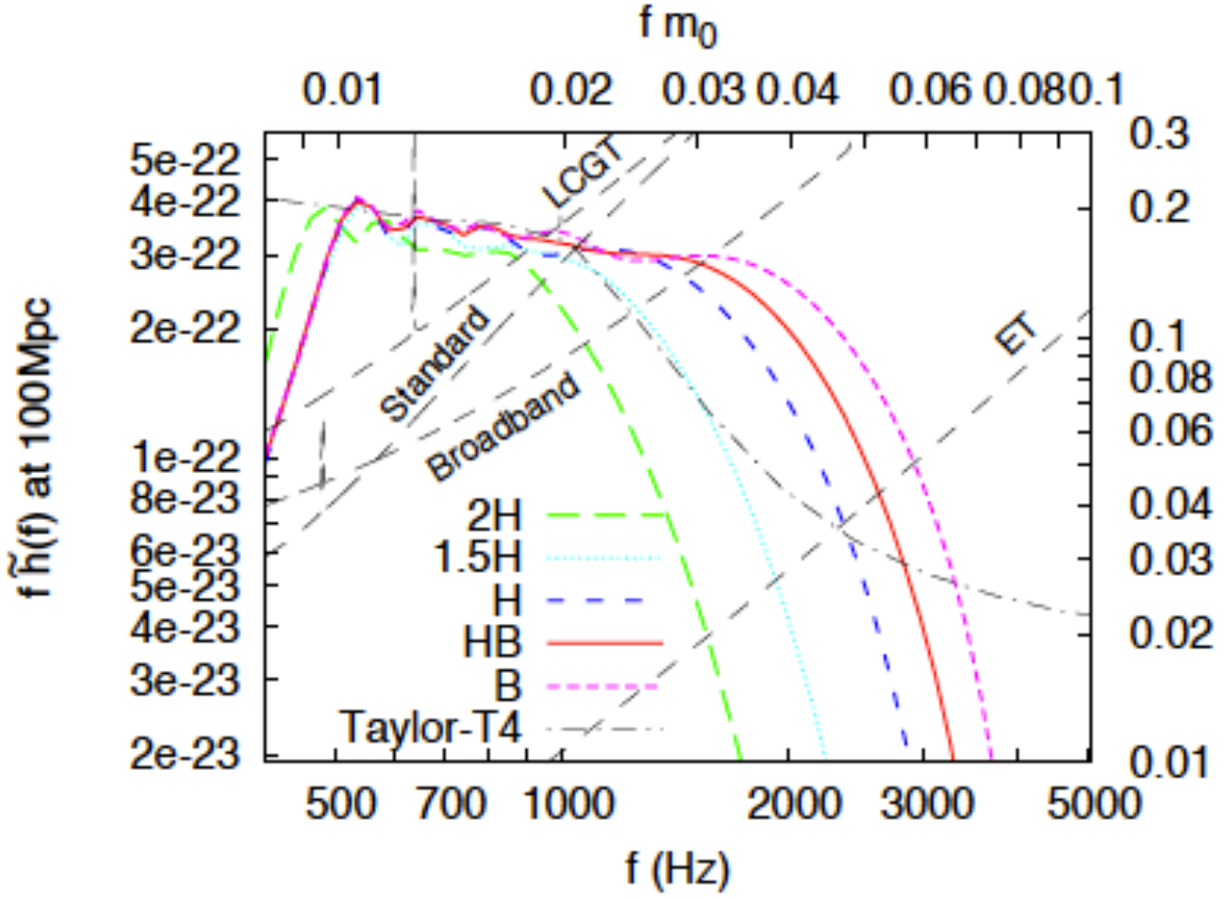
Figs: Read et al. 2013

Stacking ~20-40 typical events also allows EoS measurements (Del Pozzo et al. 2013)

Still need better waveform models! (Wade et al. 2014)

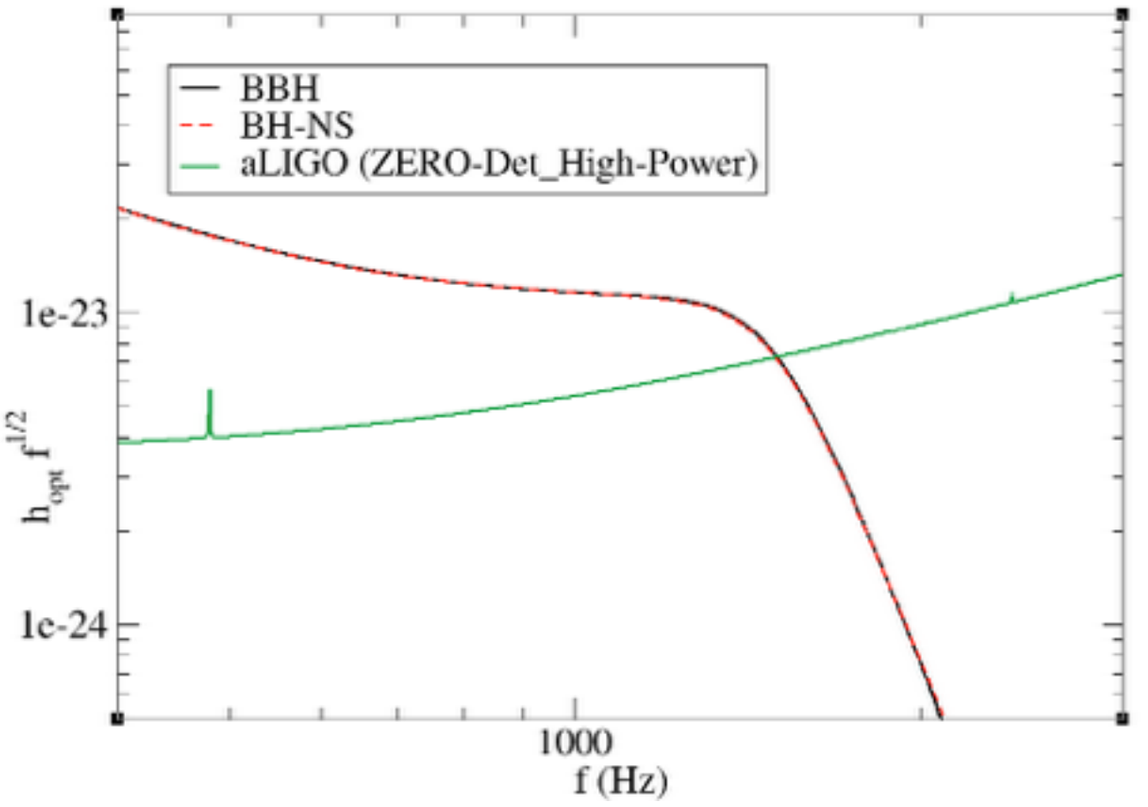
Grav. Waves: BH-NS

GW signal - low mass



Kyutoku et al. 2011

GW signal - high mass

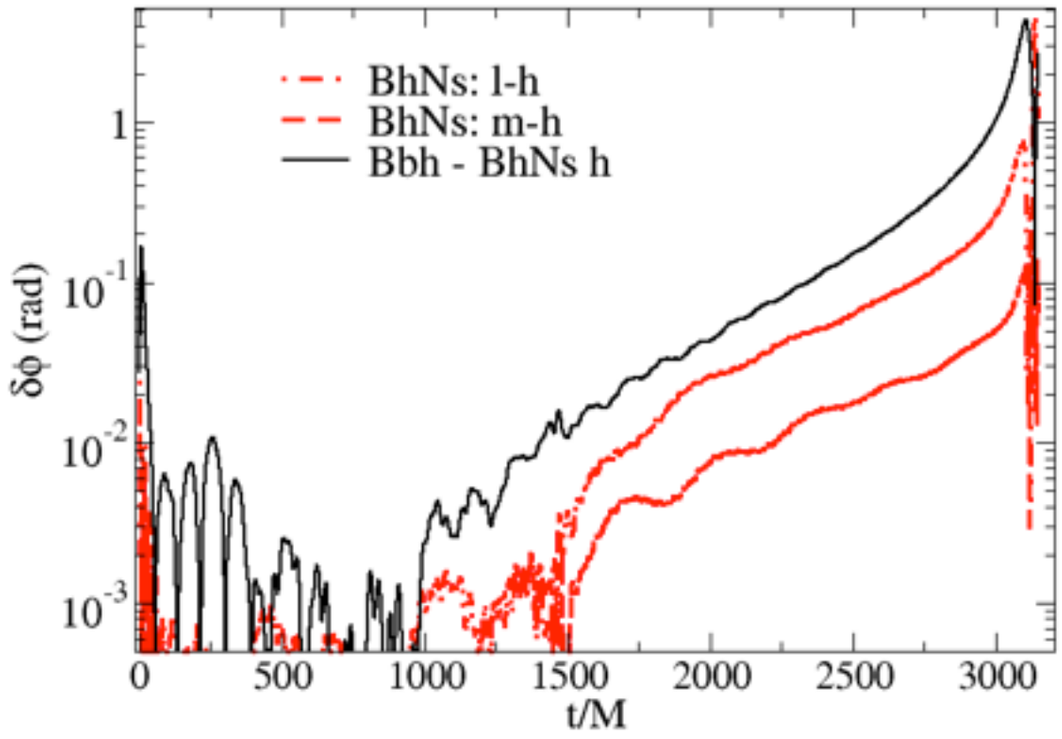


Foucart et al 2013

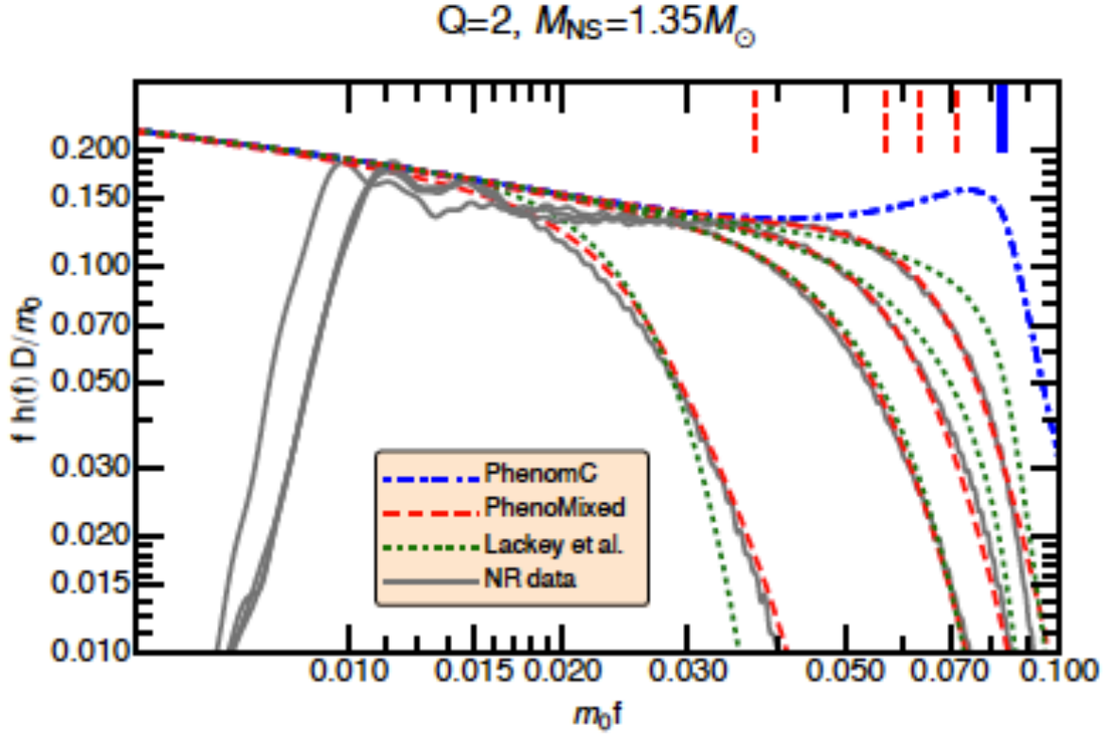
- Finite size effects matter for low mass systems / high spins (Lackey et al. 2013)
- Weak effects for "typical" NS-BH system

Informing GW Modeling

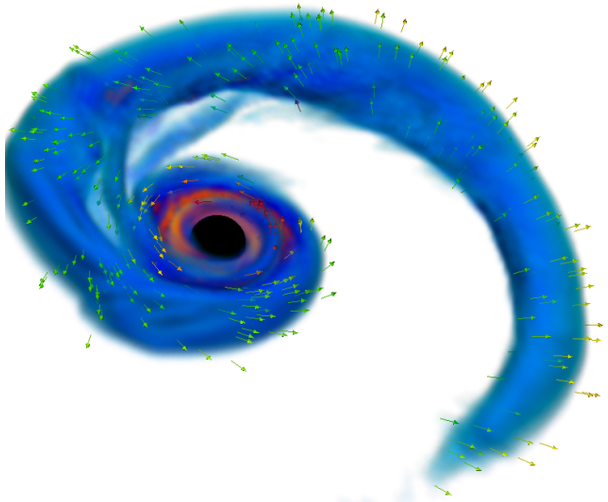
- Point particle: Use BH-BH
- Tidal effects: PN/EOB
- Disruption/Ringdown: Phenomenological



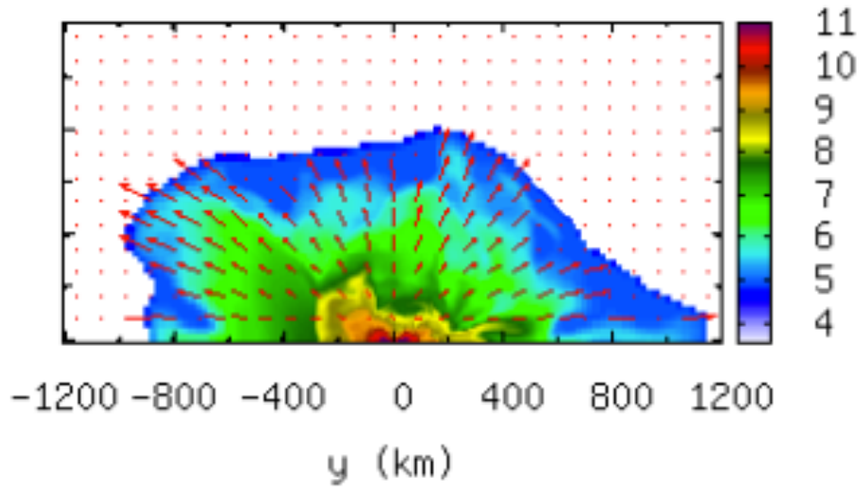
PRELIMINARY: Accuracy of BhNs waveforms (Foucart, using methods from Radice et al. 2013)



Pannarale et al 2013



Ejecta



BH-NS	NS-NS
M ~ 10	M ~ 10
Cold, Y	Large range of T, Y
Equatorial, Asymmetric	Isotropic
<v> ~ 0.2c - 0.3c	<v> ~ 0.2c - 0.3c
Produce 2	Produce all r-process elements (?)
IR peak, lasts ~week	Poss. IR and optical components

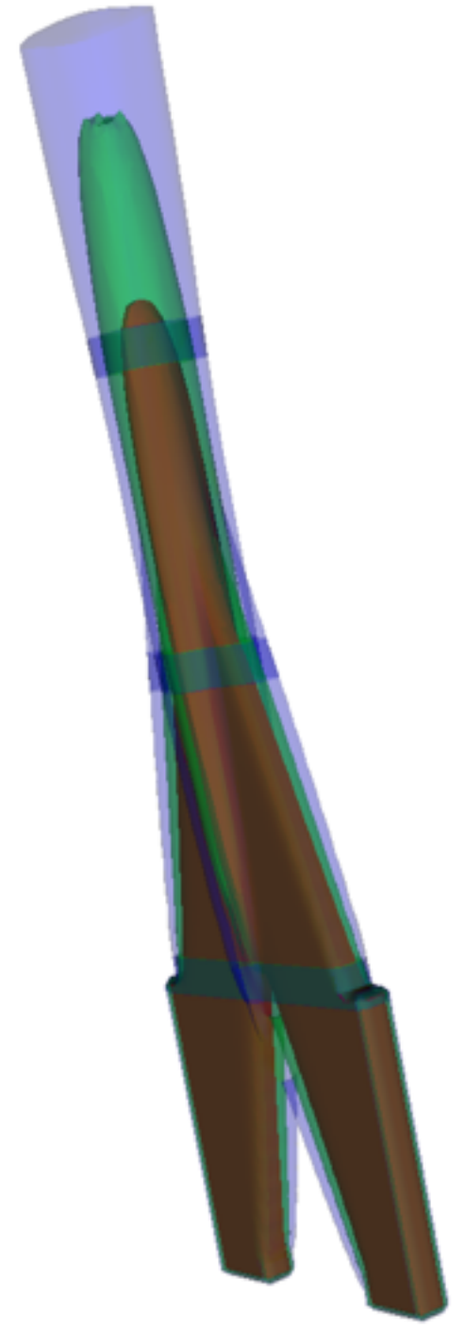
See Barnes & Kasen 2013, Deaton et al. 2013, Foucart et al. 2013/4, Hotokezaka et al. 2013, Korobkin et al. 2012, Kyutoku et al. 2013, Roberts et al. 2011, Tanaka et al. 2014, Wanajo et al. 2014

Microphysics

- Magnetic fields
  - Unimportant before merger
  - Generally under-resolved after merger
    - Growth in contact region (NS-NS)
    - MRI (NS-NS & BH-NS)
  - Jet? SGRB?
- Neutrinos
  - Cooling: $L>10^{53}$erg/s just after merger
  - Absorption: critical for outflow composition
  - Wind? Energy deposition above disk?

Neutrino: Methods

- Leakage
  - Cooling prescription
  - No absorption, order of magnitude accurate
- Moment formalism
  - Evolve neutrino energy, flux
  - Gives spatial dependence, absorptions
  - Energy dependence too expensive so far
  - Known artifacts with current closure



Conclusions

- Mostly covered full binary parameter space with basic physics (GR+Hydro)
- Constraints on global remnant properties
- Rapid progress in microphysics
- Still many complex issues to address:
  - Cost of more detailed physics
  - Higher accuracy waveforms
  - Jets / SGRBs? Disk outflows?