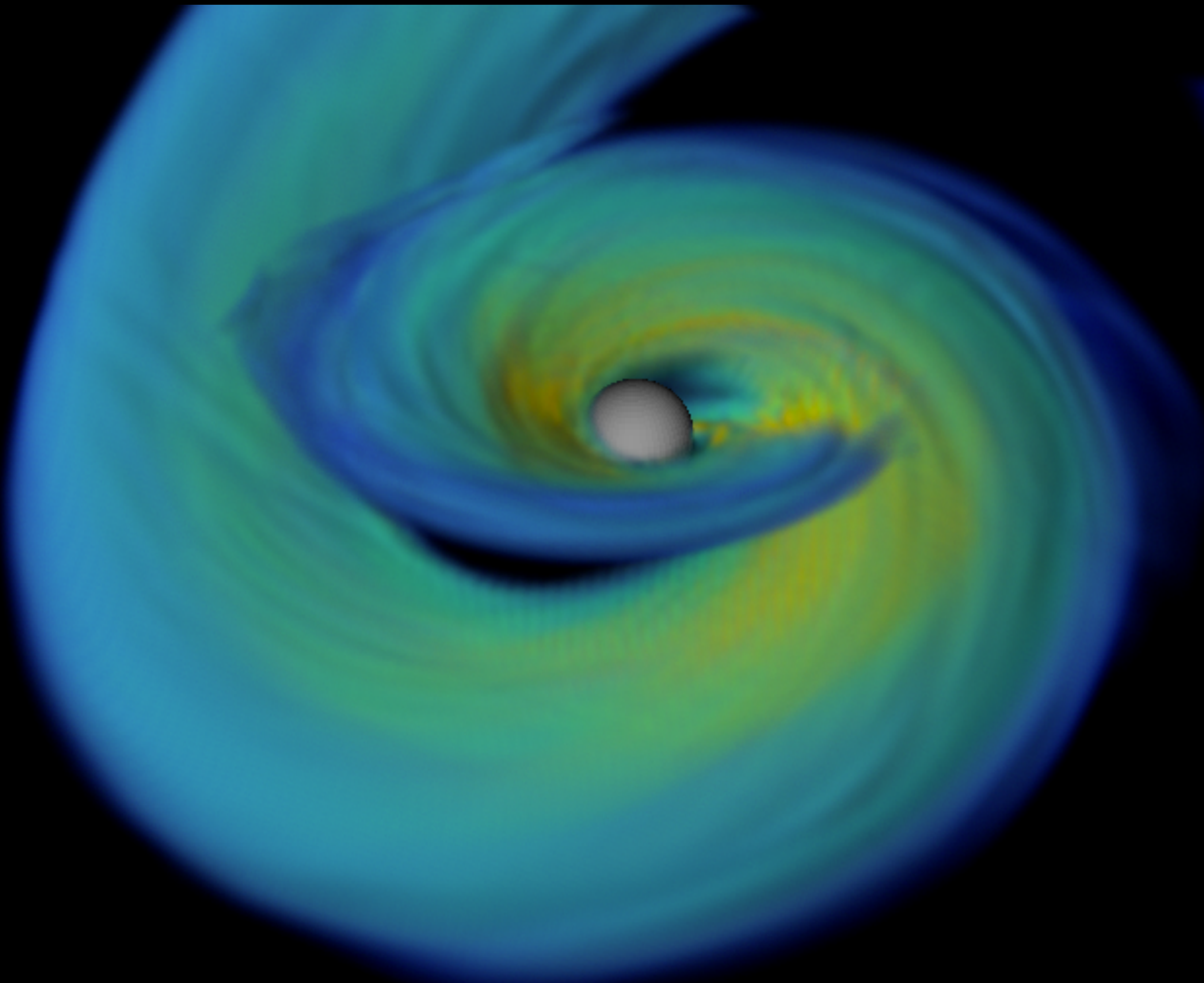
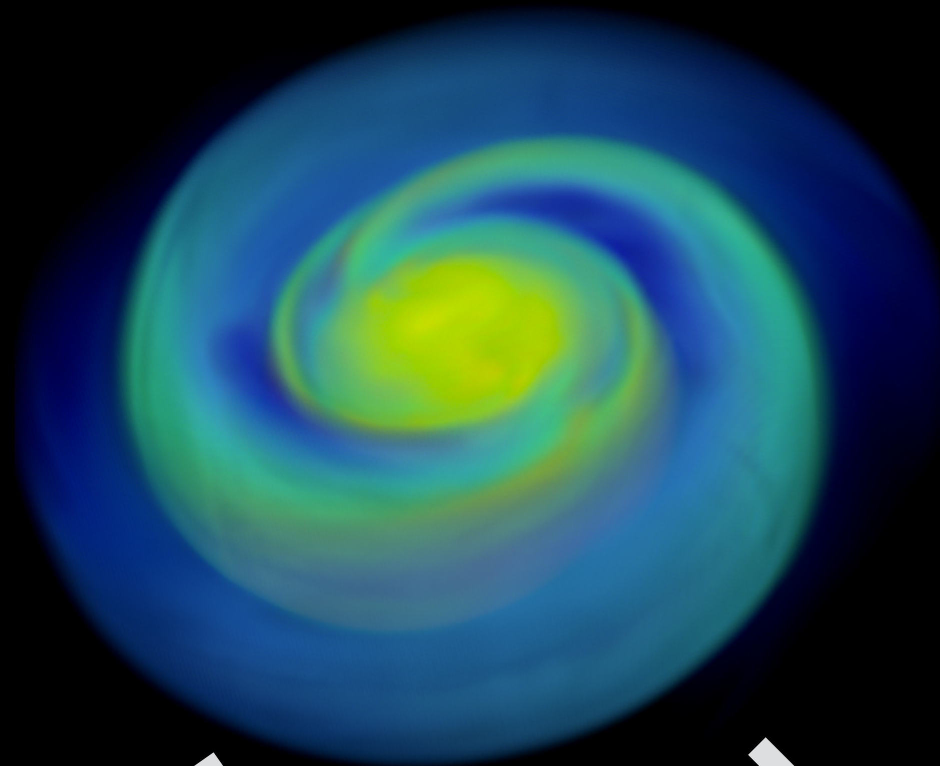
Numerical Simulations of Merging Black Holes and Neutron Stars



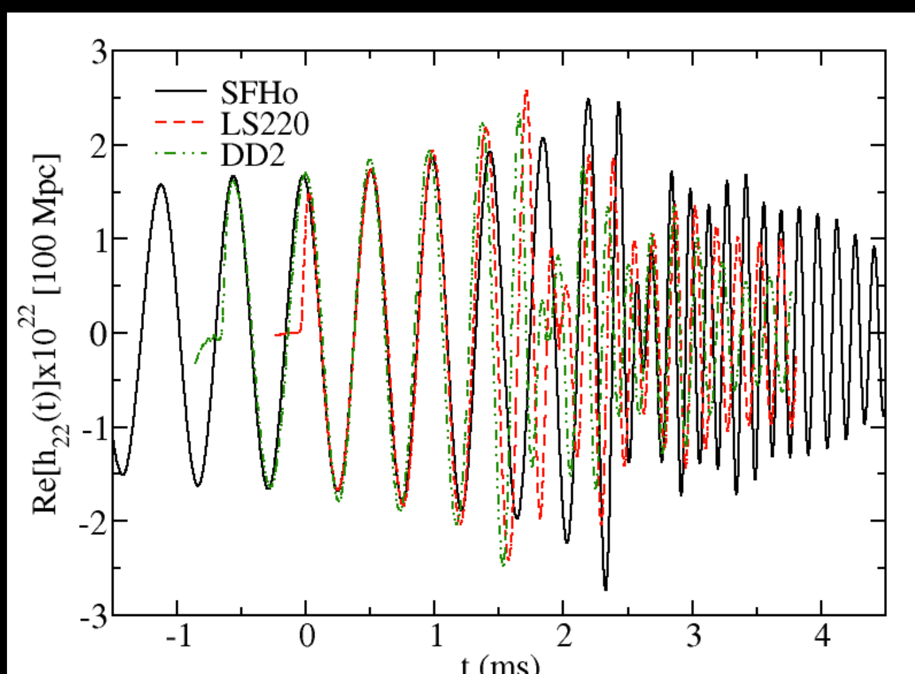
Francois Foucart (LBNL, Einstein Fellow)
SxS Collaboration

Einstein Fellows Symposium
Oct 19th 2016

Neutron Star Mergers : Extreme Astrophysical Laboratories



Gravitational Waves



r-process / IR transients

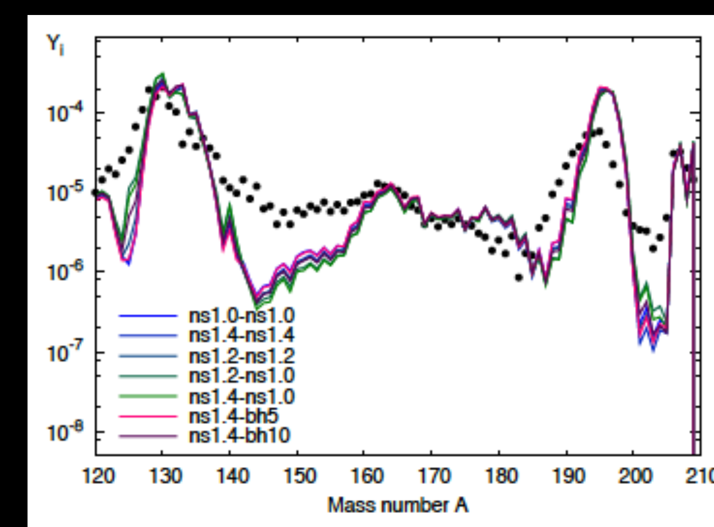
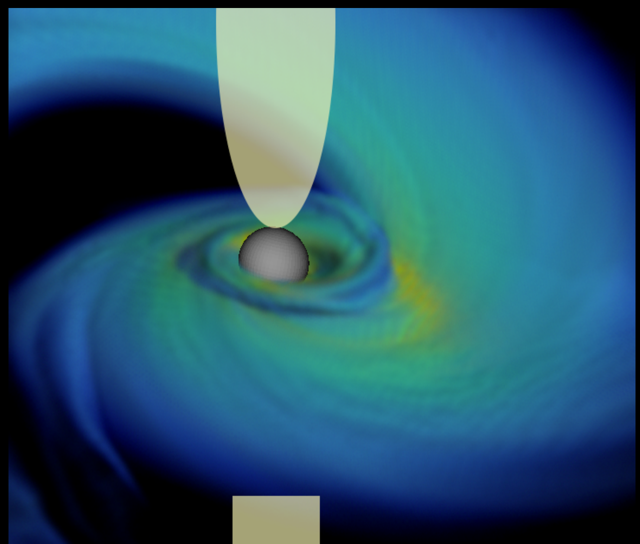


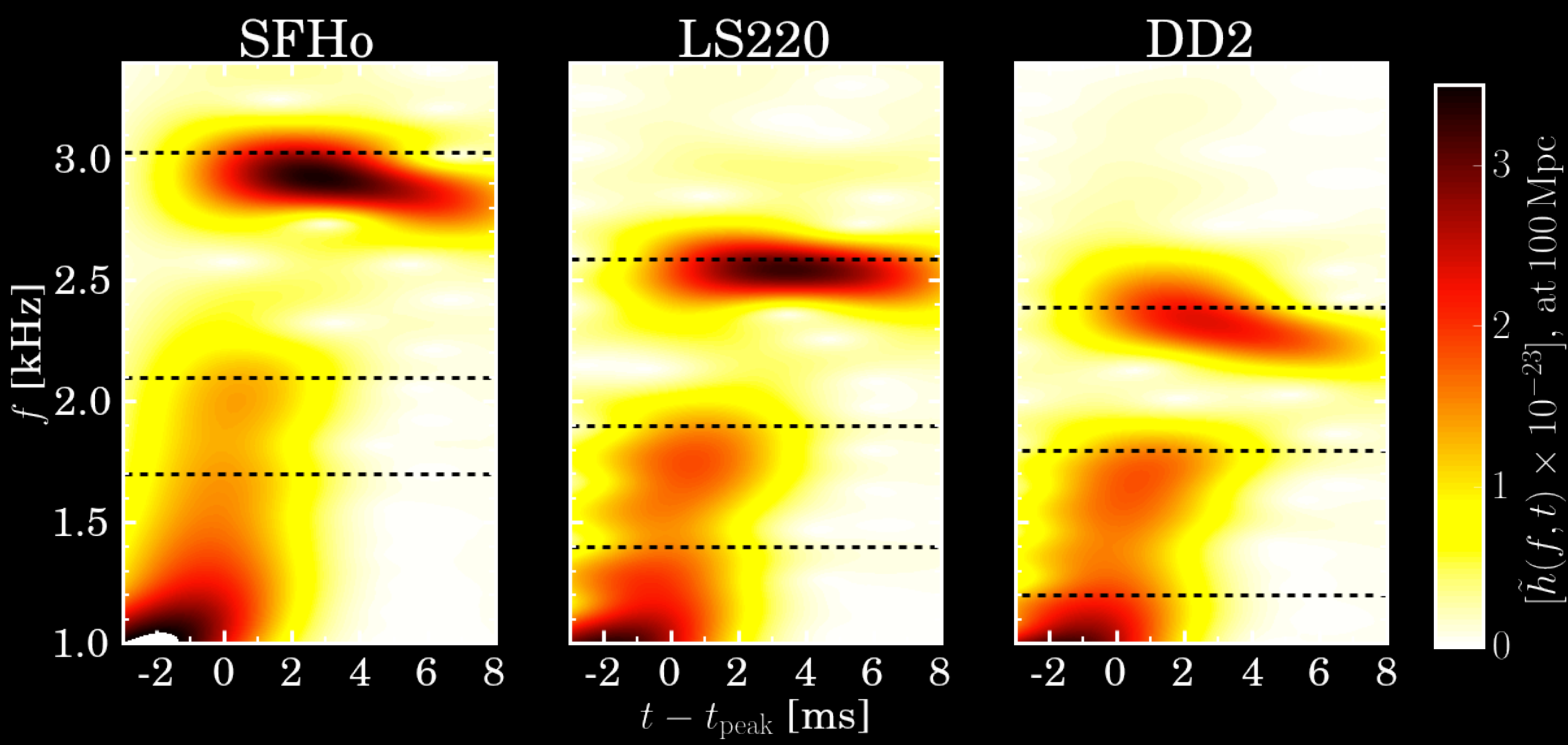
Image: Korobkin et al. 2012

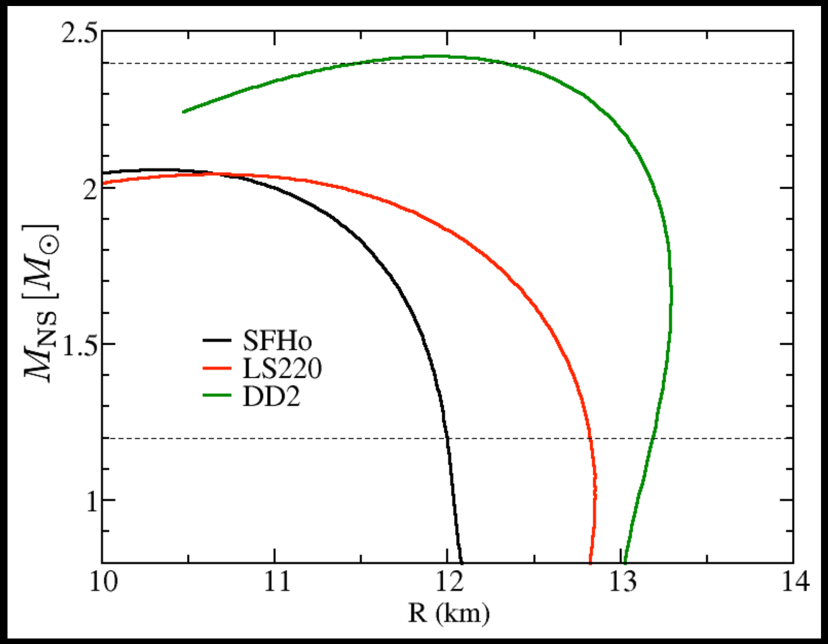
Short Gamma-ray bursts



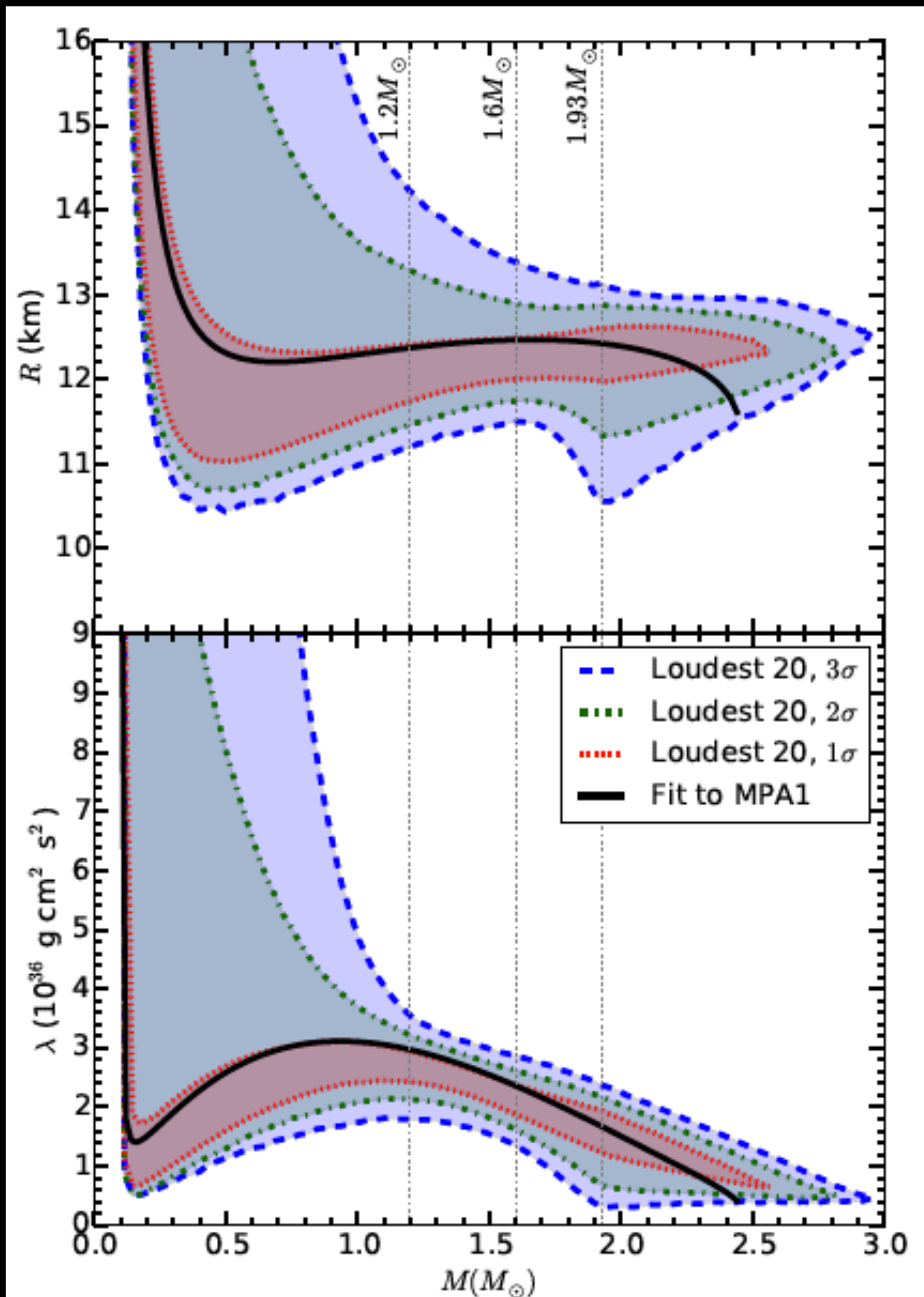
What can we learn from mergers?

Gravitational Waves:
Test General Relativity
Measure NS/BH mass & spin distributions
Constrain nuclear physics through NS equation of state





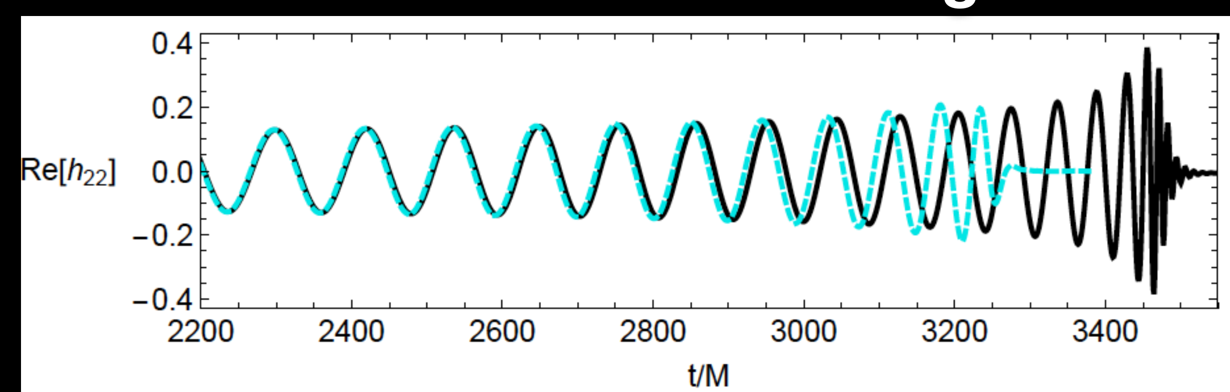
Finite size effects: inspiral



Tides in neutron stars cause large stars to merge faster!

1 yr of `*typical*' LIGO data
➡
Radii measured to ~10%

BH-BH vs BH-NS merger



Important caveat:
Assumes perfect waveform model

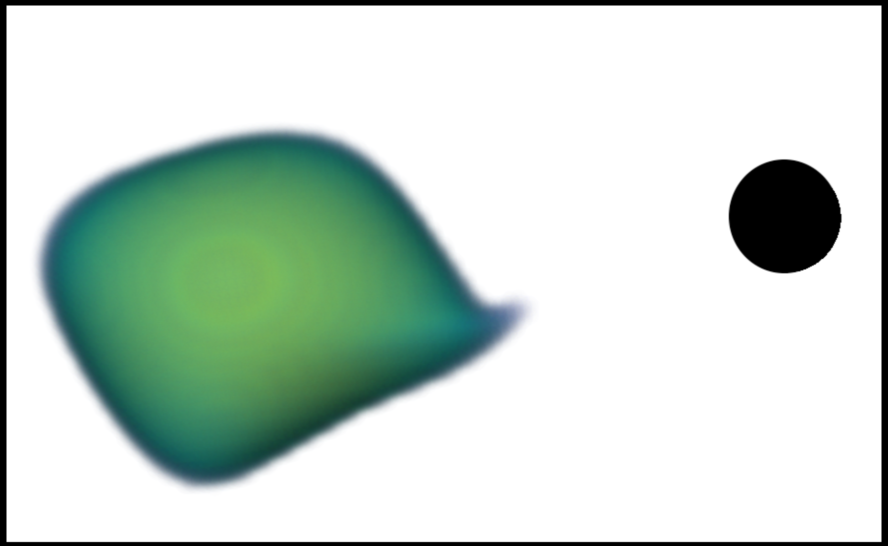
Image: Lackey & Wade 2015, see also Del'Pozzo et al. 2013

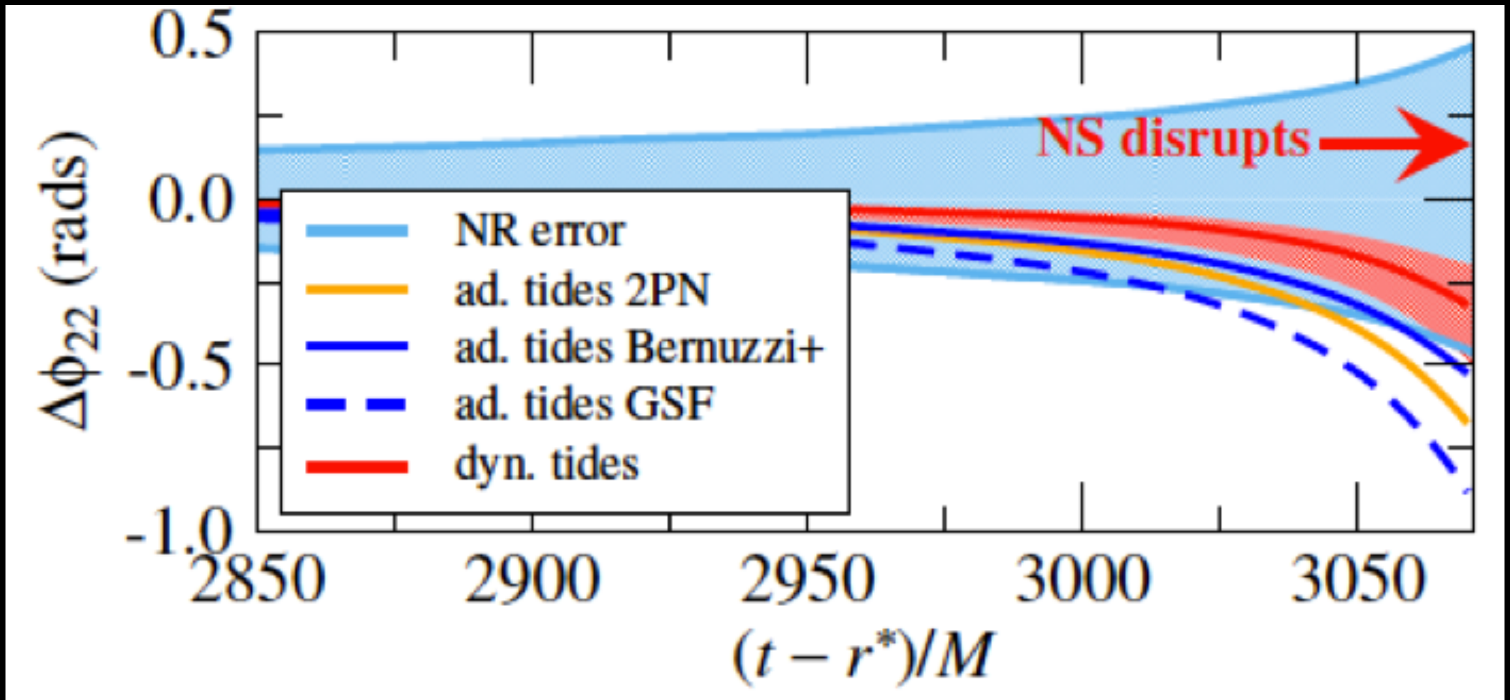
Inspiral models: Current status

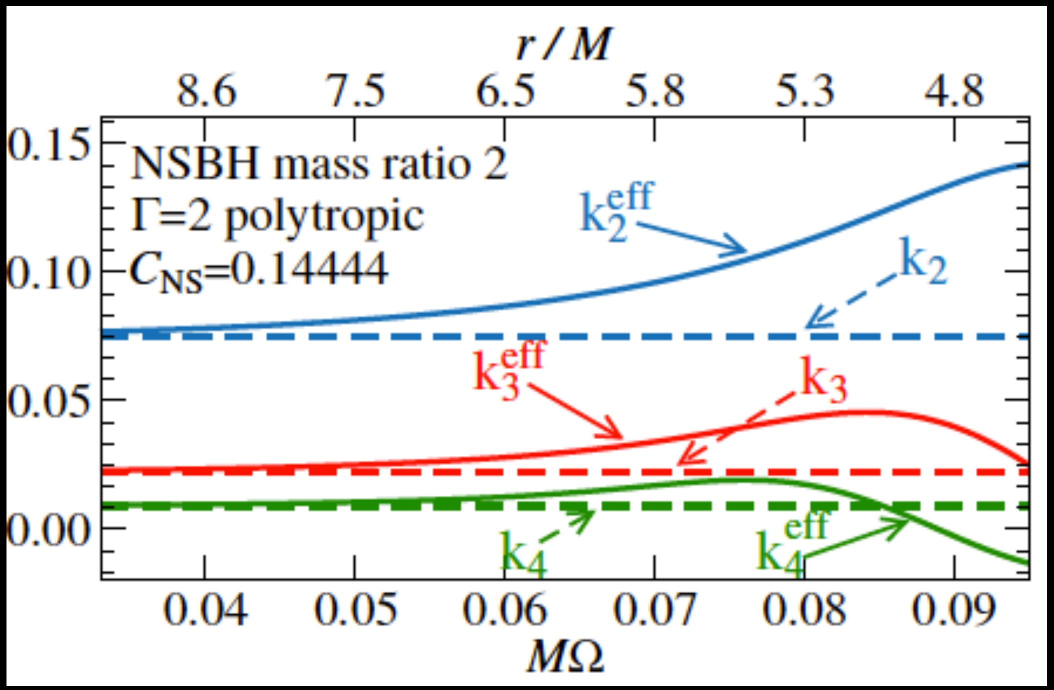
Build semi-analytical model (e.g. Effective One Body)

Perform high-accuracy numerical simulations

Calibrate model parameters



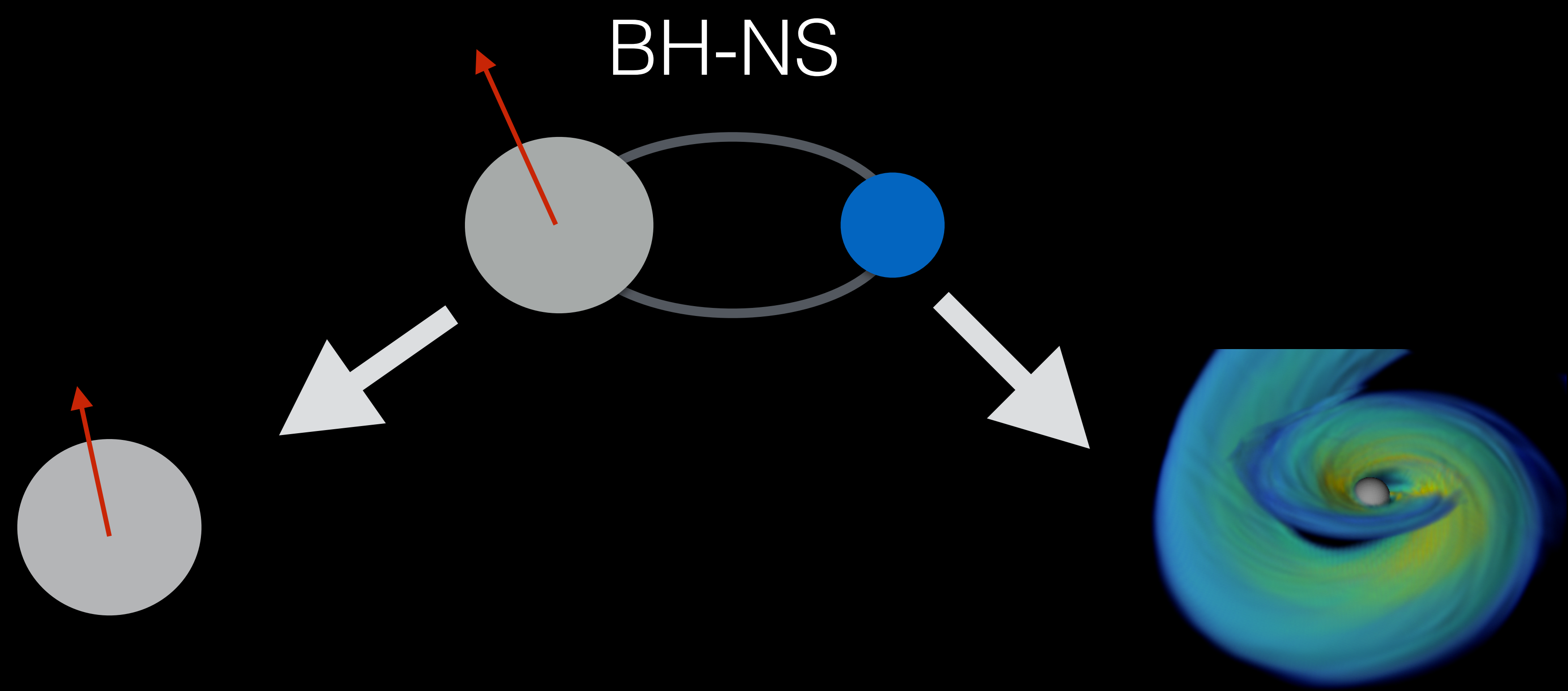




Hinderer, ..FF et al. 2016

What can we learn from mergers?

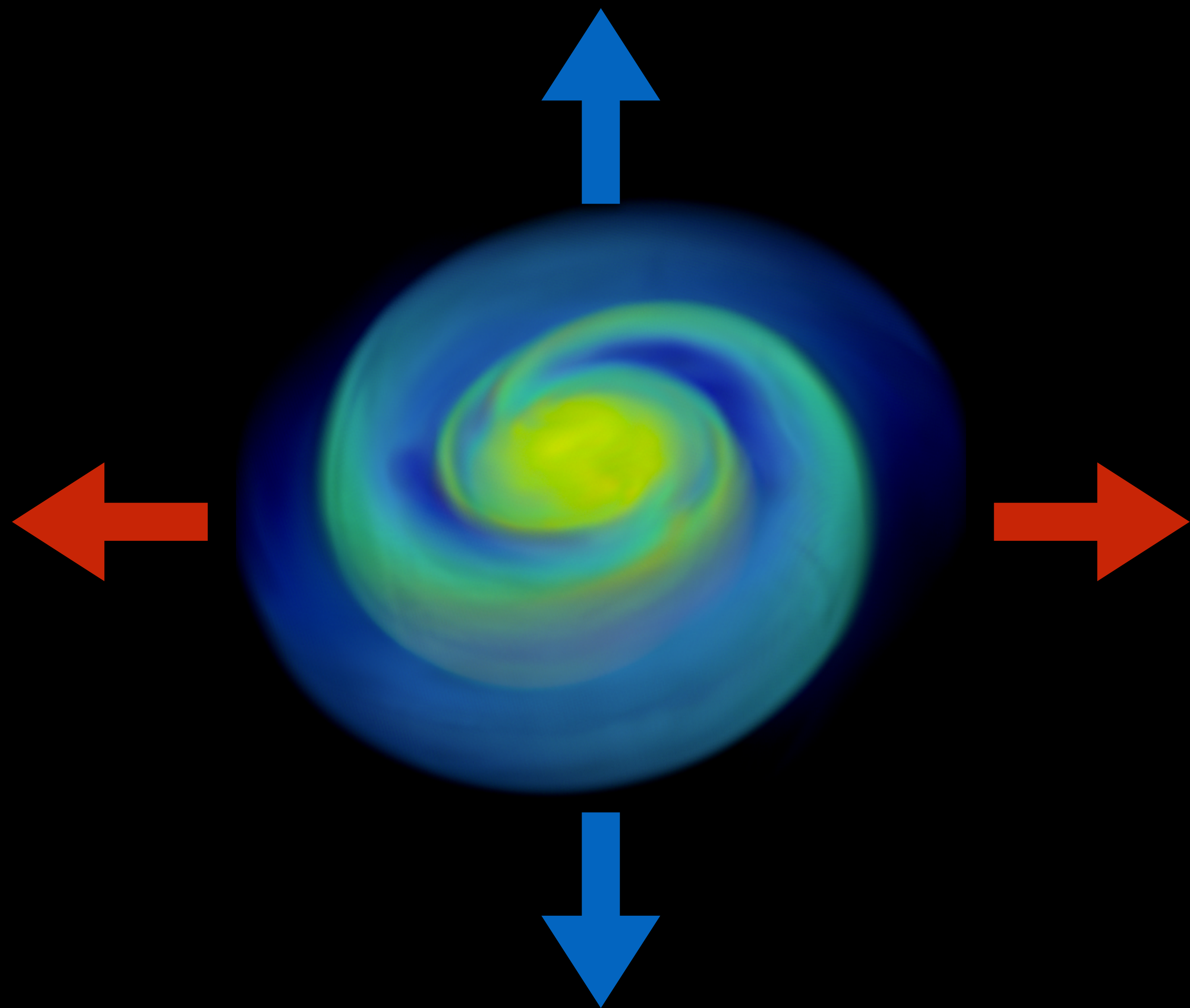
EM signals (SGRB, kilonova):
Demonstrate origin of SGRBs
Estimate contributions to r-process elements production
Merger environment: host galaxy, ISM density
Independent constraints on NS/BH properties



No post-merger EM signals

Potential post-merger EM signals

Types of merger ejecta and neutrino effects



<u>Tidal Ejecta</u>

Cold, mostly neutrons

<u>Favored by:</u>

Large stars

Asymmetric mergers

<u>Shocked Ejecta</u>

Hot, less neutrons

Only for NS-NS

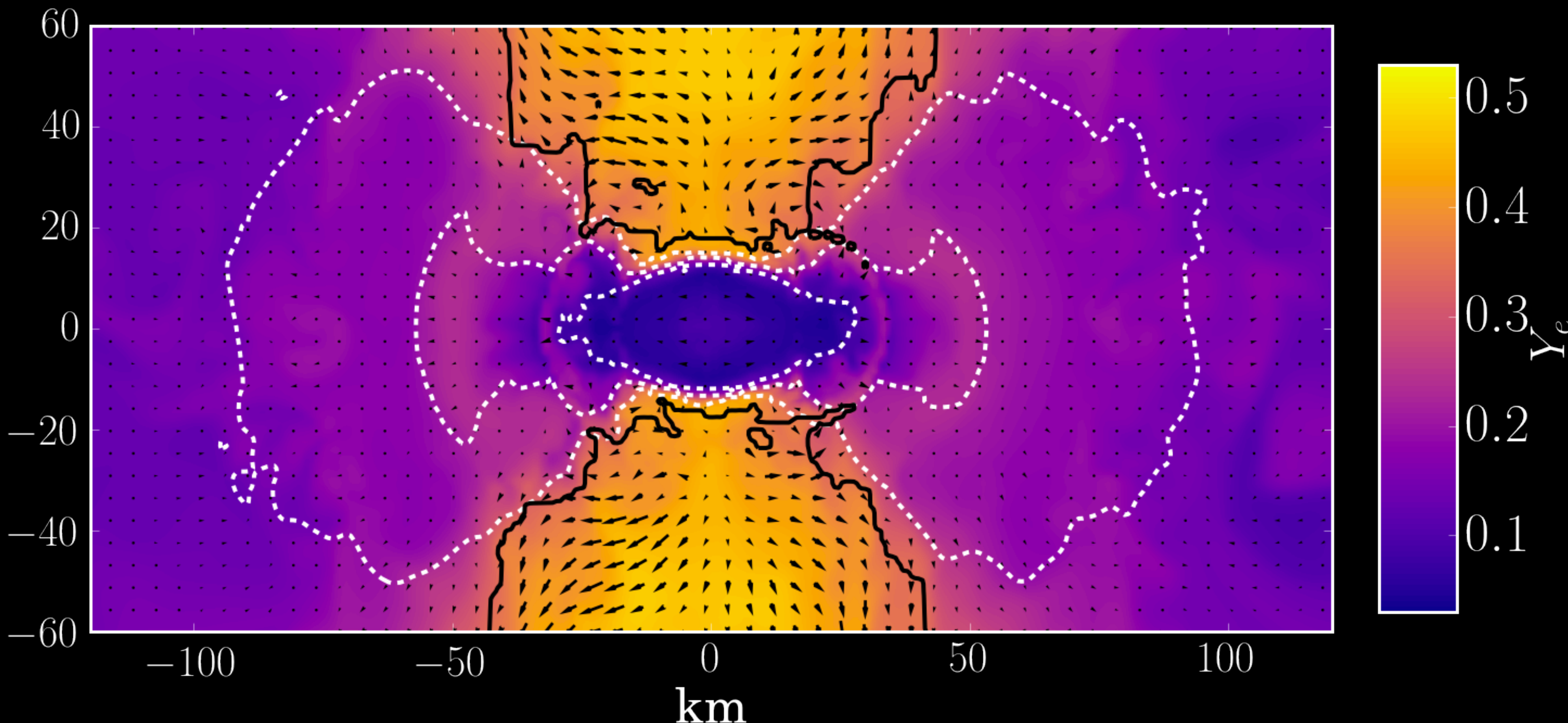
Favors small radii

<u>Post-Merger Disks:</u>

Winds (B-fields, ν)

Strong ν effects

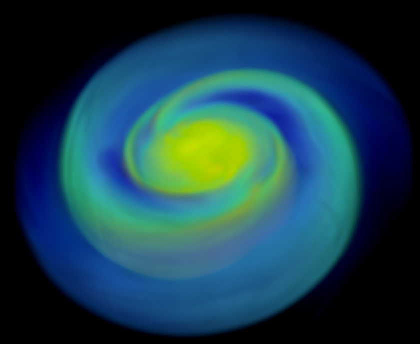
Dynamical ejecta: Always neutron rich (Y_e ~ 0.05)
Shocked ejecta / wind: Neutrino absorption drive Y_e up



Neutron rich (Y_e<0.25) : produce heavy r-process elements (A~120-210) [IR transient]
Otherwise : produce lower mass r-process elements (A~90) [Optical transient]

From simulations to observables:

Full GR simulations



Long disk evolutions (fixed metric)

Outflow models

Light curves (3D radiation transport)

r-process (nuclear reaction network)

Critical improvement:
Realism of simulations

Conclusions

- Wide range of physical effects can be studied through BH-NS / NS-NS mergers
- Merger dynamics and outcome can only be studied with general relativistic simulations
- Good qualitative understanding of merger dynamics
- Improving waveform models for NS, still need to reduce systematics for upcoming LIGO detections
- Post-merger evolution requires detailed, complex microphysics, and is still work in progress