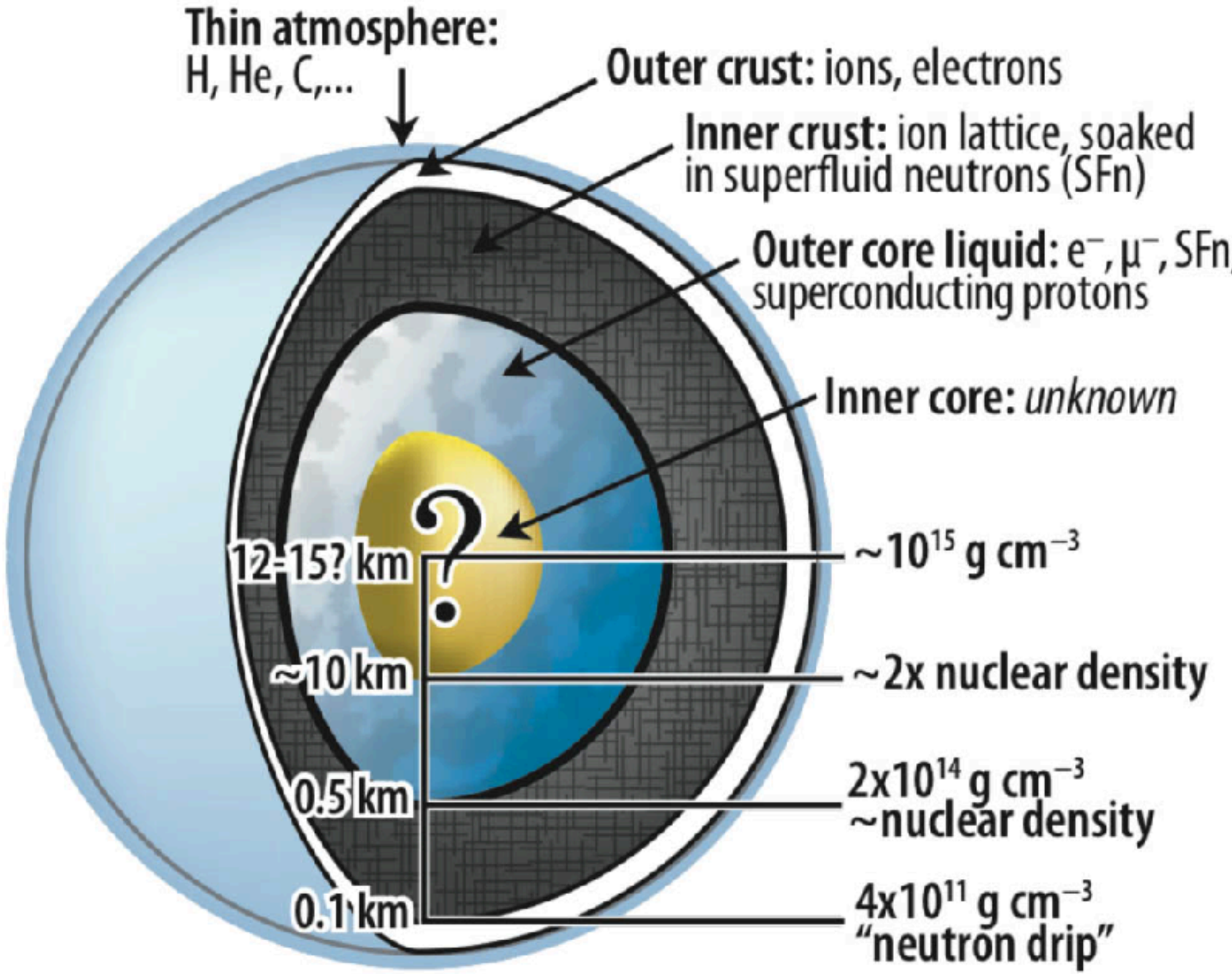
Numerical Modeling of Binary Neutron Star Mergers

David Radice[1,2]

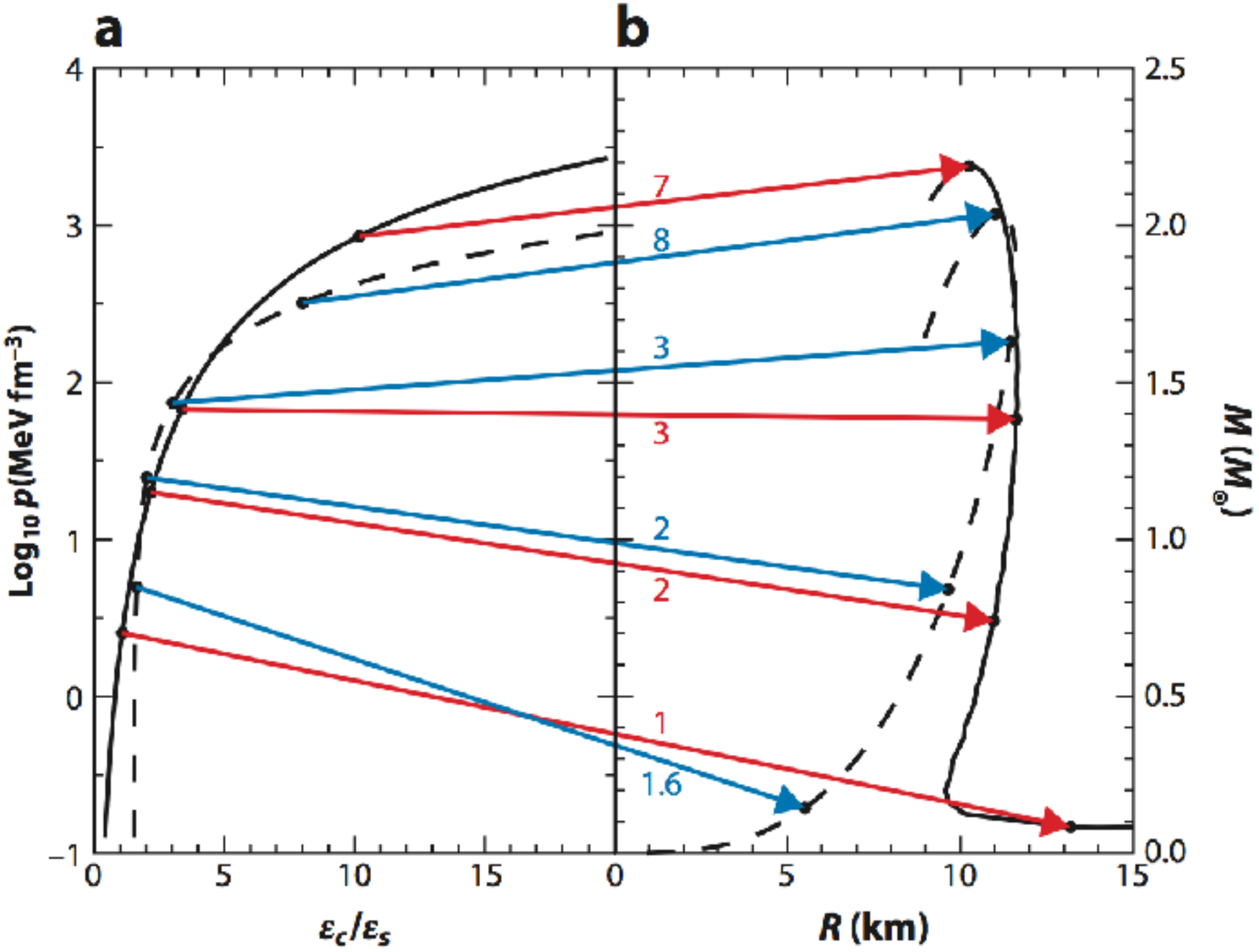
[1] Research Associate, Princeton University
[2] Taplin Member, Institute for Advanced Study

GW170817: The First Double Neutron Star Merger — KITP — Dec. 6, 2017



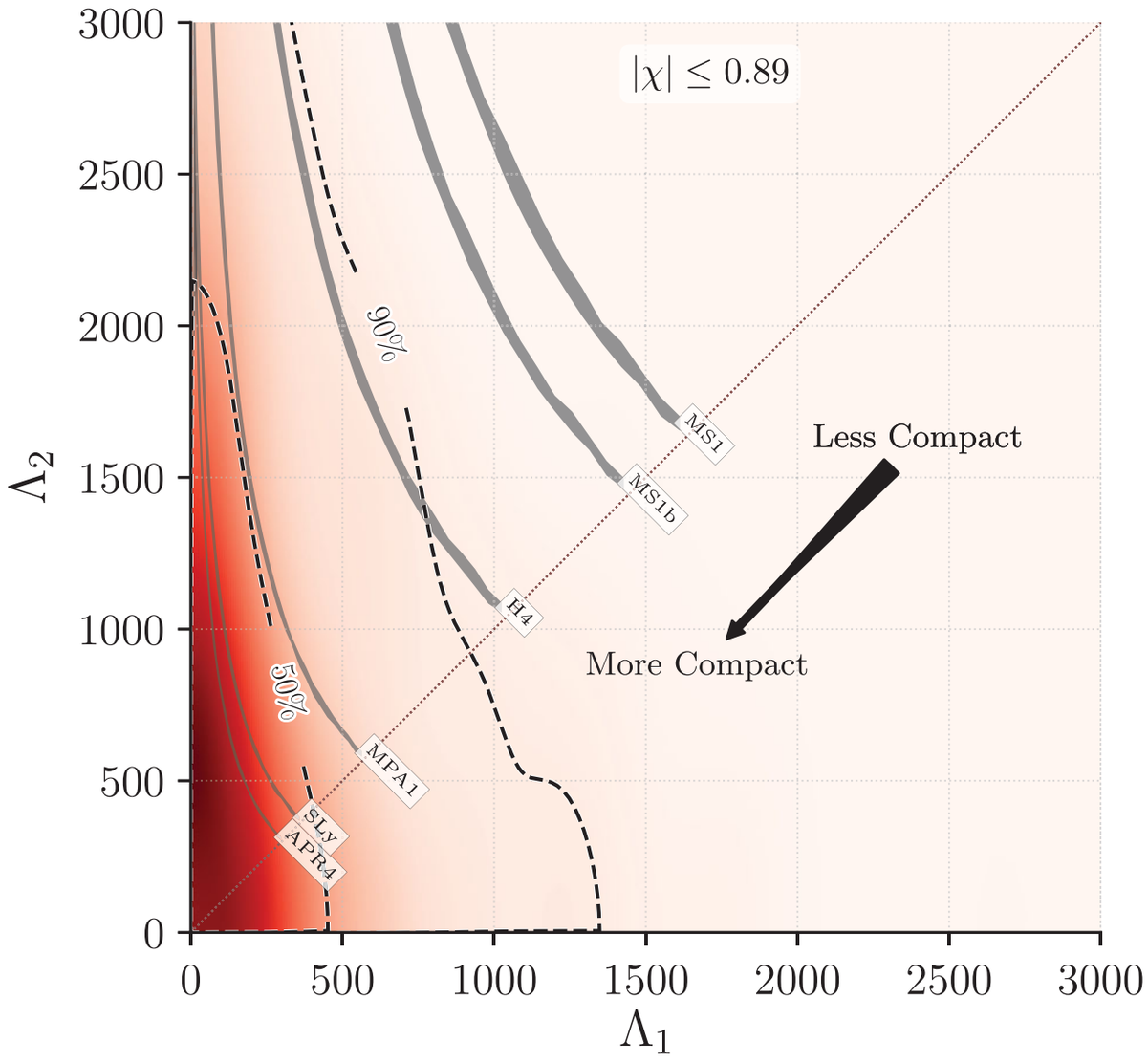
Credit: NASA/NICER

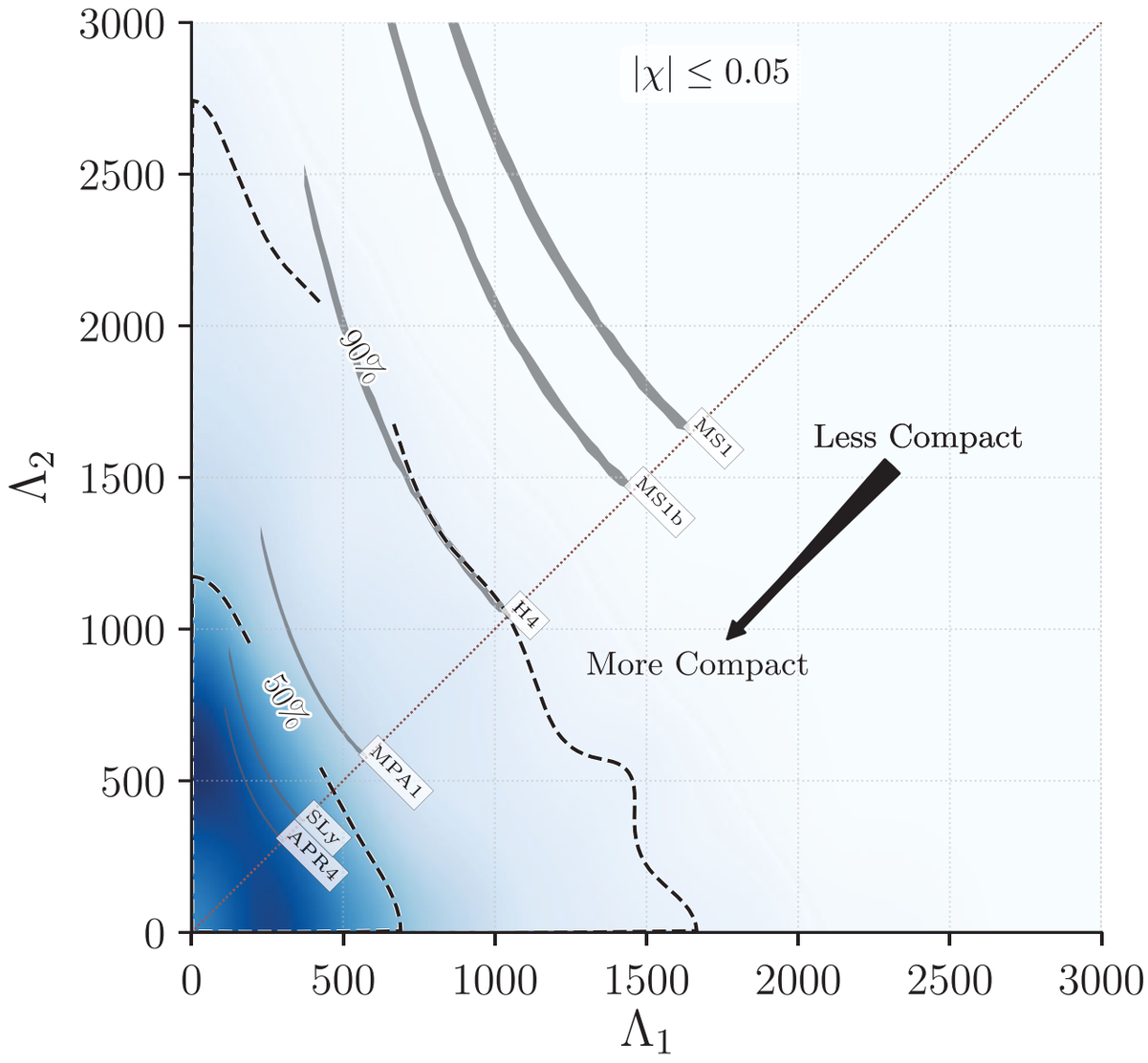
Neutron star equation of state



From Lattimer 2012

EOS constraints from GWs

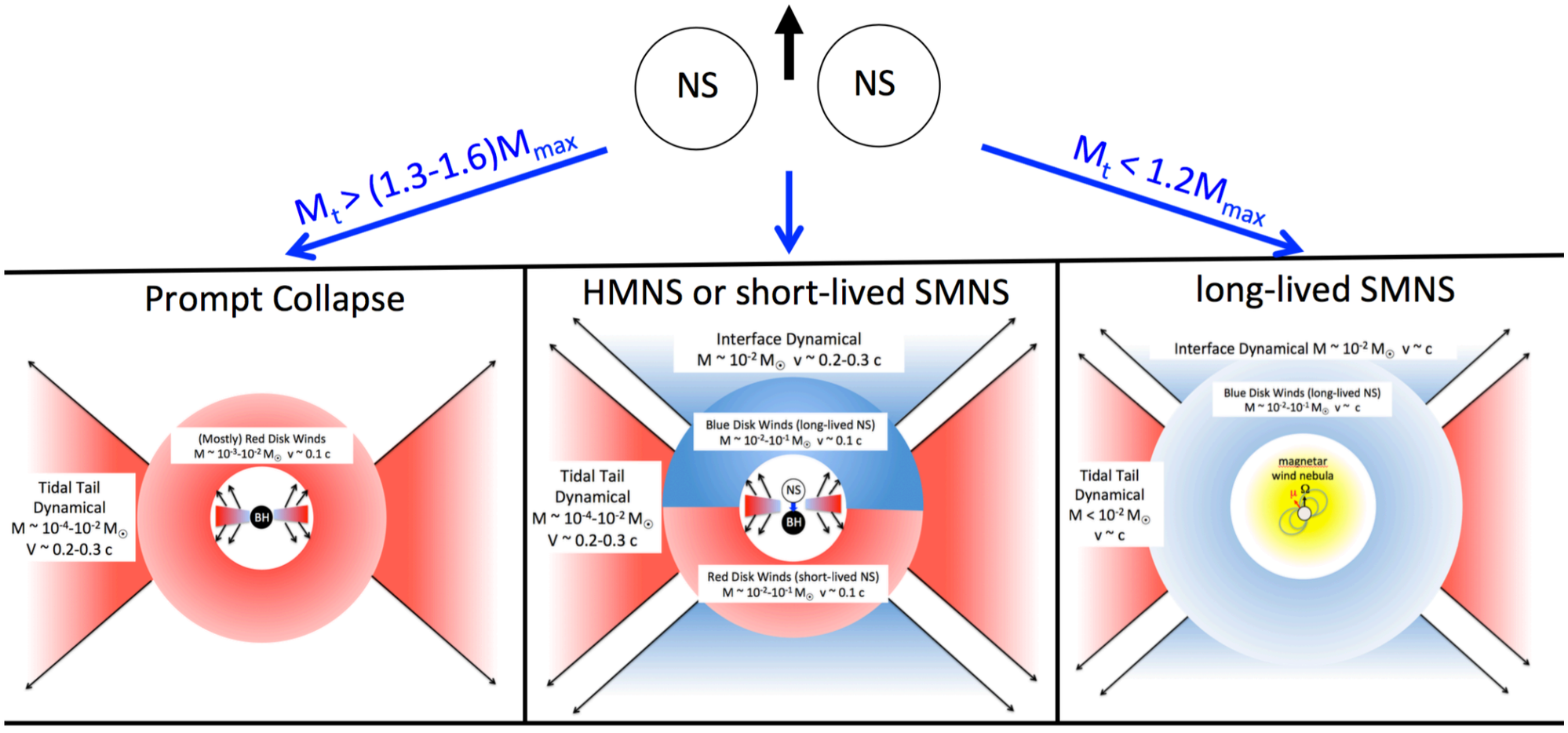




$$\tilde{\Lambda} = \frac{16}{13}\left[\frac{(M_A + 12M_B)M_A^4\tilde{\Lambda}_2^{(A)}}{(M_A + M_B)^5} + (A \leftrightarrow B)\right] \leq 800$$

From LIGO/Virgo collaboration, PRL 119, 161101 (2017)

EOS constraints from GW+EM



From Margalit & Metzger 2017

Assumption: no prompt BH formation —> EOS must be stiff enough

Assumption: no stable remnant —> EOS must soft enough

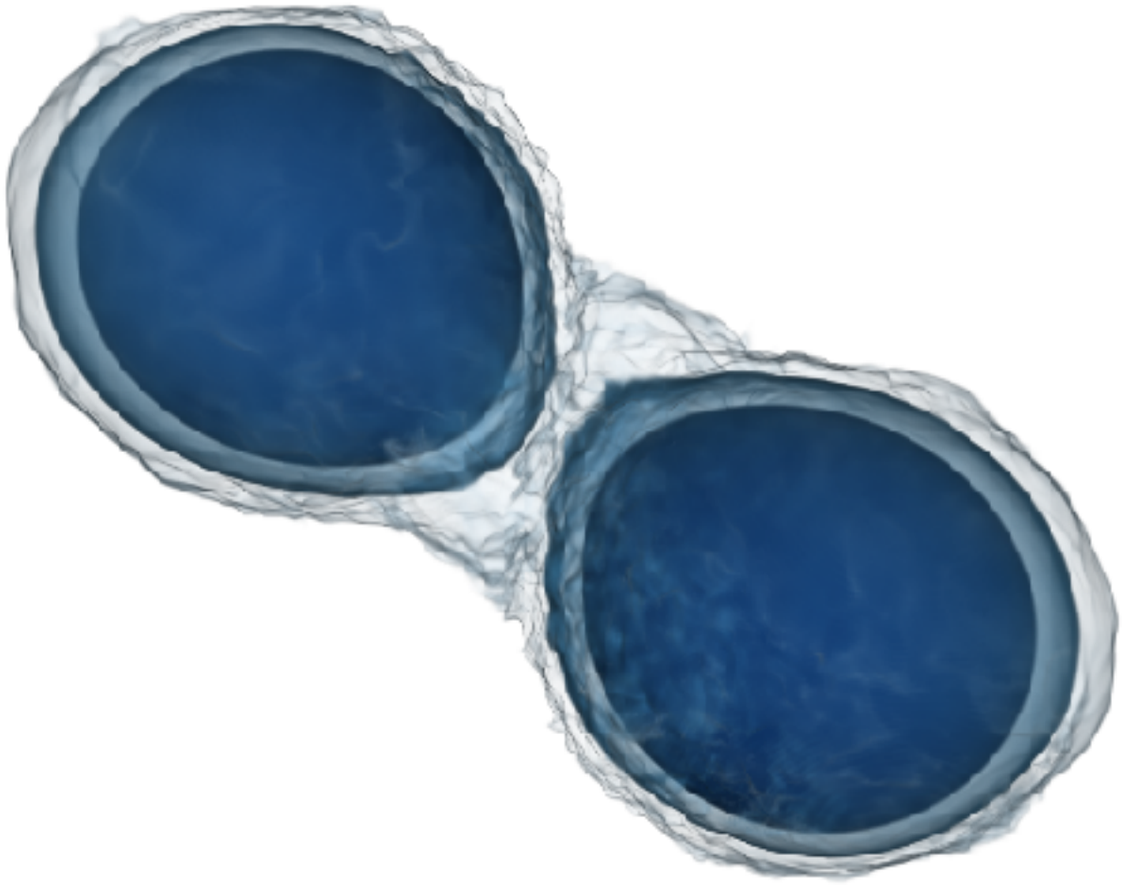
See also Bauswein+, Rezzolla+, Shibata+, Ruiz+ (2017)

Combine

EM+GW data with simulations

WhiskyTHC

http://www.astro.princeton.edu/~dradice/whiskythc.html



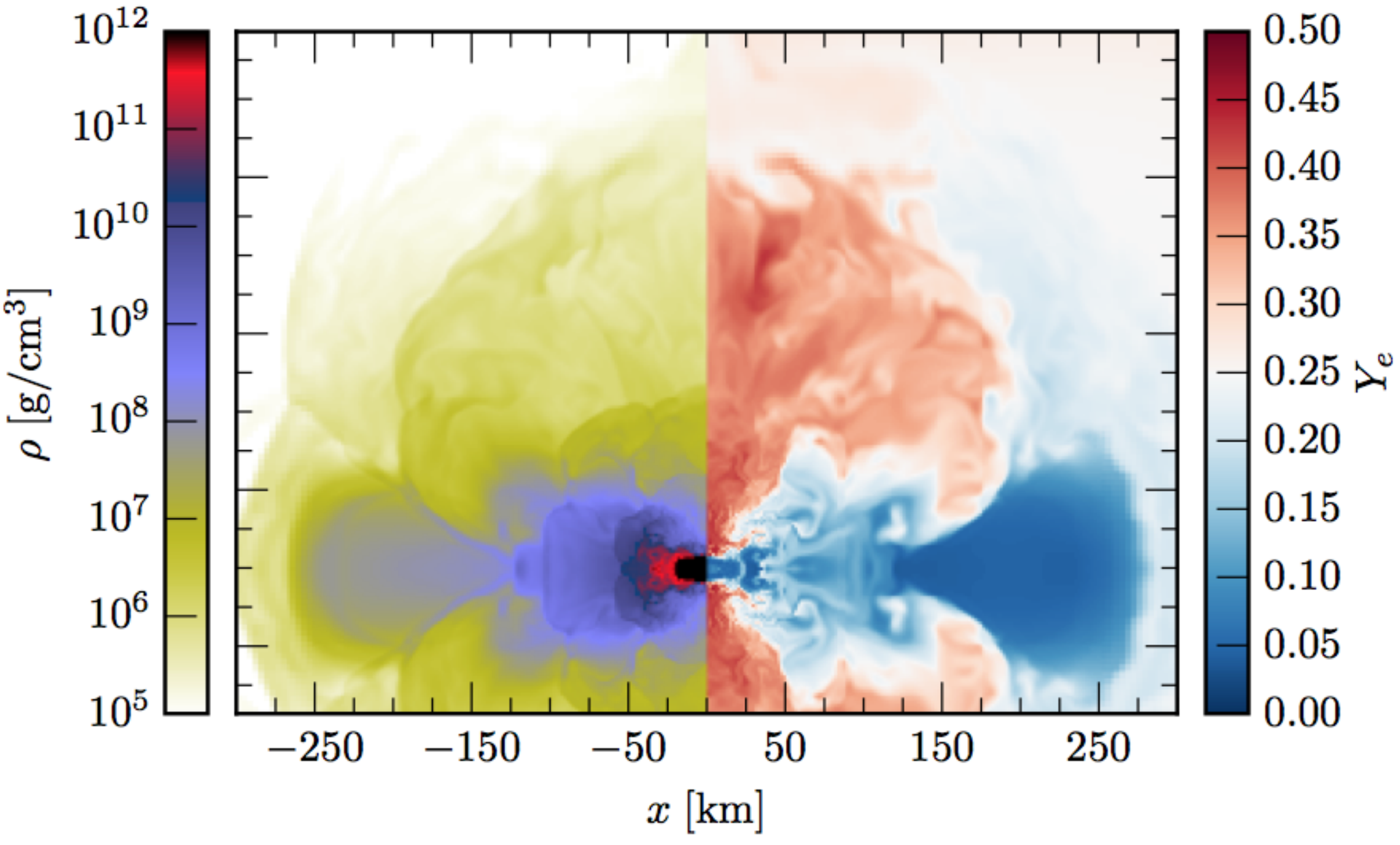
- Full-GR, dynamical spacetime*
- Nuclear EOS
- Effective neutrino treatment
- High-order hydrodynamics
- Open source!

* using the Einstein Toolkit metric solvers

THC: Templated Hydrodynamics Code

Volume
Var: HYDROBASE--Y_e
0.5
0.4
0.3
0.2
0.1
Time = 0 ms

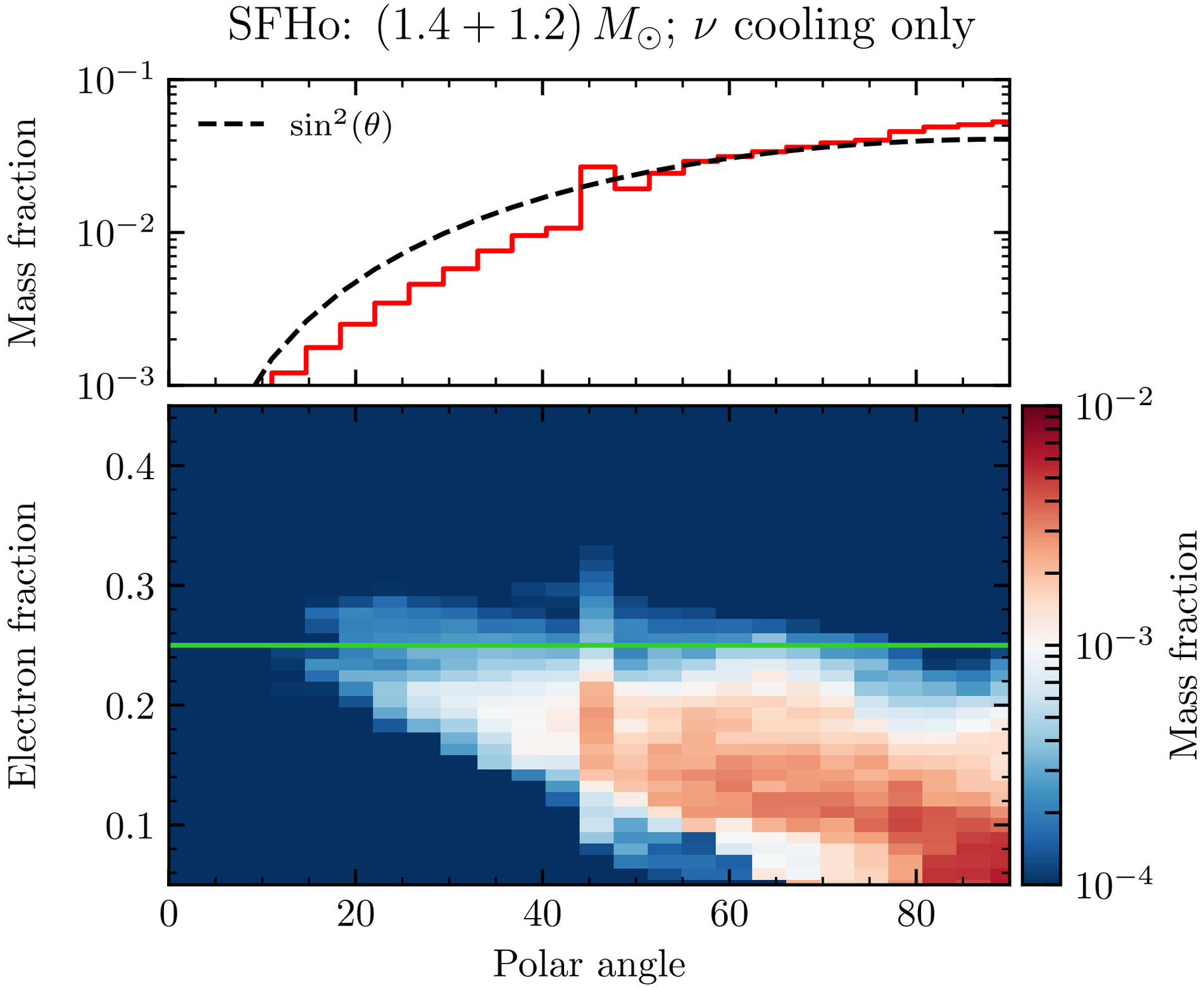
Neutron rich outflows



See also Wanajo+ 2014,
Sekiguchi+ 2015, 2016, Foucart+ 2016

DR, Galeazzi+ MRAS 460:3255 (2016)

Dynamic ejecta: role of neutrinos



Perego, **DR**, Bernuzzi, arXiv:1711.03982

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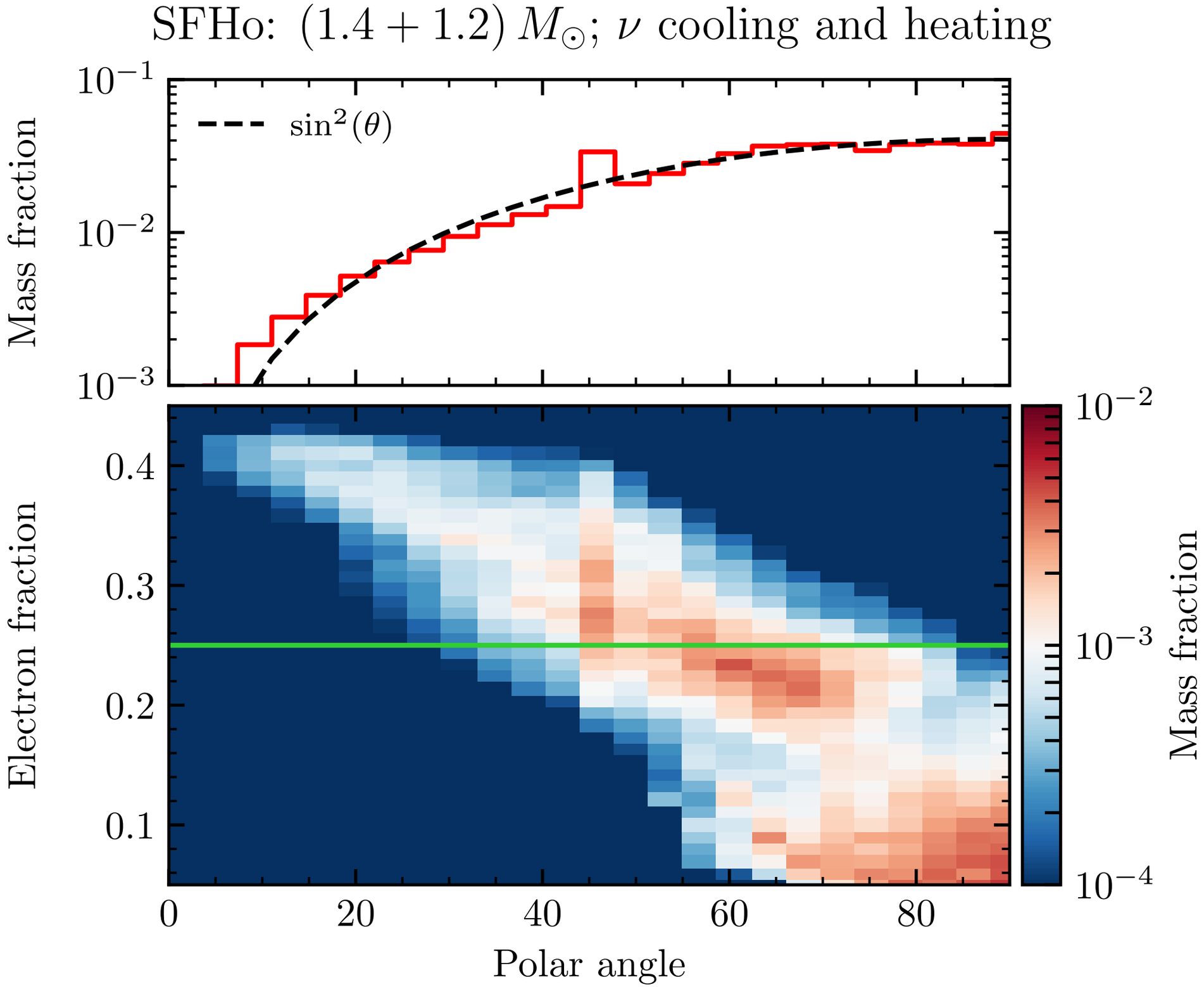
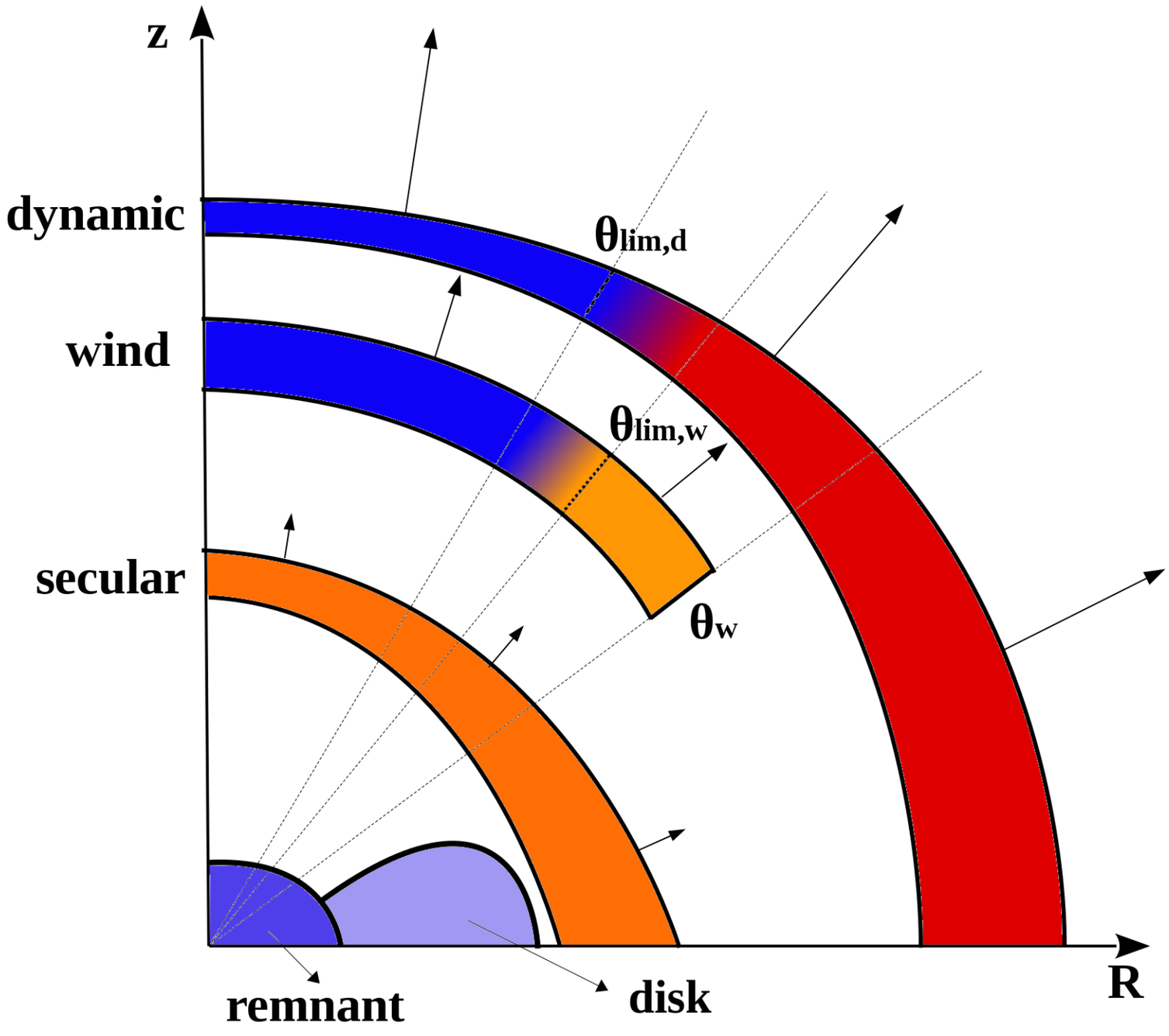


Perego, **DR**, Bernuzzi, arXiv:1711.03982

Neutron rich outflows: model



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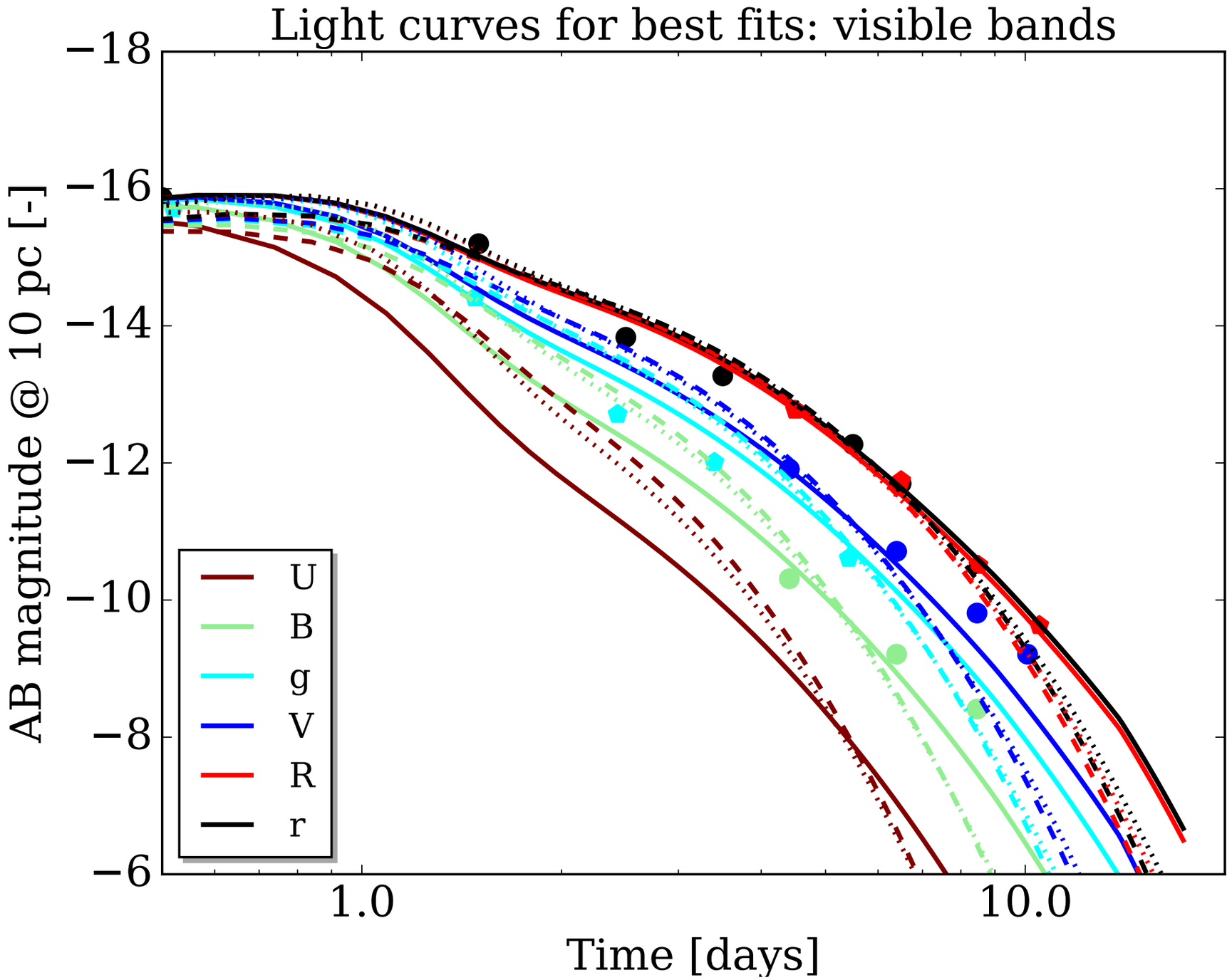
Kilonova modeling (I)



See also: Chornock et al. 2017; Cowperthwaite et al. 2017;
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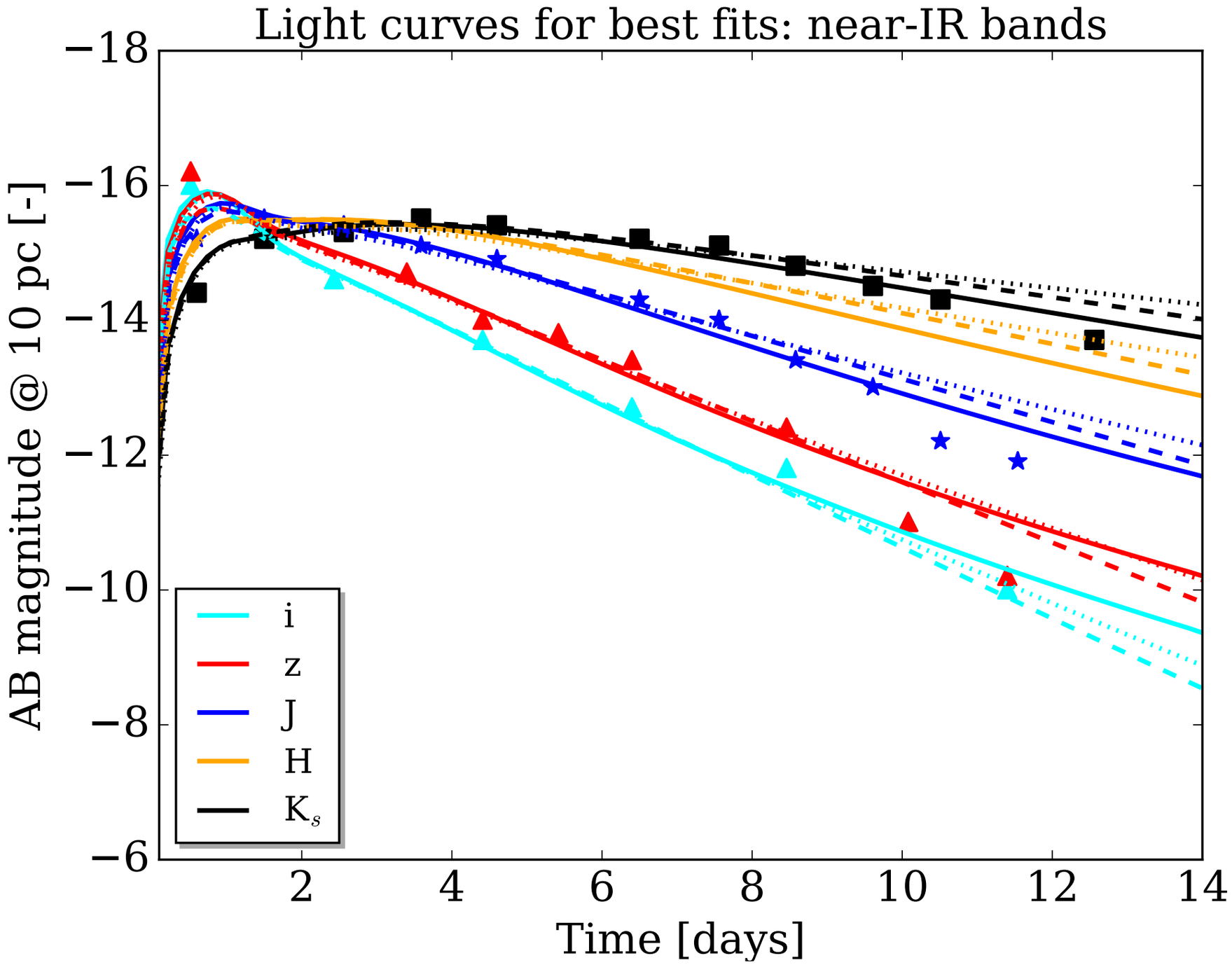
Kilonova modeling (II)



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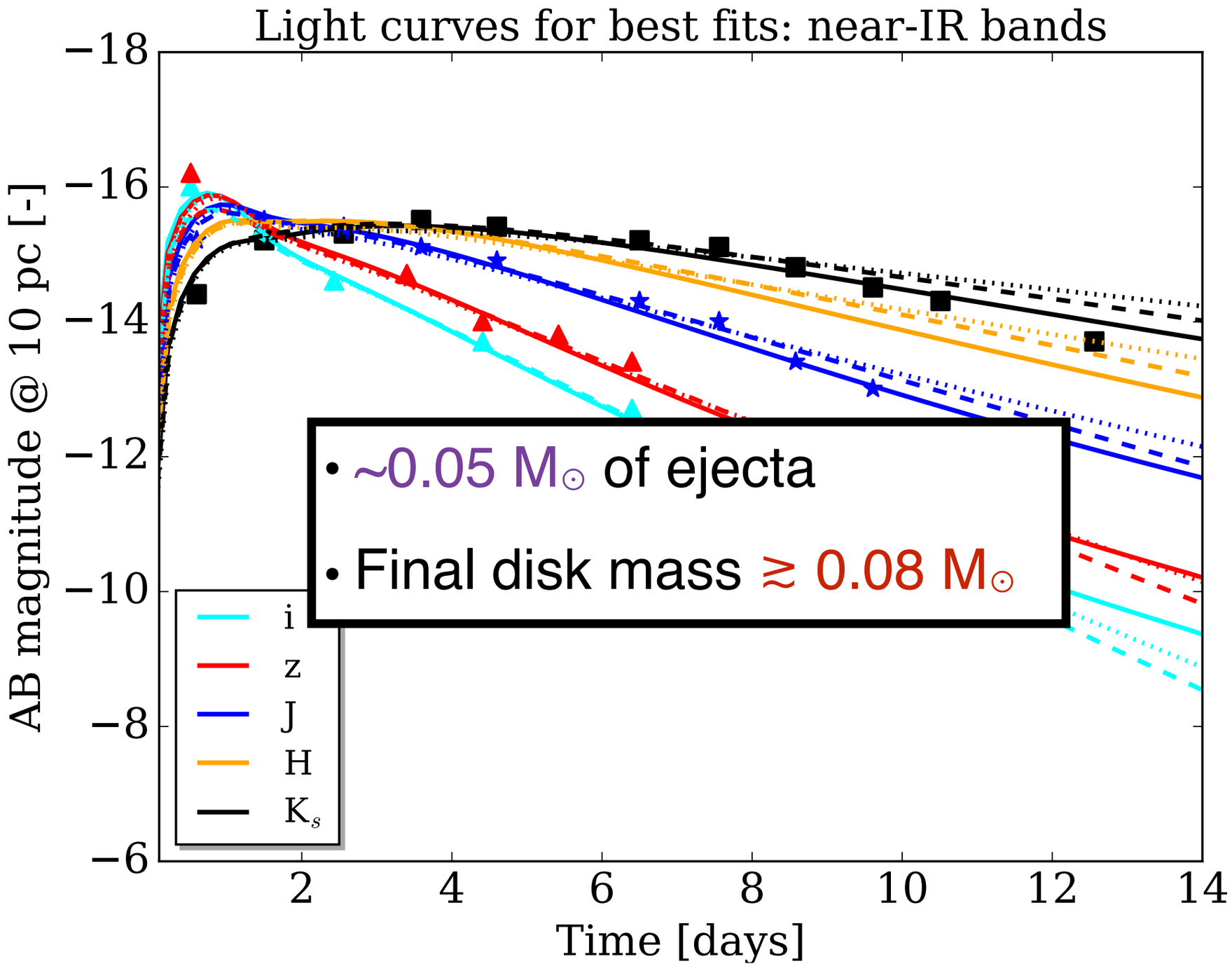

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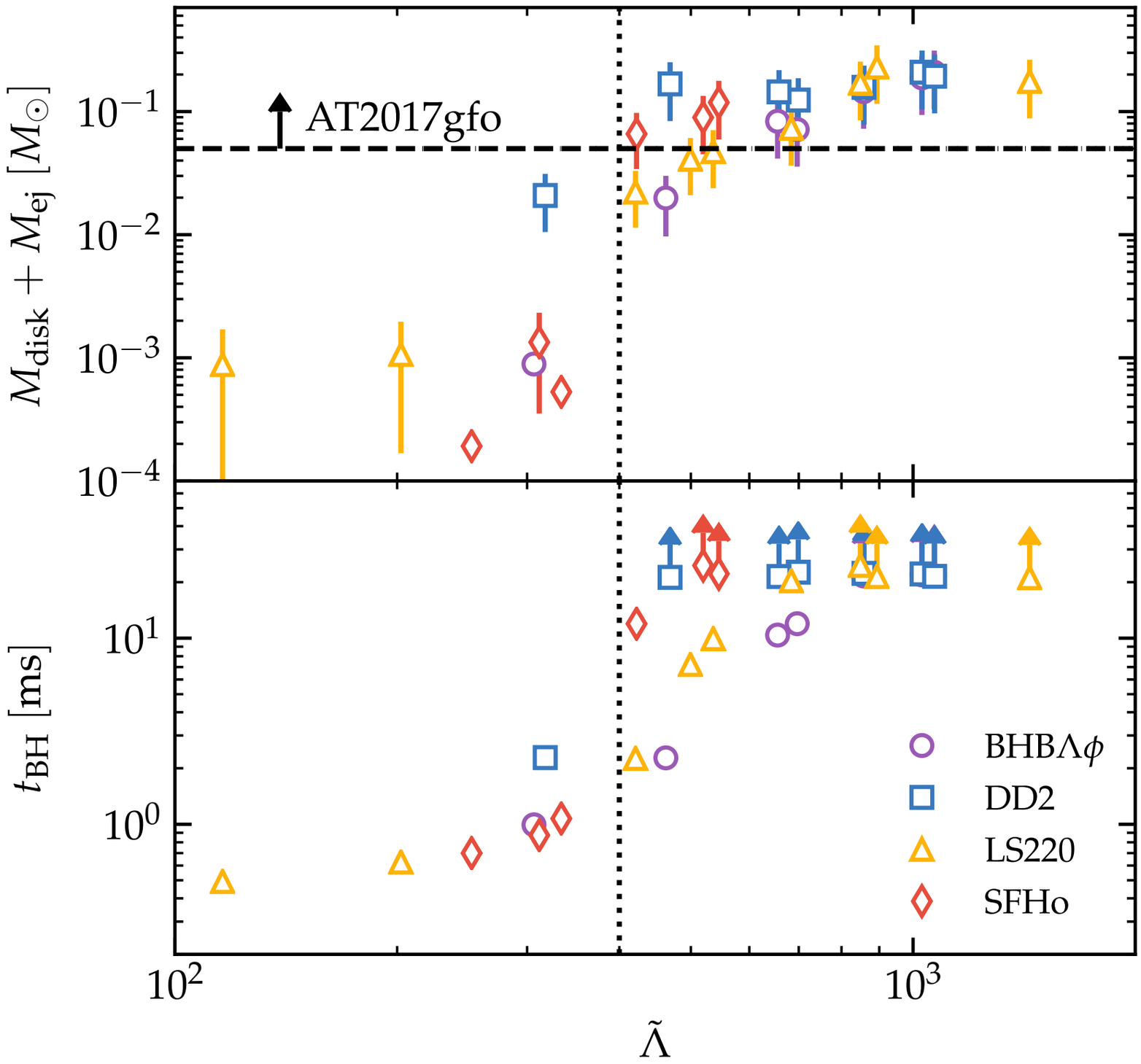
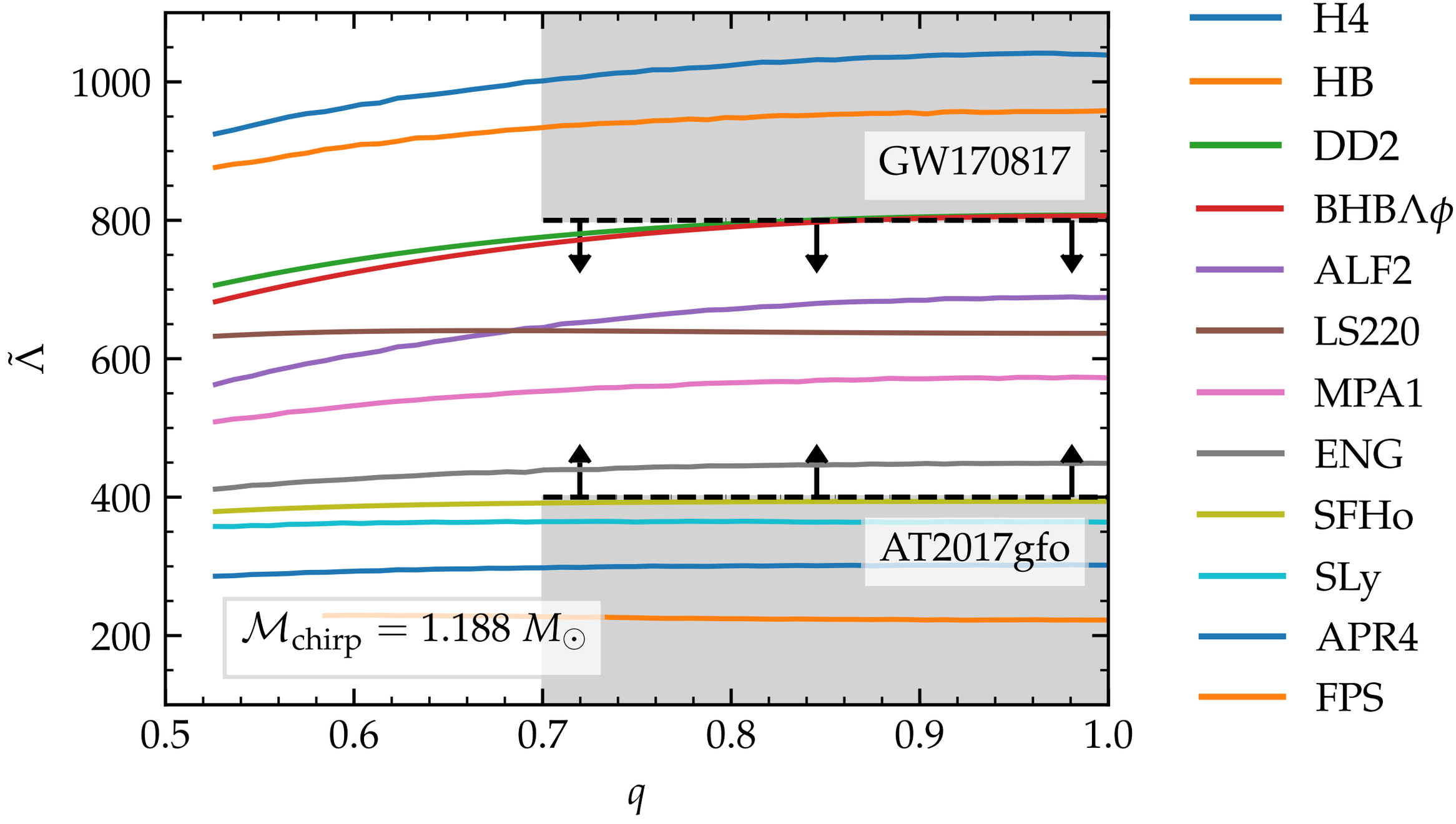
Simulation results



DR, Perego, Zappa, arXiv:1711.03647

NS EOS constraints



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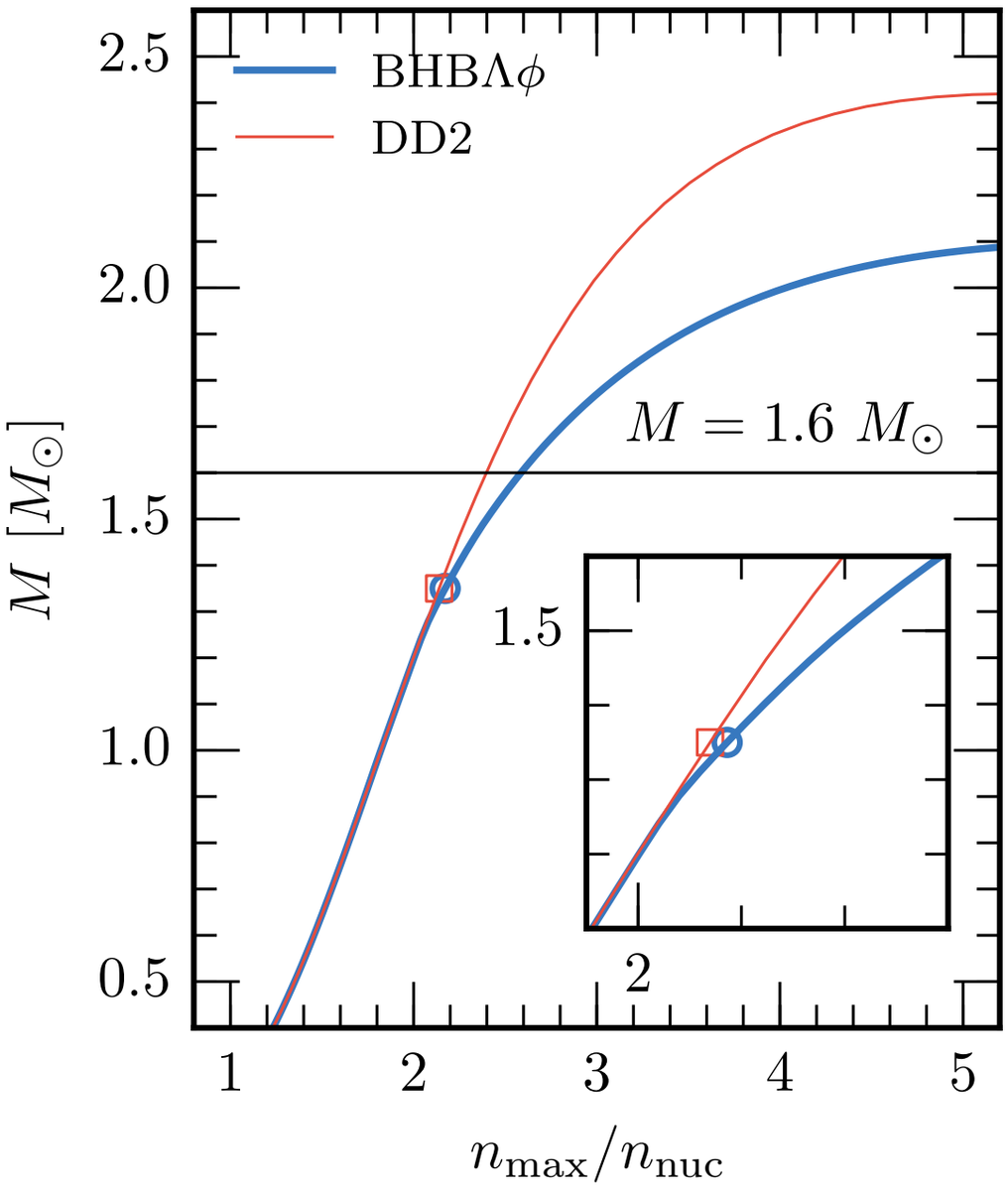
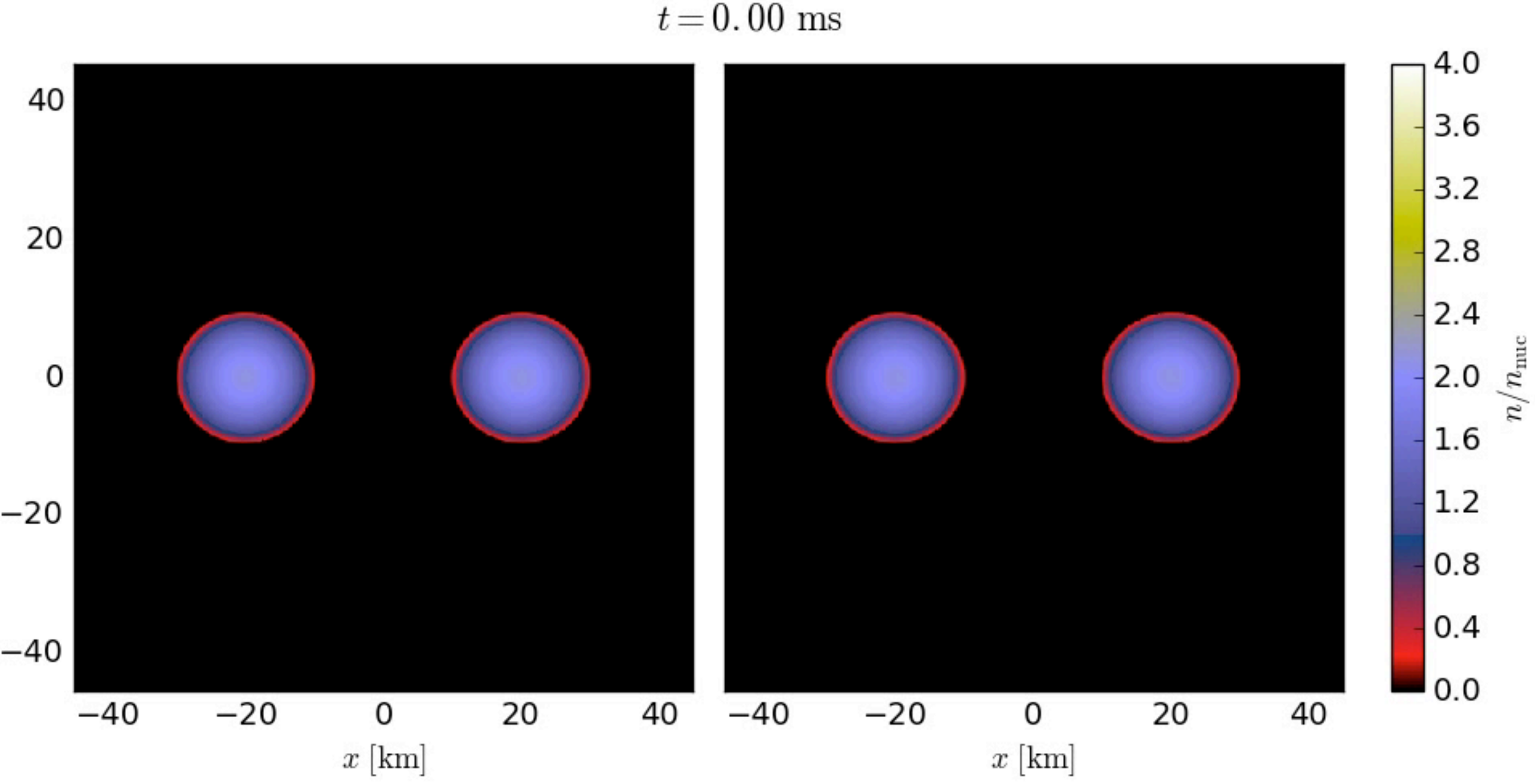
Extreme-density physics



- Same EOS at low density; softening at high density
- Typical binaries have the same $\tilde{\Lambda}$!
- Different compactness, collapse time of remnant
- Can we tell them apart? Yes with the postmerger!

DR, Bernuzzi, Del Pozzo+, ApJL 842:L10 (2017)

Effect on the evolution

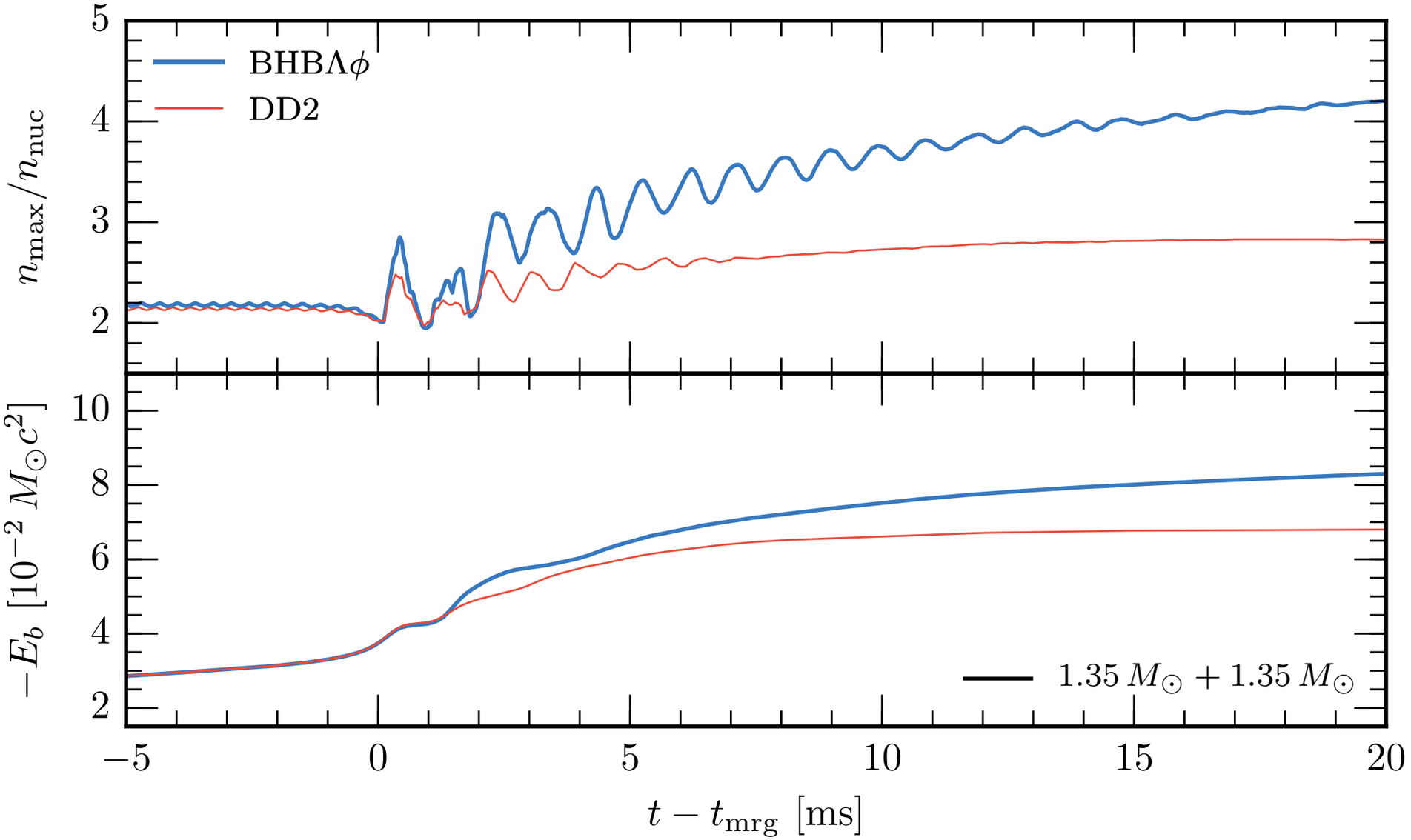


Hyperons

No Hyperons

DR, Bernuzzi, Del Pozzo+, ApJL 842:L10 (2017)

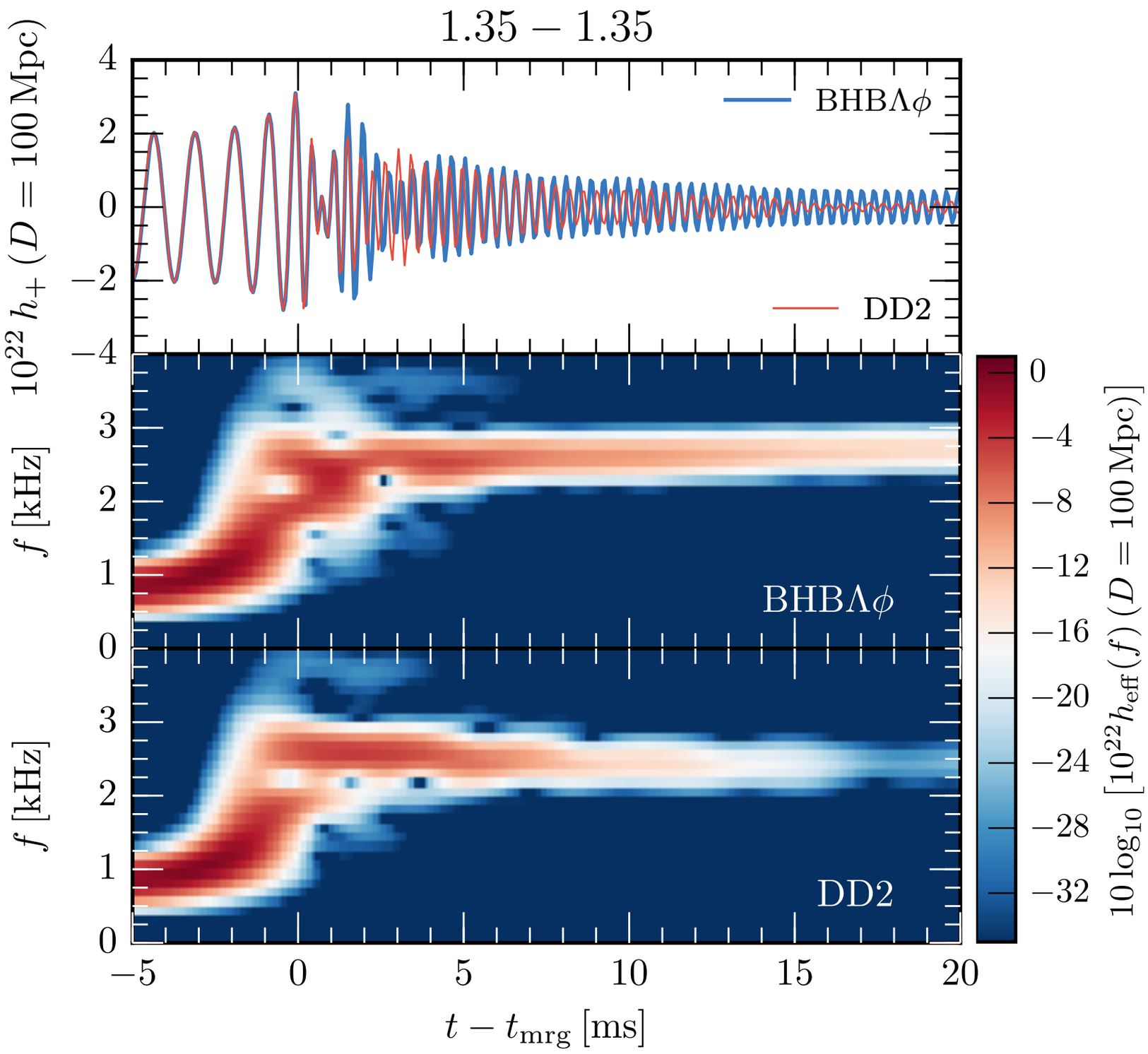
Binding energy



High-density EOS encoded in the binding energy

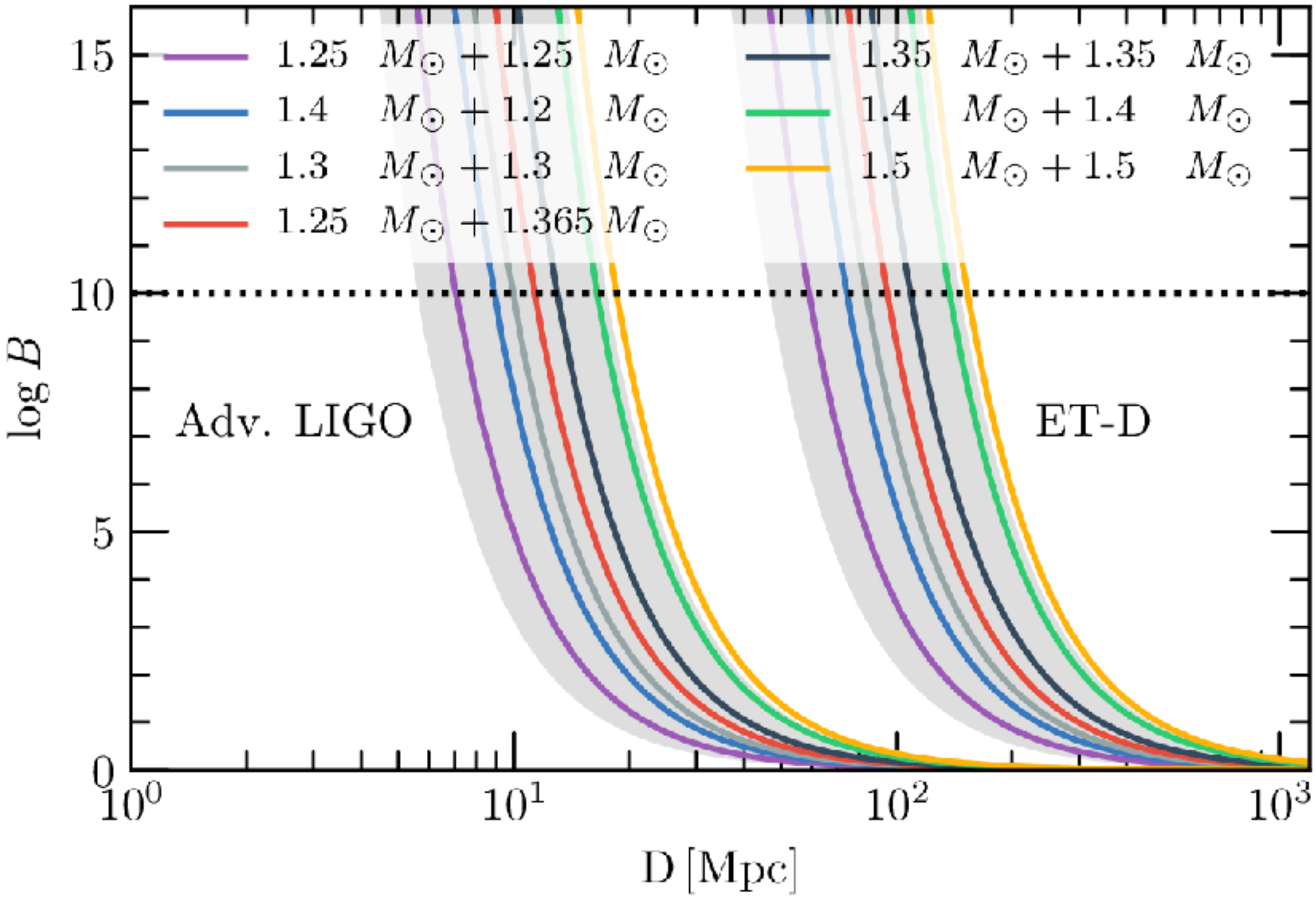
DR, Bernuzzi, Del Pozzo+, ApJL 842:L10 (2017)

Gravitational waveform



DR, Bernuzzi, Del Pozzo+, ApJL 842:L10 (2017)

Detectability



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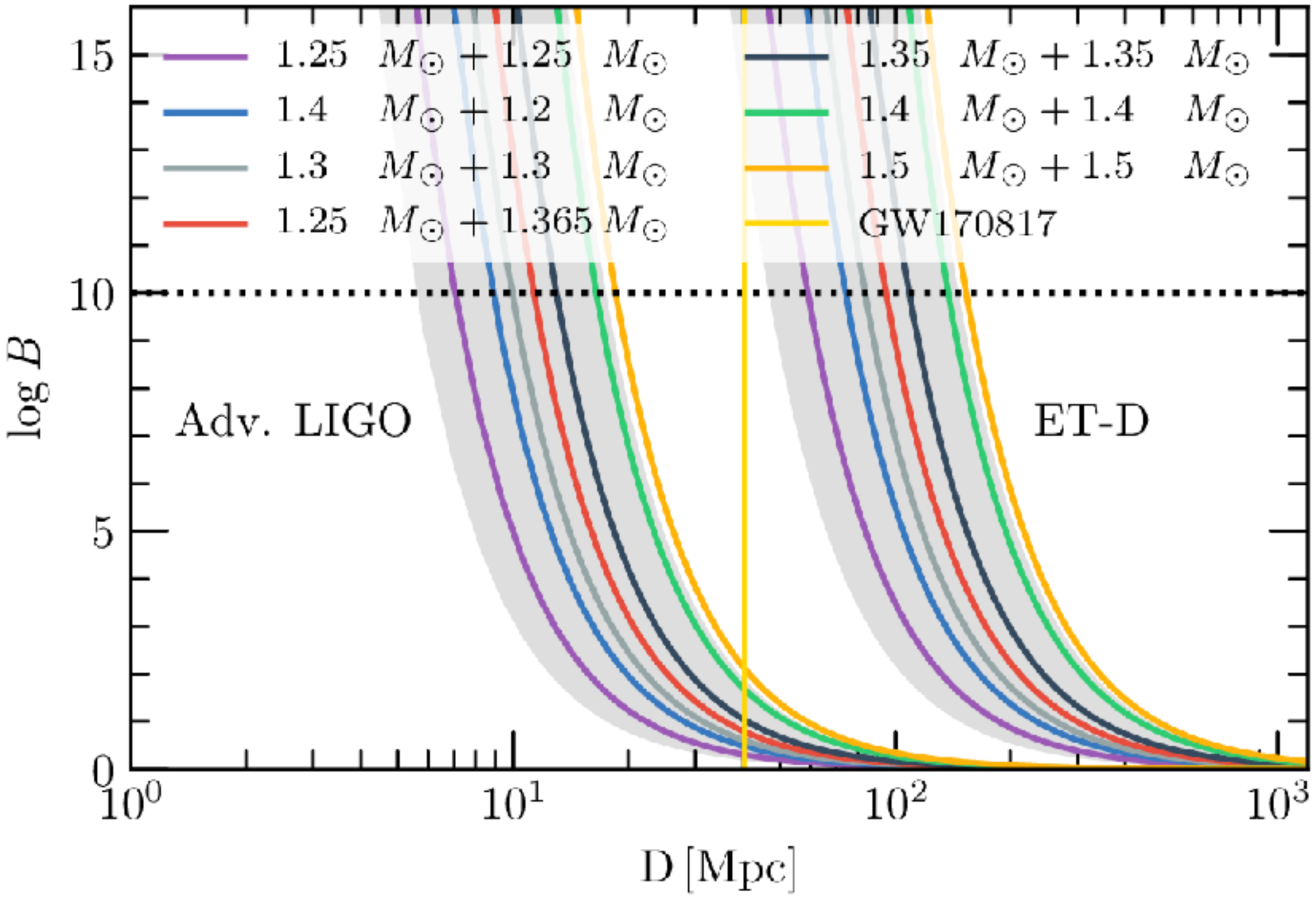

DR, Bernuzzi, Del Pozzo+, ApJL 842:L10 (2017)

Conclusions & outlook

- Simulations can bridge GW and EM observations
- First results: constraints on the NS EOS
- Going forward: better neutrino transport, MHD, and longer simulations are needed
- Hope for the future: detection of the postmerger signal