PennState
Eberly College of Science

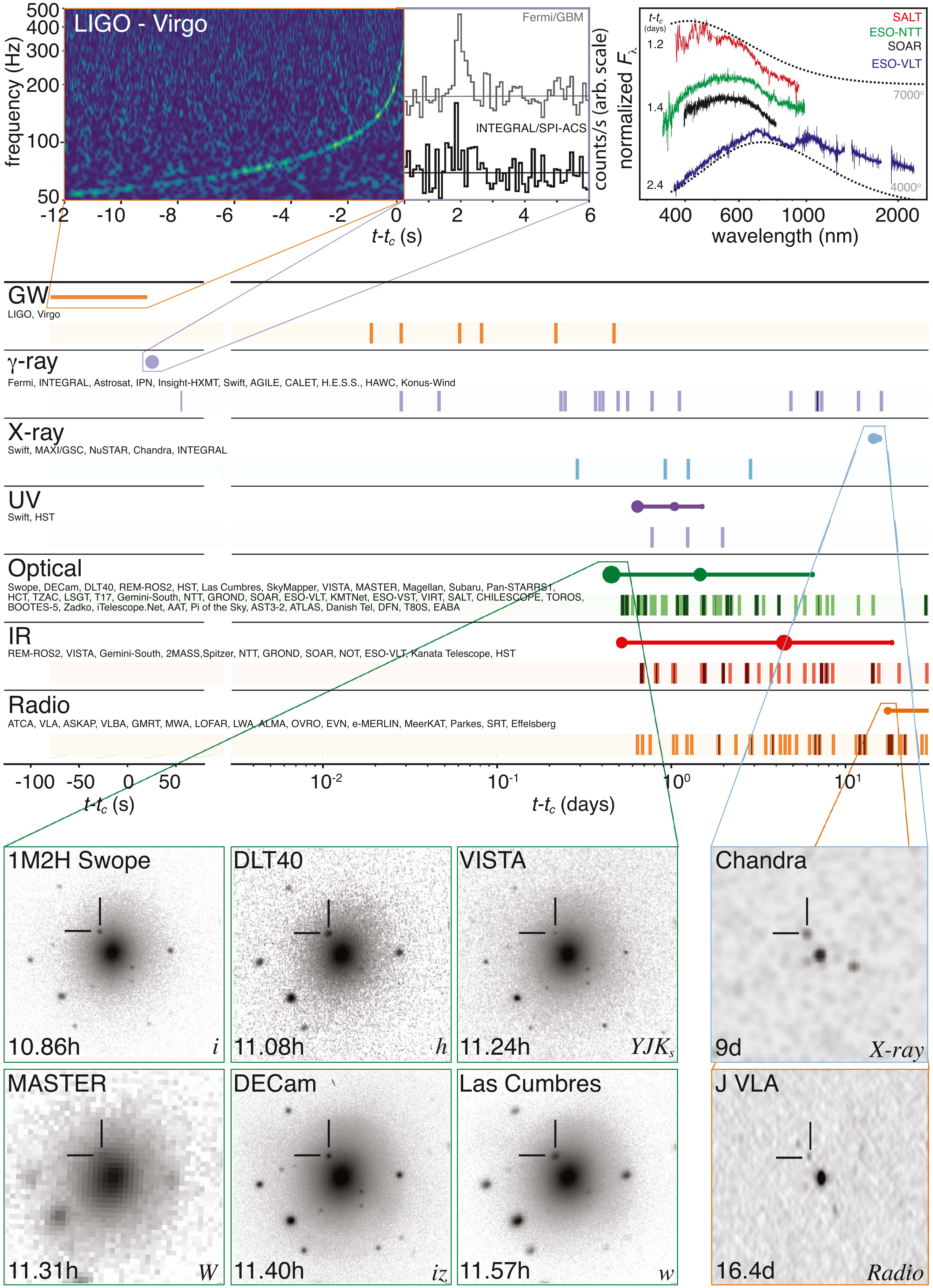
Neutron Star Mergers

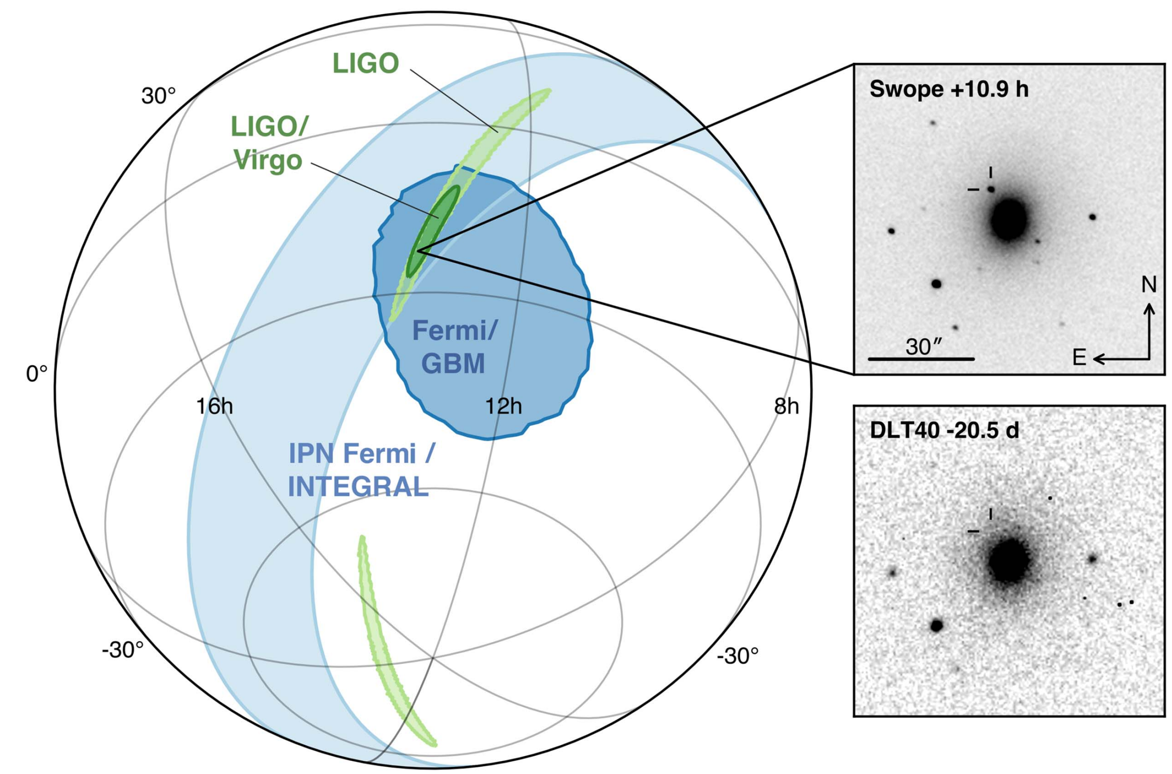
What has been done in theory and what has not

www.computational-relativity.org

arXiv:2002.03863

David Radice — July 6, 2020

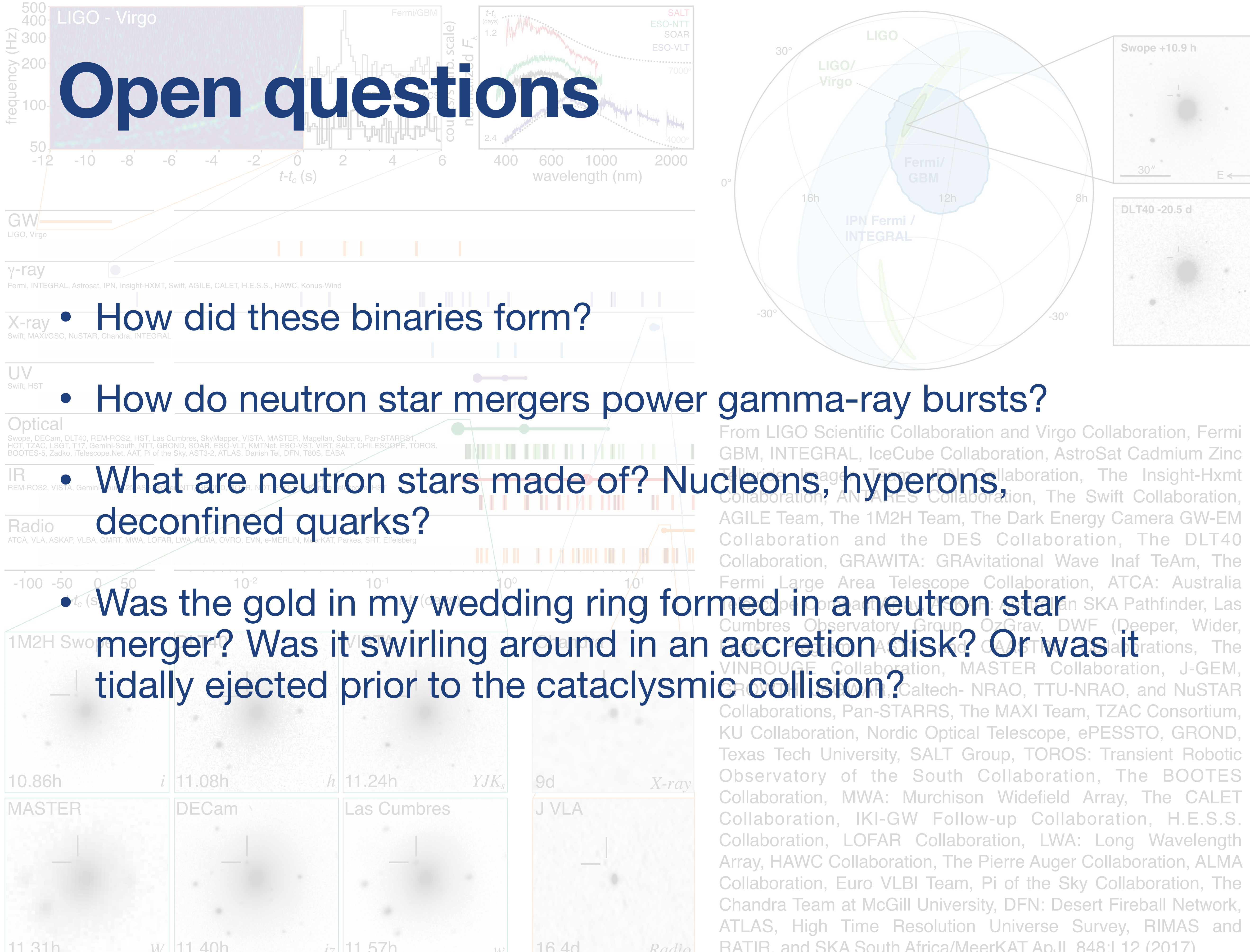




From LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech- NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT ApJL 848:L12 (2017)

Open questions

- How did these binaries form?
- How do neutron star mergers power gamma-ray bursts?
- What are neutron stars made of? Nucleons, hyperons, deconfined quarks?
- Was the gold in my wedding ring formed in a neutron star merger? Was it swirling around in an accretion disk? Or was it tidally ejected prior to the cataclysmic collision?



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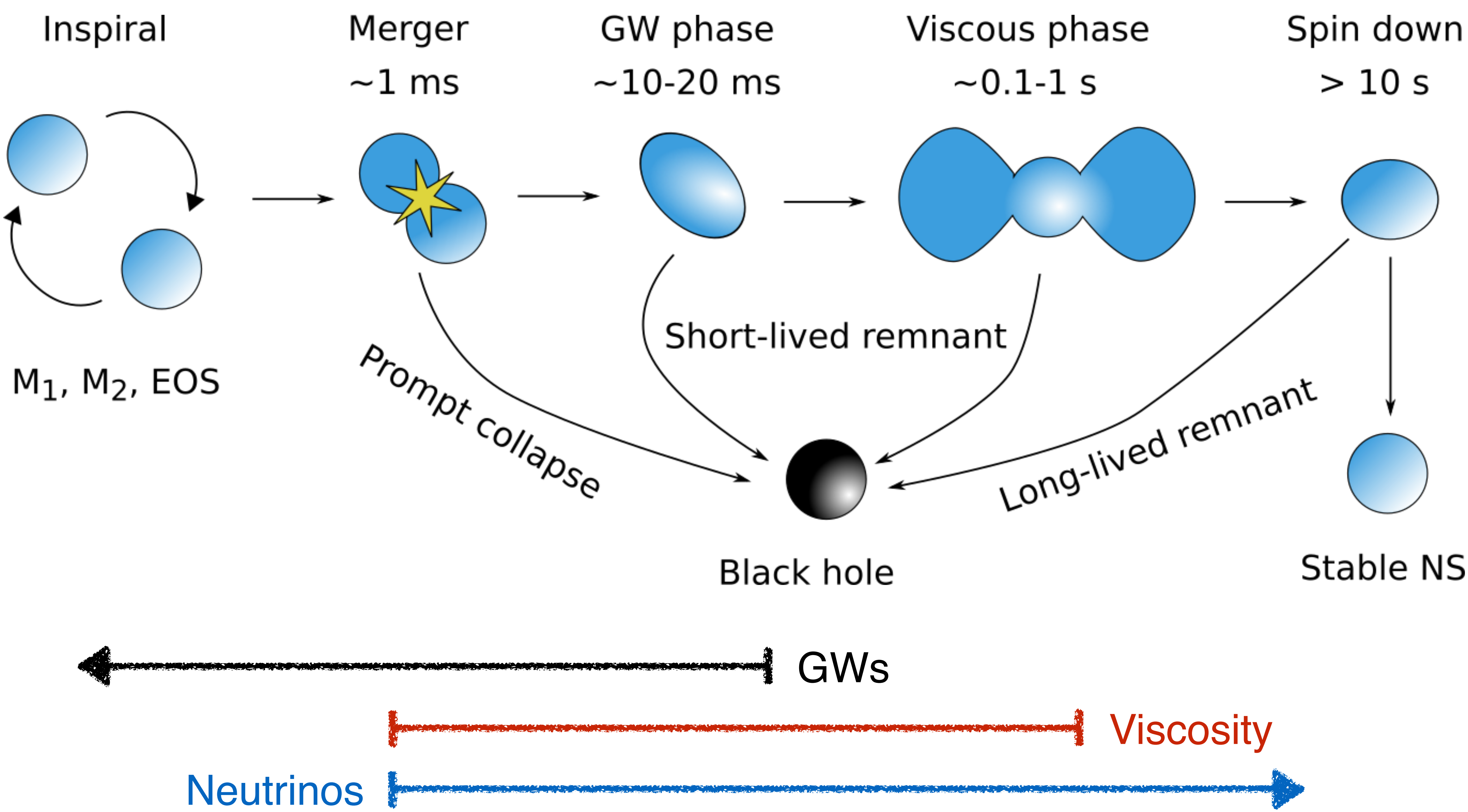
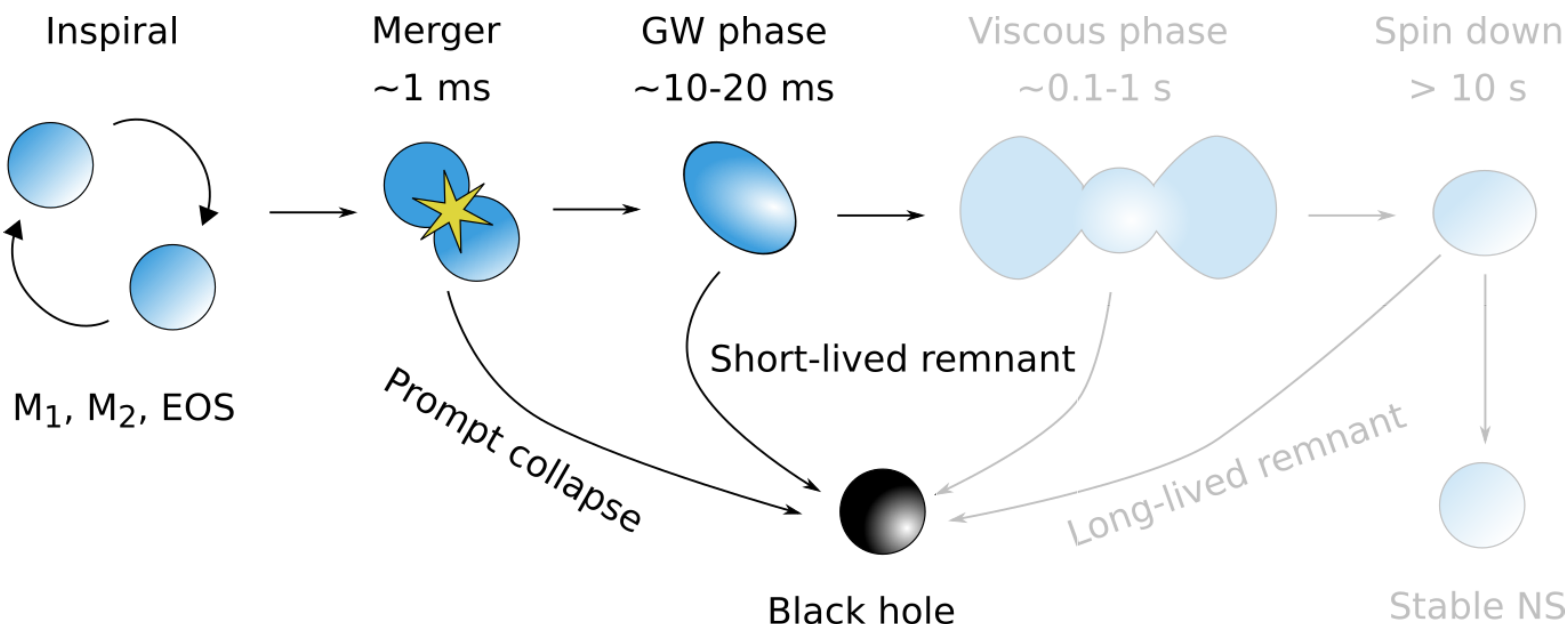
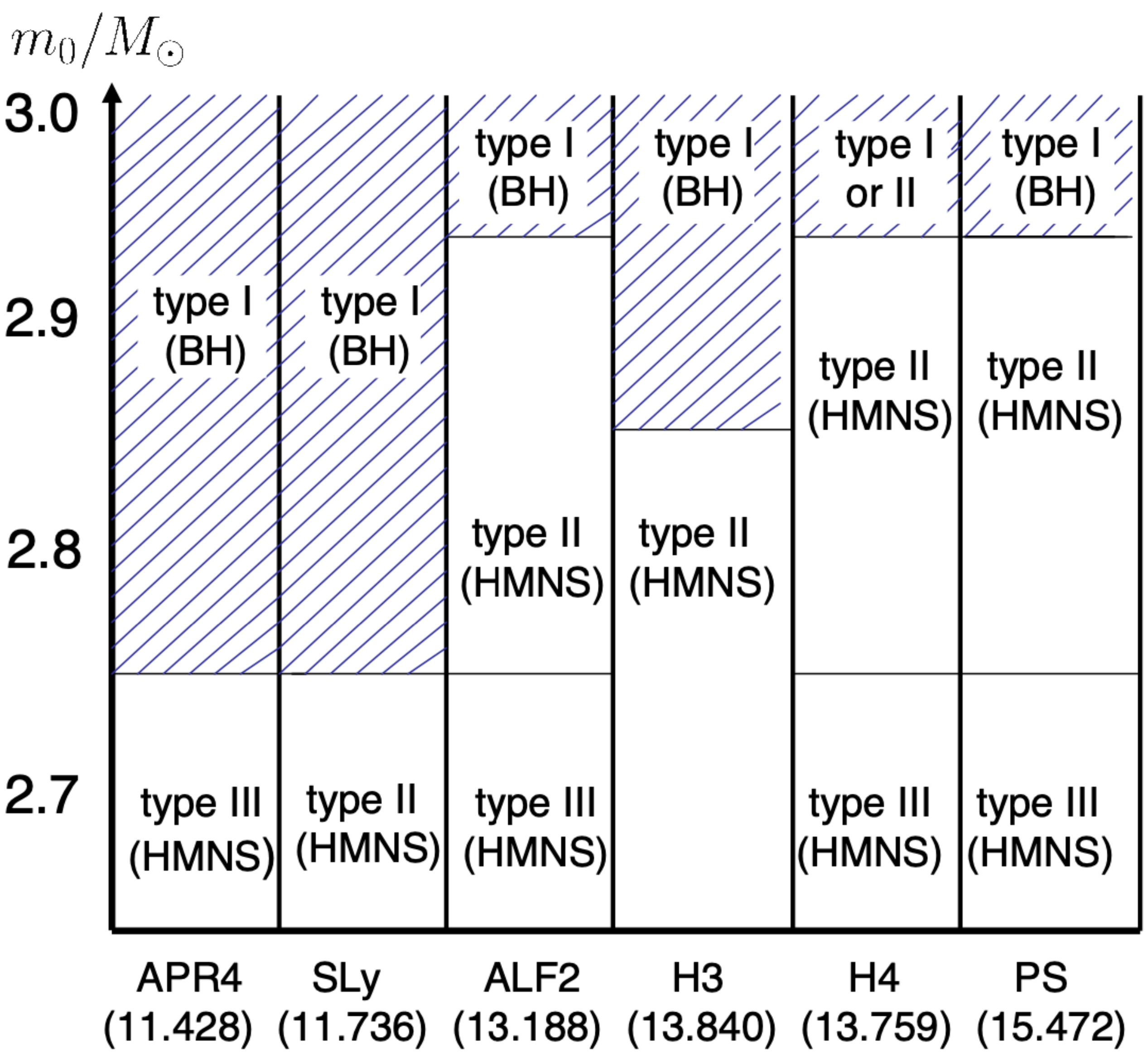
Neutron star merger evolution

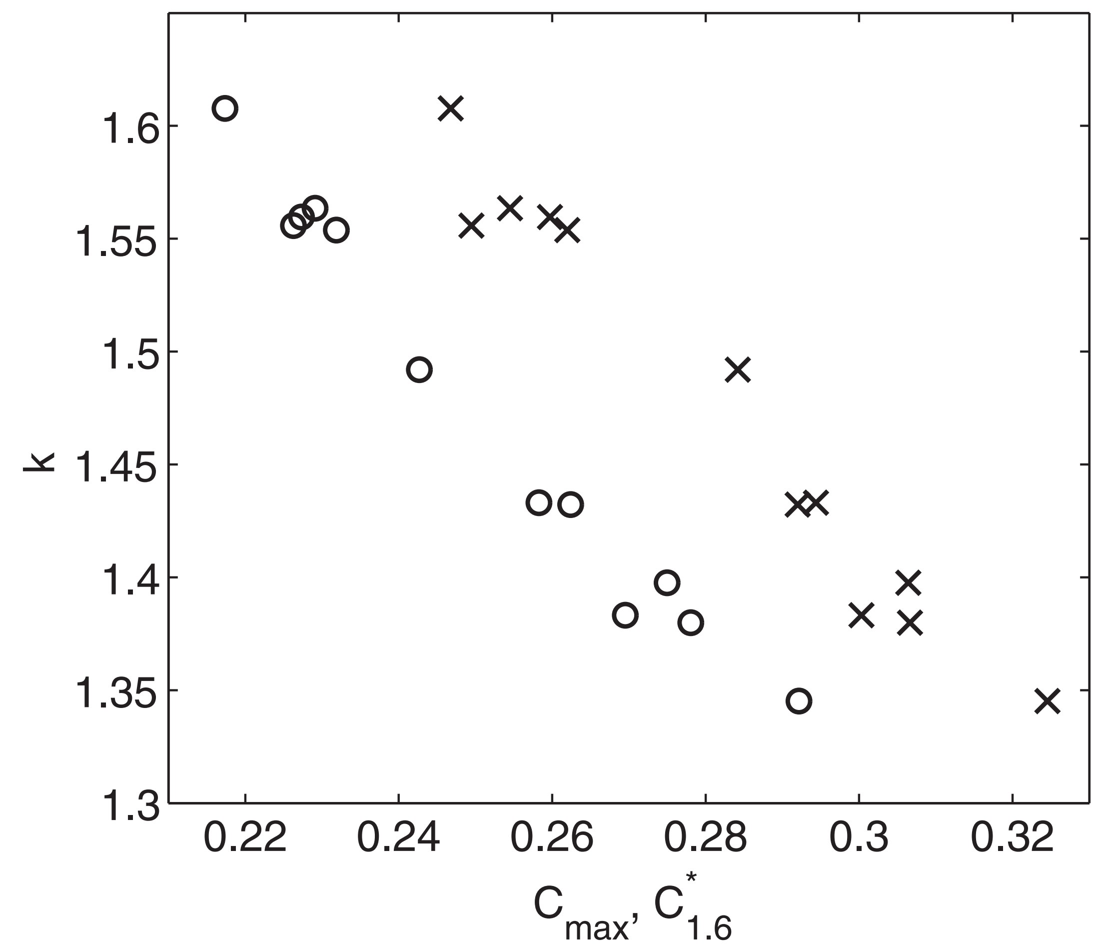


Early postmerger evolution



Prompt BH formation: $q \simeq 1$





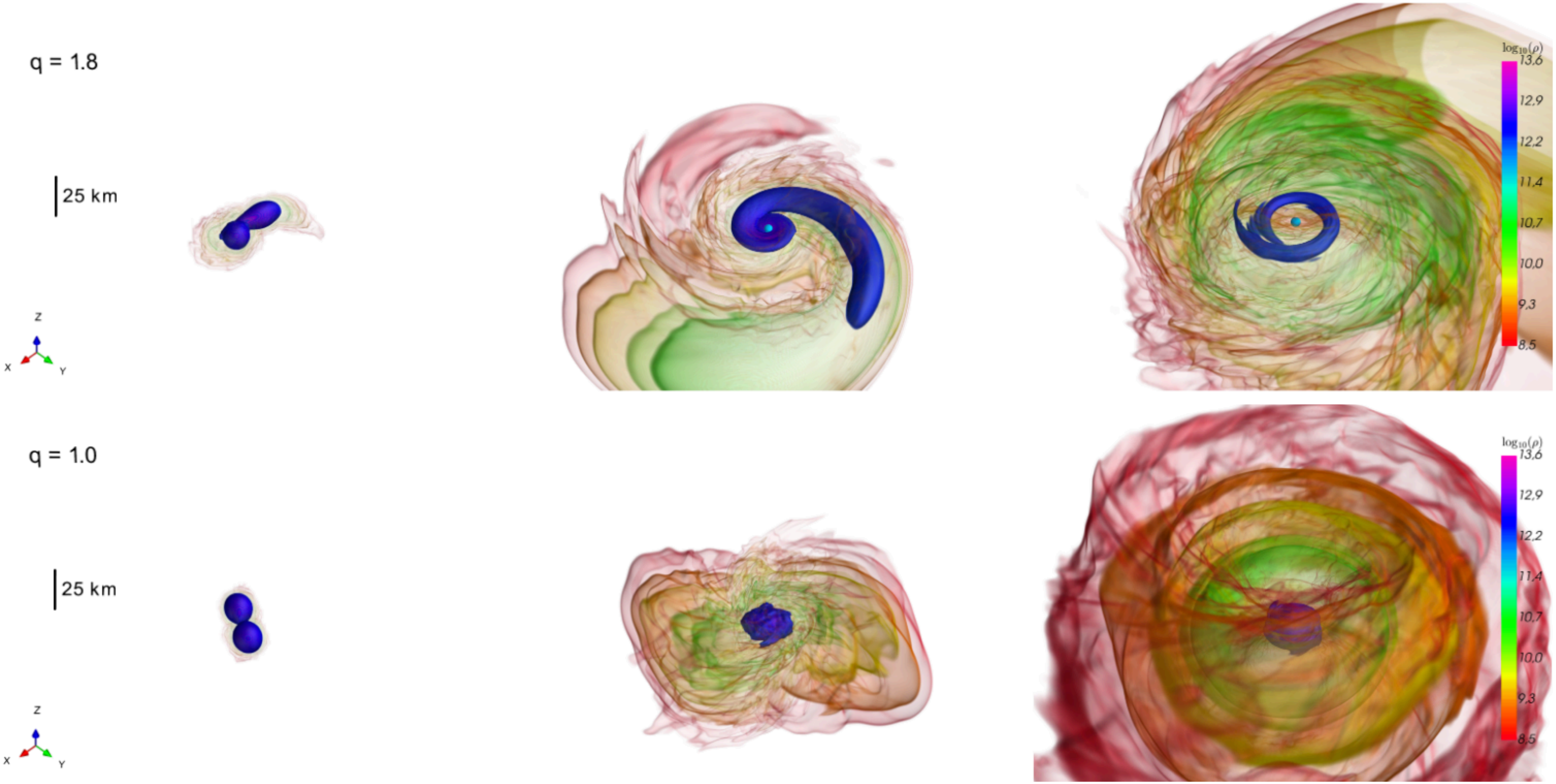
$$M_{\rm thr} = k_{\rm thr} M_{\rm max}$$

From Hotokezaka+ 2011

From Bauswein+ 2013

See also Bauswein+ 2017, Köppel+ 2019, Agathos+ 2019, Bernuzzi+ 2020

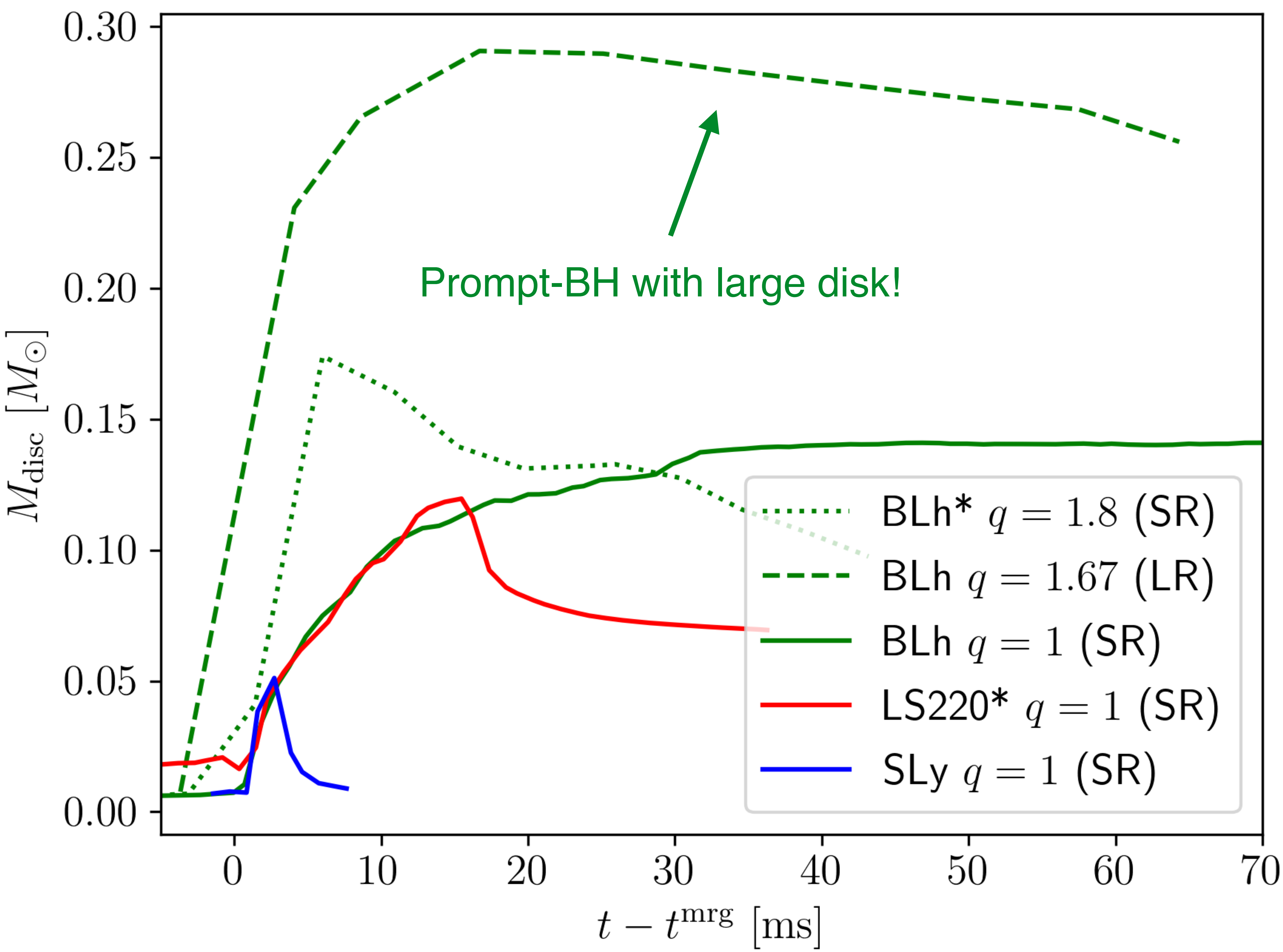
Disk formation I



$$\mathcal{M}_{\rm chirp} = 1.188\ M_\odot$$

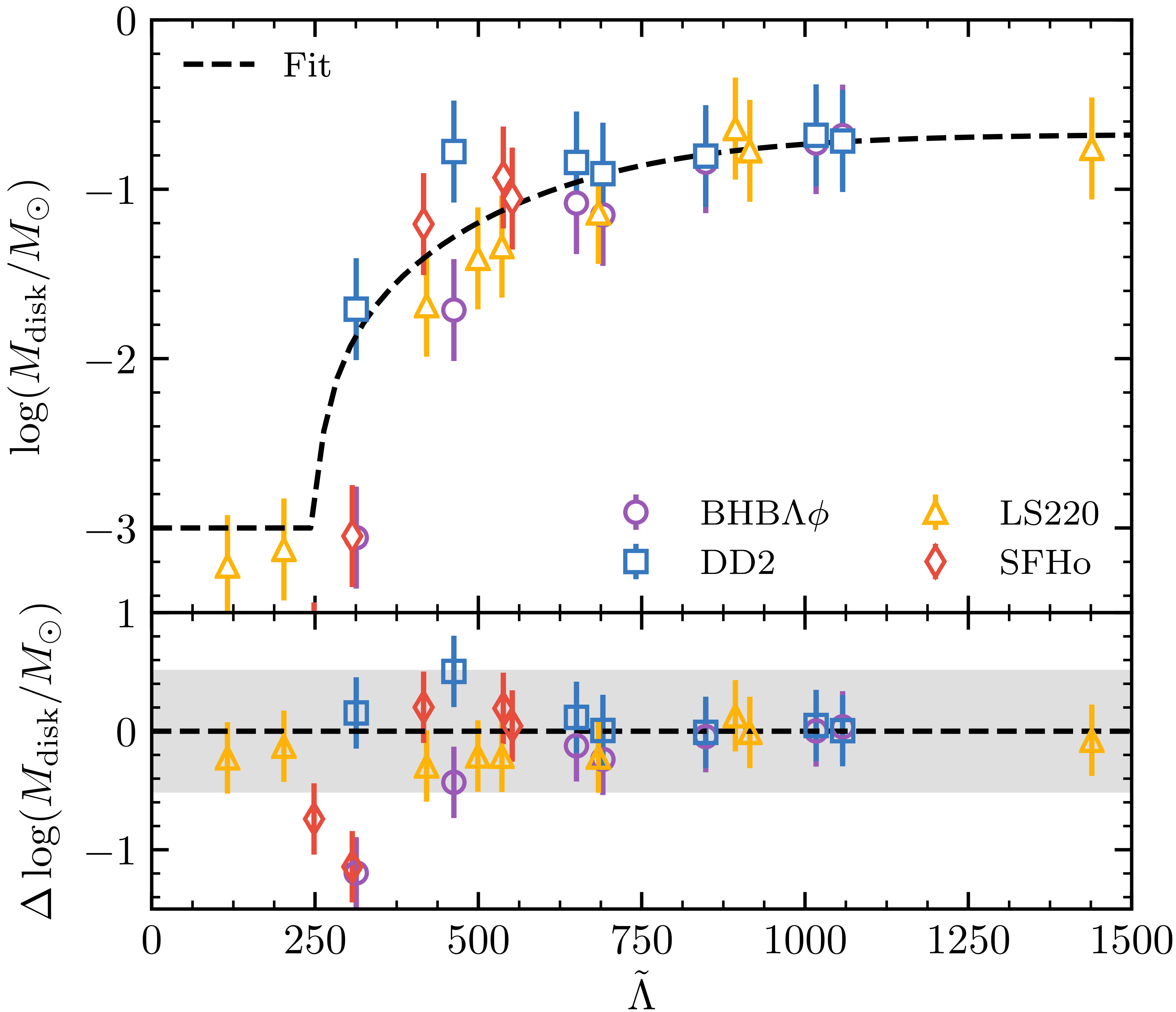
Bernuzzi, …, **DR**+, arXiv:2003.06015

Disk formation II



Bernuzzi, …, **DR**+, arXiv:2003.06015

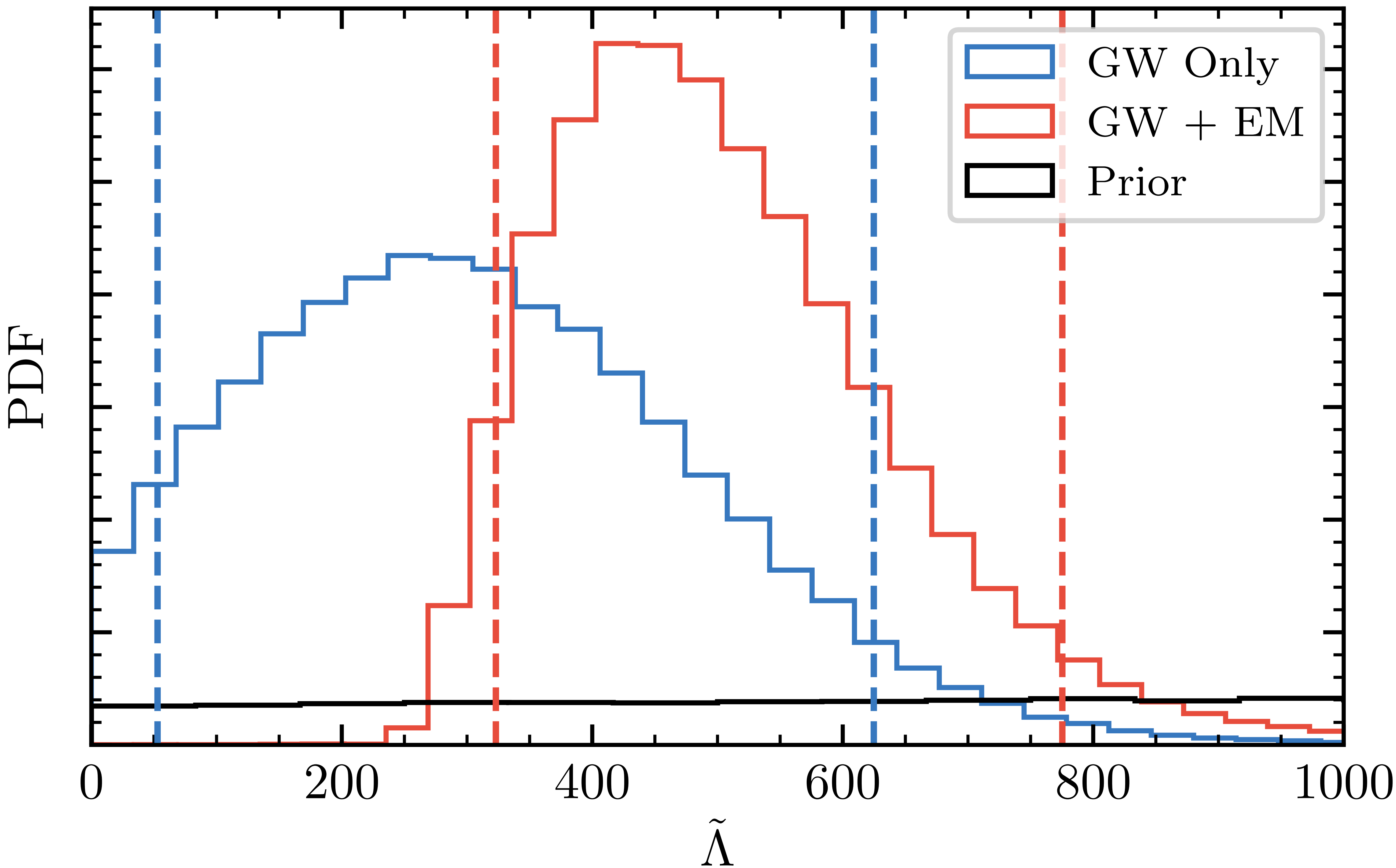
Disk masses



See also Krüger+ 2020; Salafia+ 2020; …

DR, Perego+ ApJL 852:L29 (2018);
DR & Dai, Eur. Phys. J. A 55: 50 (2019)

Equation of state constraints



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DR & Dai, Eur. Phys. J. A 55: 50 (2019)

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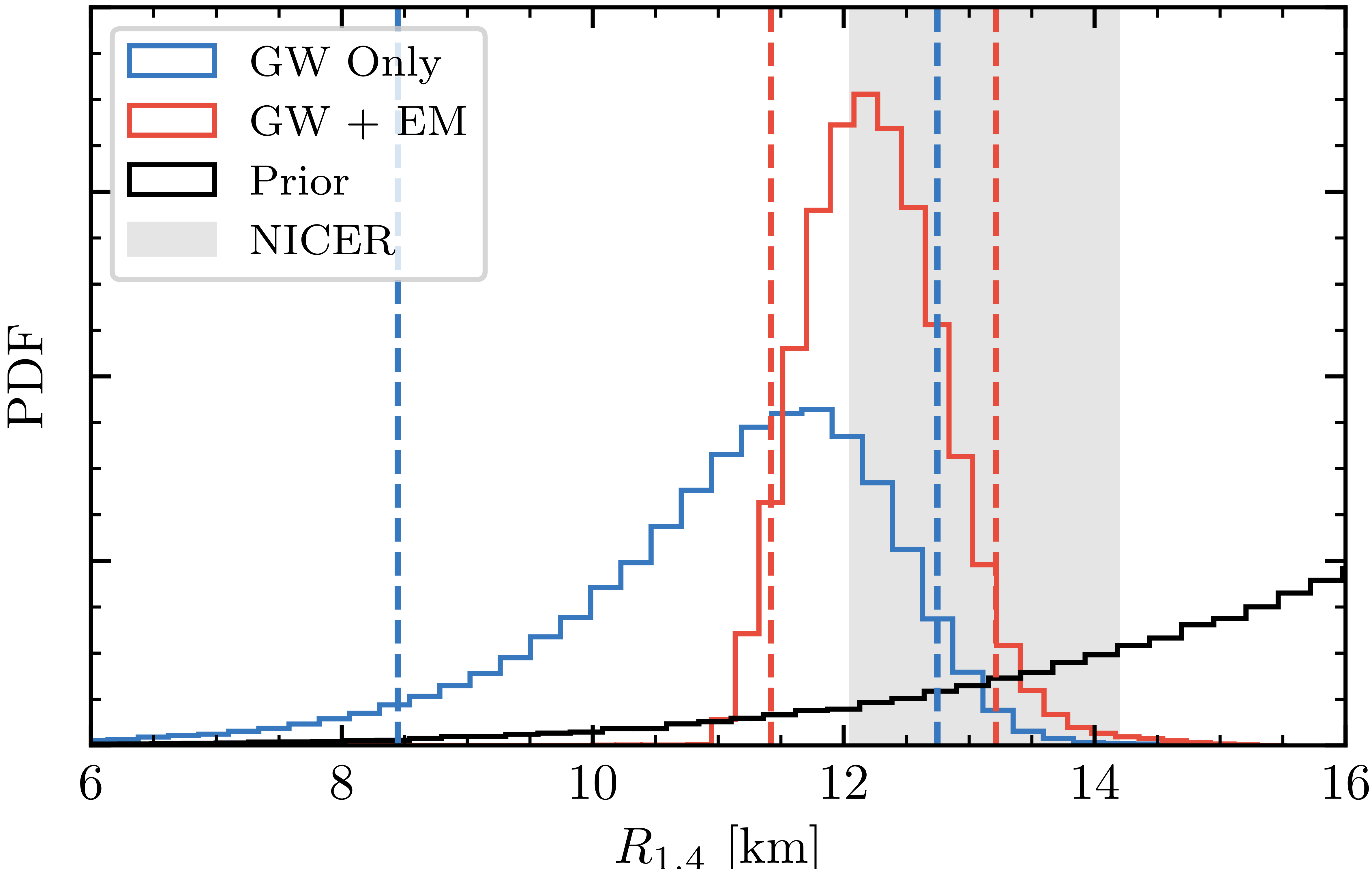

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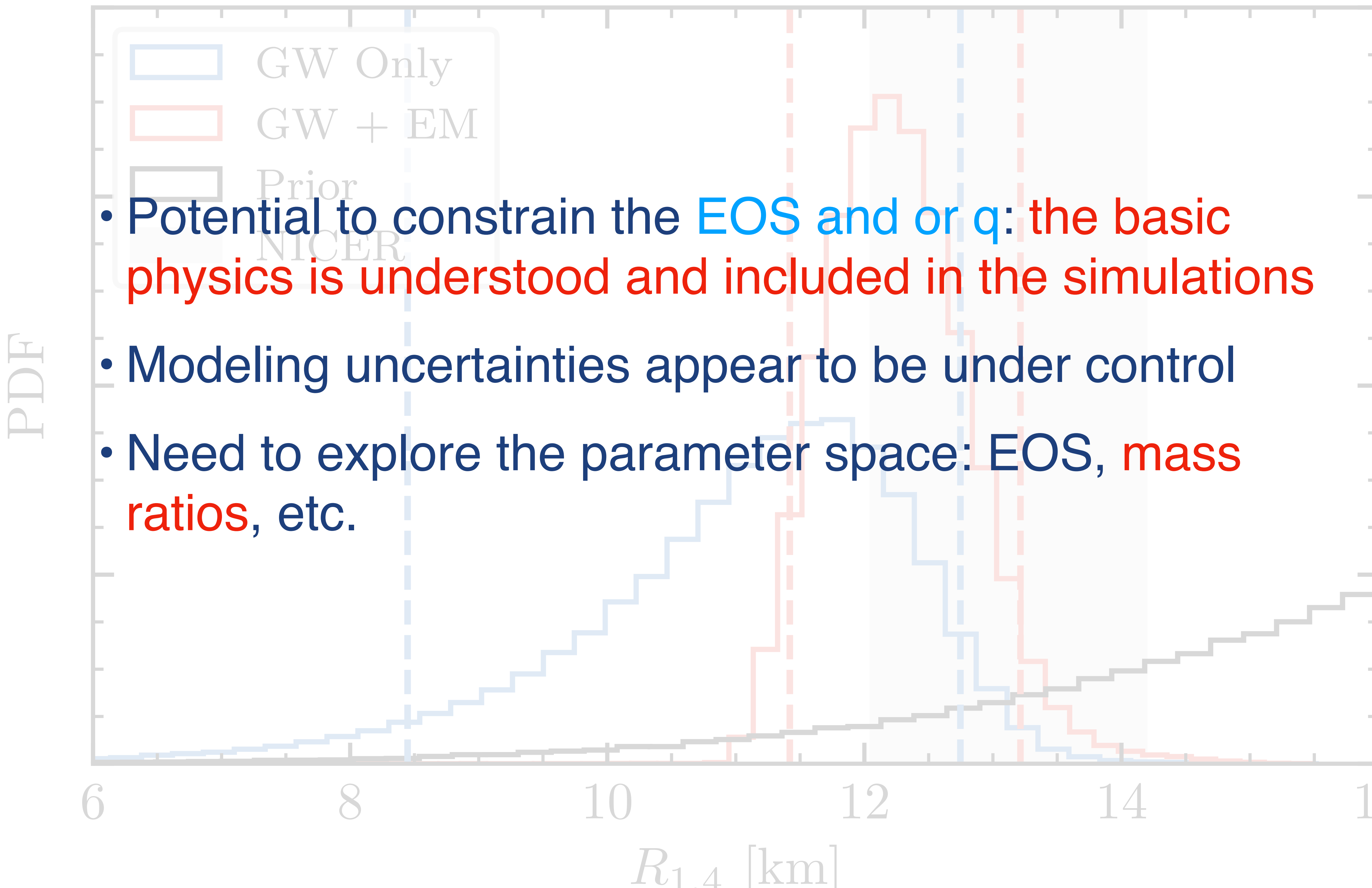
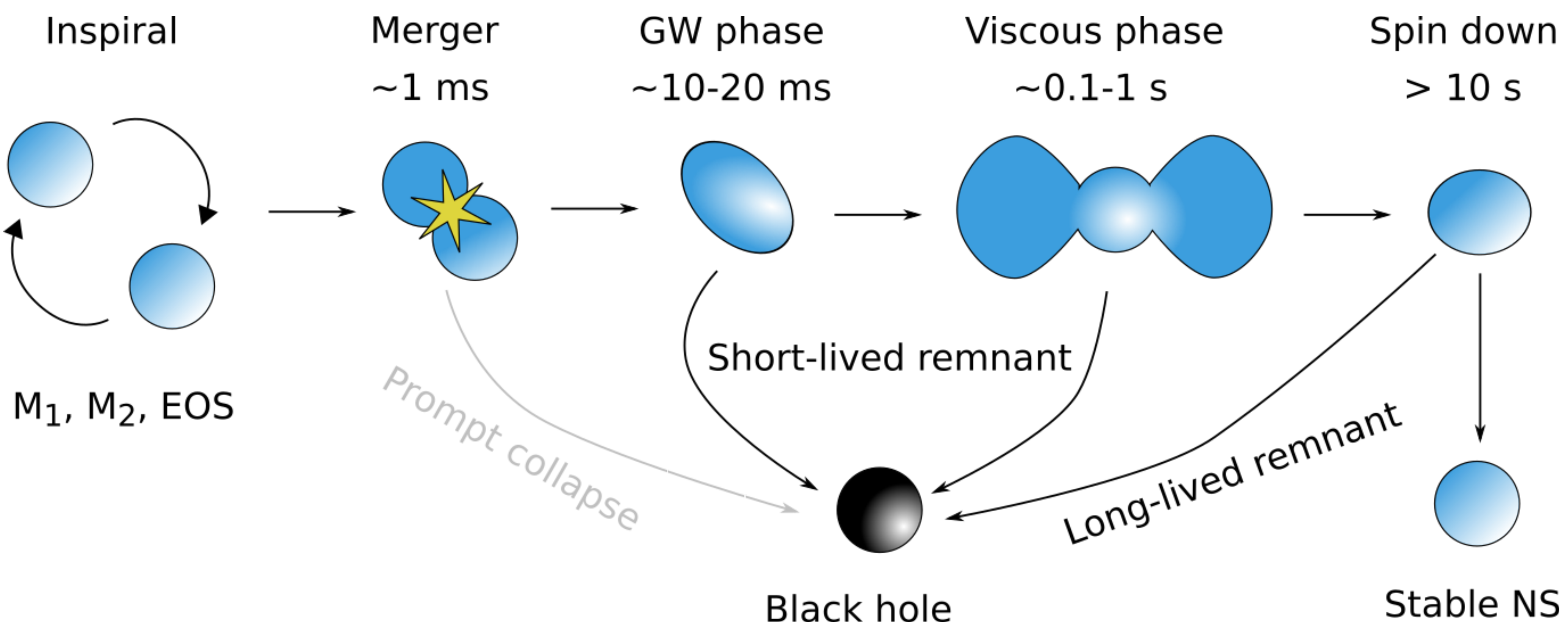
Equation of state constraints



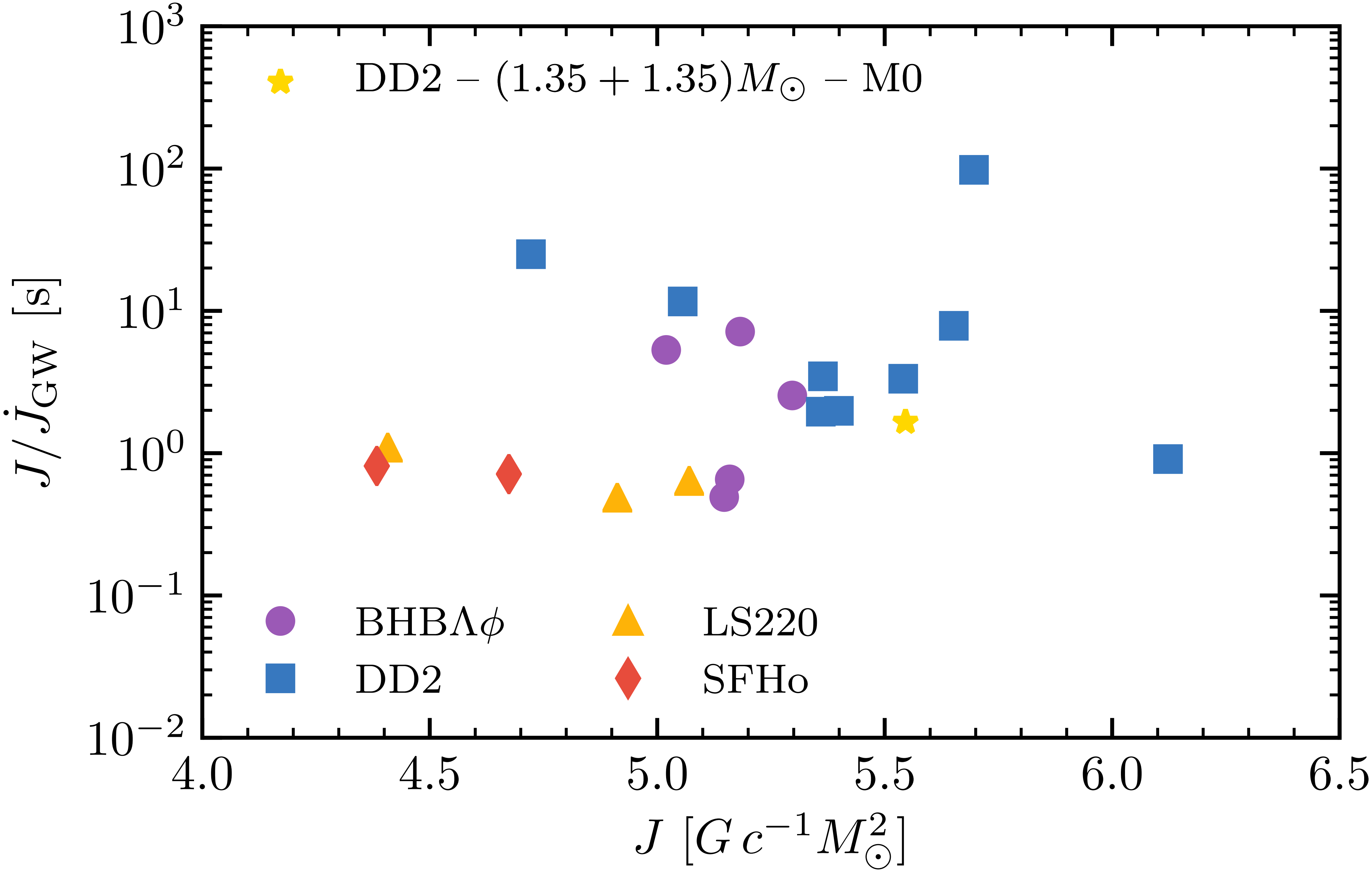
- Potential to constrain the EOS and or q: the basic physics is understood and included in the simulations
- Modeling uncertainties appear to be under control
- Need to explore the parameter space: EOS, mass ratios, etc.

DR, Perego+ ApJL 852:L29 (2018);
DR & Dai, Eur. Phys. J. A 55: 50 (2019)

Long-term evolution

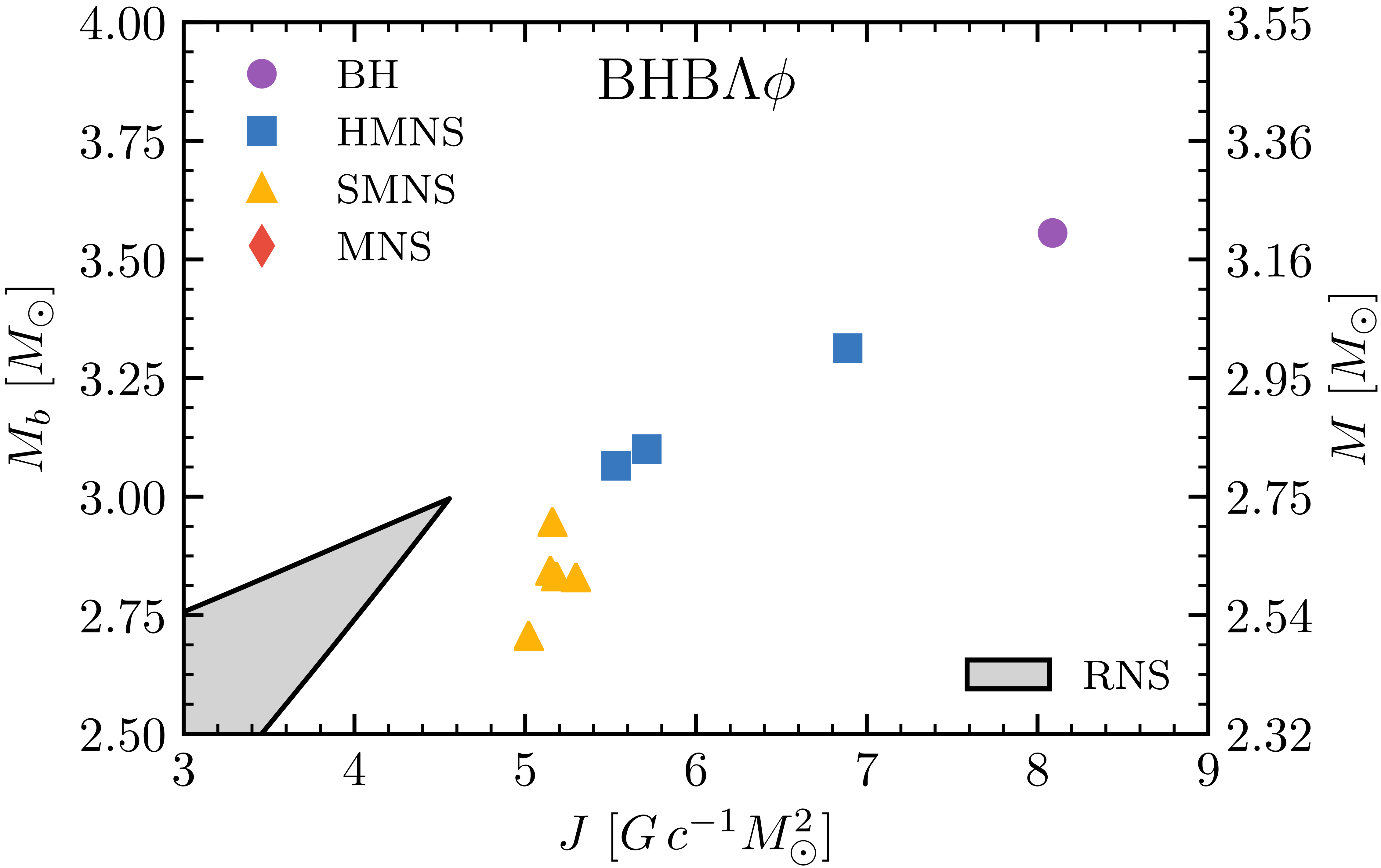


End of the GW-driven phase



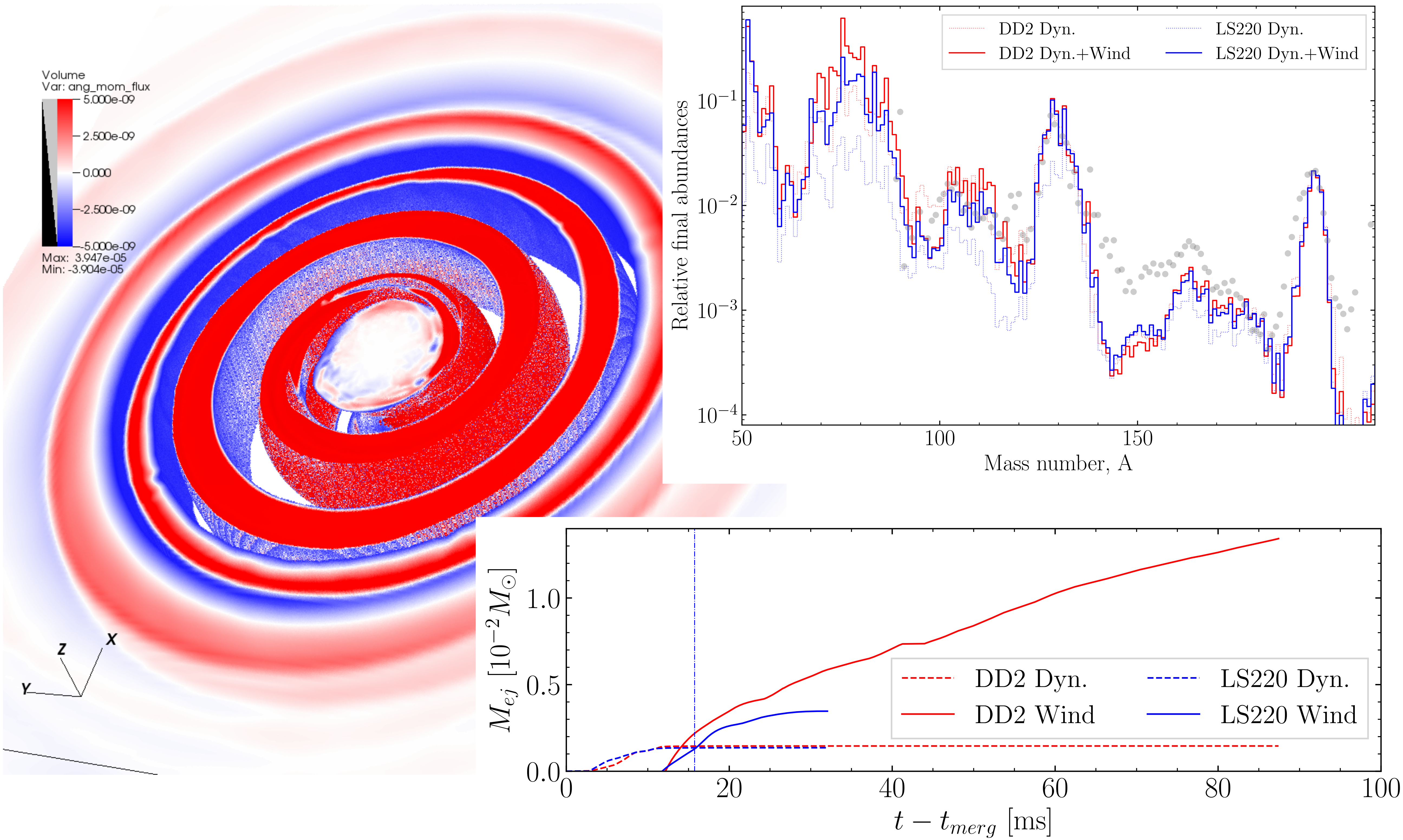
DR, Perego, Bernuzzi, Zhang, MNRAS 481:3670 (2018)

Secular evolution



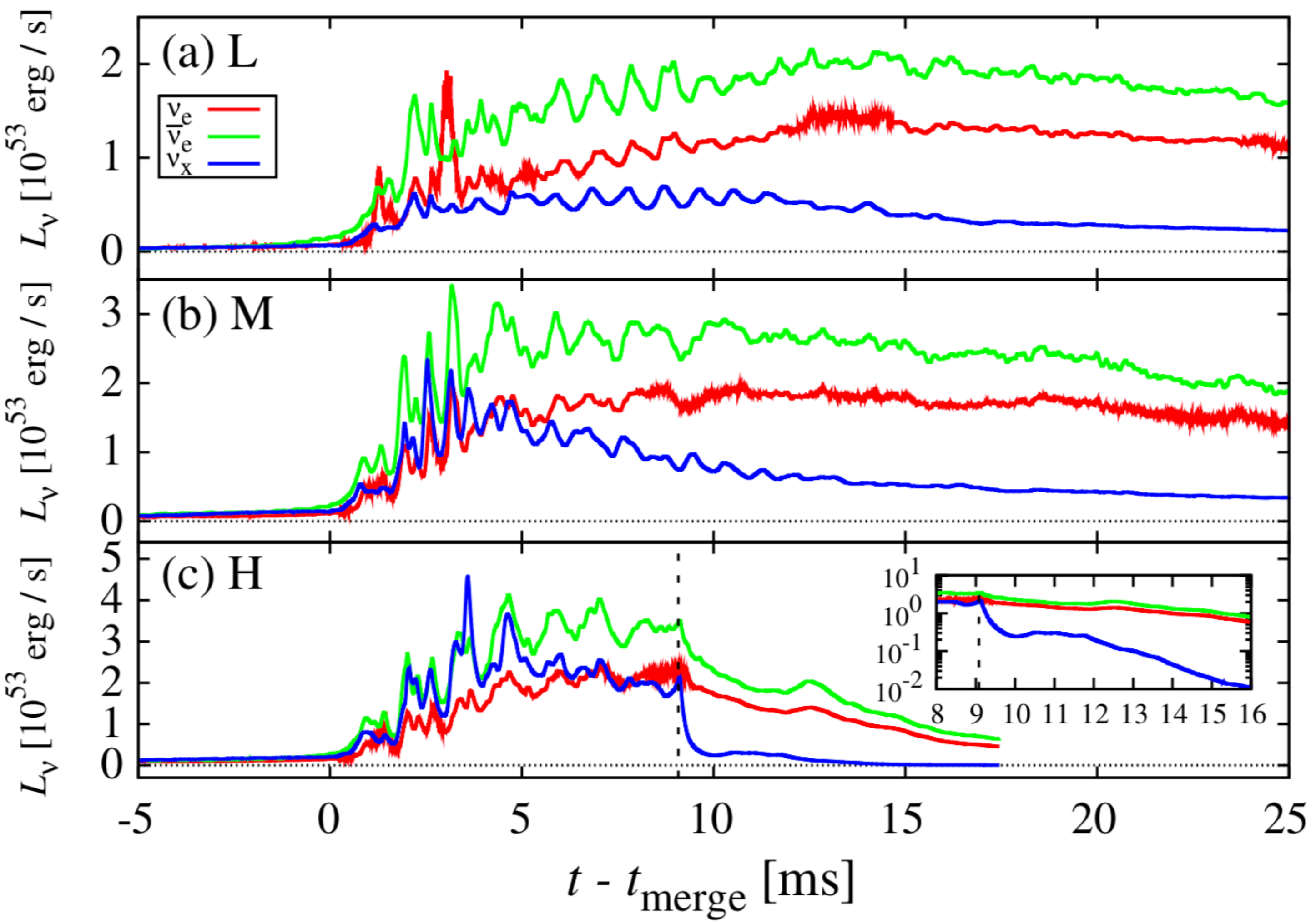
DR, Perego, Bernuzzi, Zhang, MNRAS 481:3670 (2018)

Nonlinear hydrodynamics

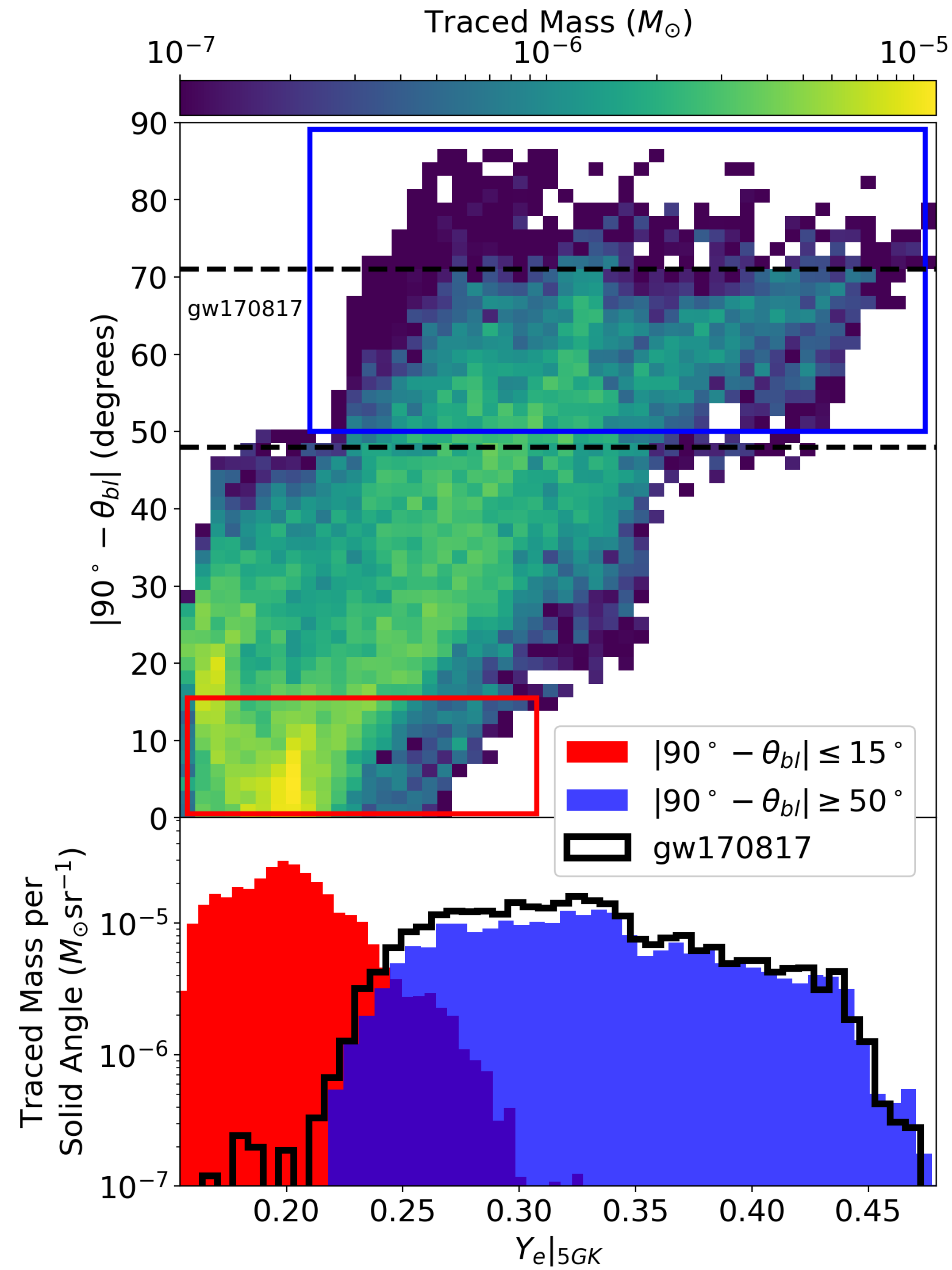


From Nedora, Bernuzzi, **DR**+, ApJL 886:L30 (2019)

Neutrino effects



From Sekiguchi+ 2011

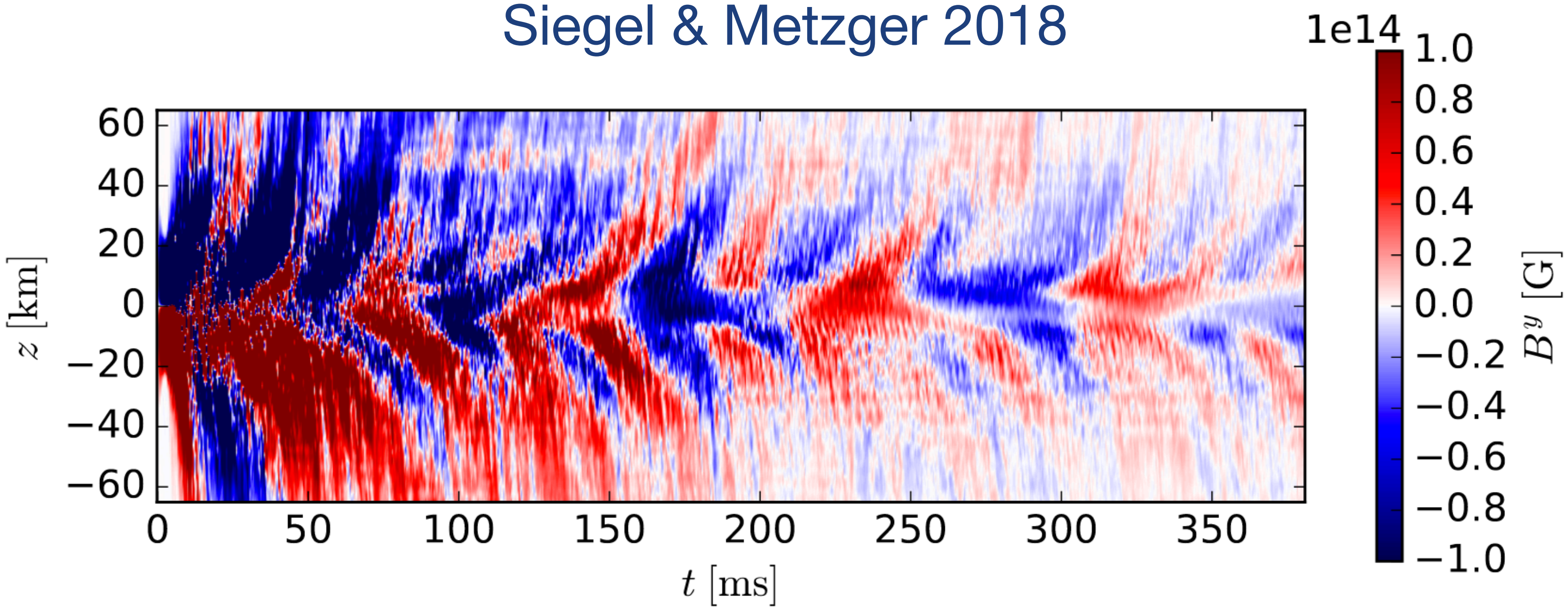


From Miller+ 2019

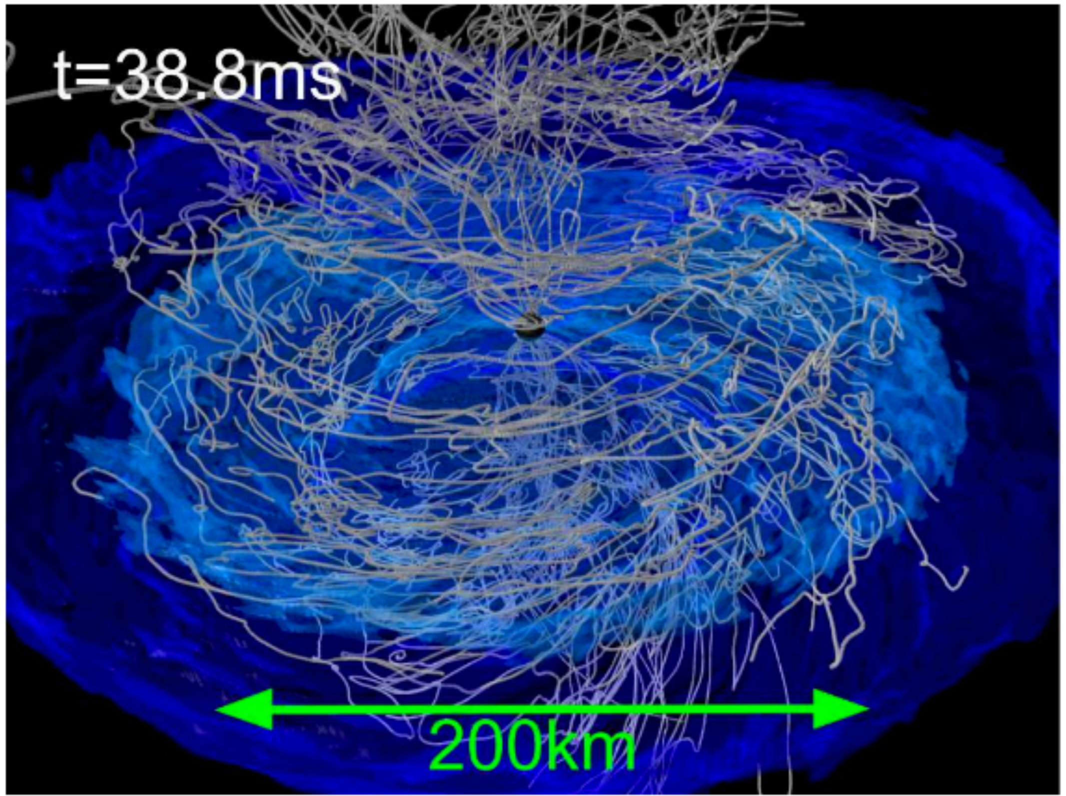
See also: Dessart+ 2008, Perego+ 2014, Just+ 2015, Metzger+ 2014, Foucart+ 2016, Siegel & Metzger 2018, …

MHD effects

Siegel & Metzger 2018

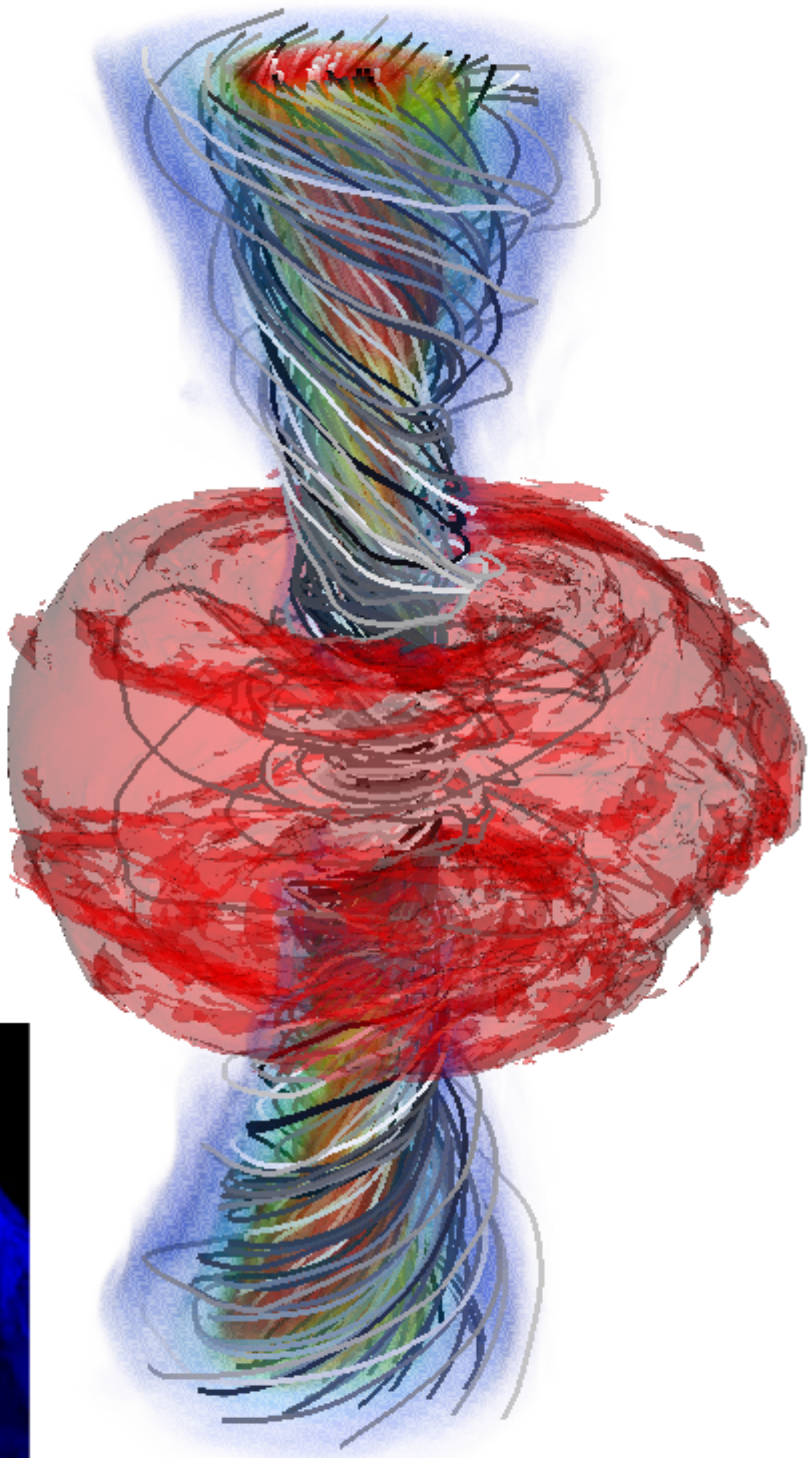


Kiuchi+ 2014



See also

Price & Rosswog 2006;
Andreson+ 2008;
Etienne+ 2011;
Endrizzi+ 2014;
Giacomazzo+ 2015;
Ruiz+ 2016;
Palenzuela+ 2016;
Fernandez+ 2018;
Ciolfi+ 2019; …



Mösta, **DR**+ 2020

Conclusions

What has been done in theory and what has not

- Inspiral and early postmerger are better understood, but there is still a vast parameter space volume to explore.

- We can already do multimessenger astrophysics!

- The physics becomes increasingly complex on longer timescales in the postmerger. Higher resolution, longer, and more sophisticated simulations are needed.