Current and future prospects on EOS constraints from gravitational waves

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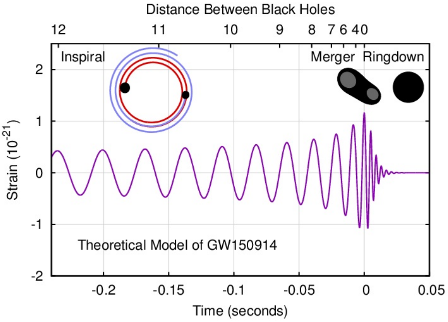
Gravitational waves

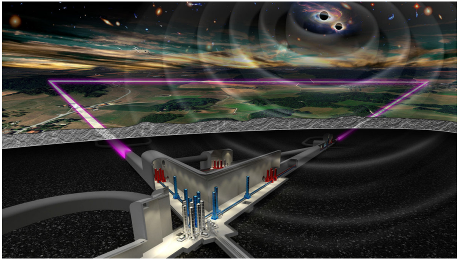
- So far: compact binary coalescences (CBC) observed, black holes and neutron stars
- Measure strain $h(t) = \delta L(t)/L$ (animation)
- 3 phases: inspiral, merger, ringdown



Gravitational wave detectors

- Currently: LIGO (Hanford, Livingston), Virgo (Italy), KAGRA (Japan)

- Future: Einstein Telescope (ET), Cosmic Explorer (CE), LISA, ...



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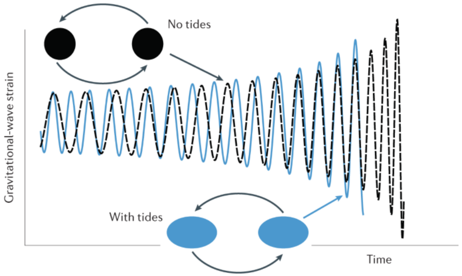
Tidal deformability

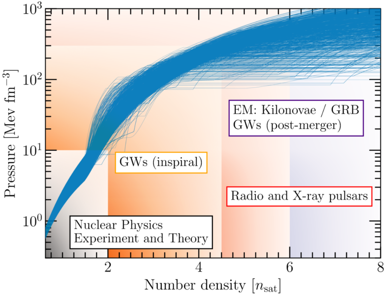
- Extended objects (neutron stars): tidally deformed in presence of external gravitational field $\mathcal{E}_{ij}$
- Develop quadrupole moment: $Q_{ij} = -\lambda \mathcal{E}_{ij}$, λ = tidal deformability
- Modifies **inspiral** phase of GW:

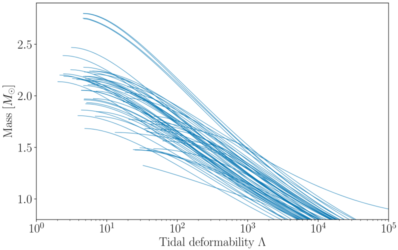
$$\tilde{h}(f) = A \exp\{i\Psi(f)\}$$
$$\Psi(f) = \Psi_{\text{point}}(f) + \Psi_{\text{tidal}}(f)(\Lambda_1, \Lambda_2)\,.$$



Relation with EOS

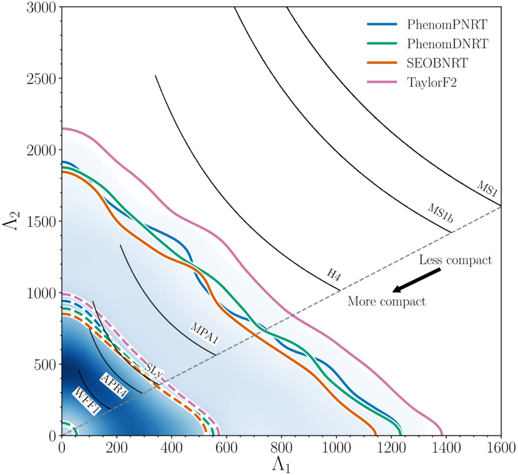
The tidal deformability is linked to the EOS: a (P, ρ) curve maps to a (M, Λ) curve.





Inspiral of neutron stars $\rightarrow$ measure (M, Λ) $\rightarrow$ constrain EOS

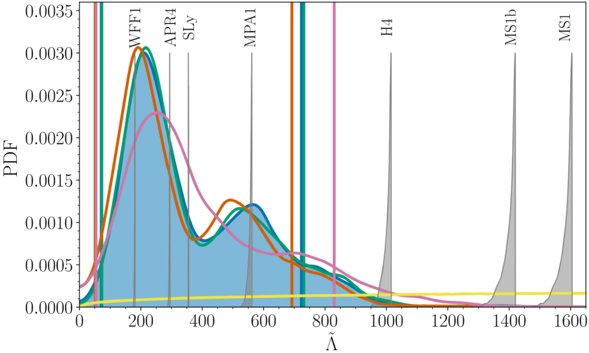
GW170817: first binary neutron star merger observed [1].



Results

GW170817: first binary neutron star merger observed [1].

$$\tilde{\Lambda} = \frac{16}{13}\frac{(m_1 + 12 m_2) m_1^4 \Lambda_1 + (m_2 + 12 m_1) m_2^4 \Lambda_2}{(m_1 + m_2)^5} \, .$$



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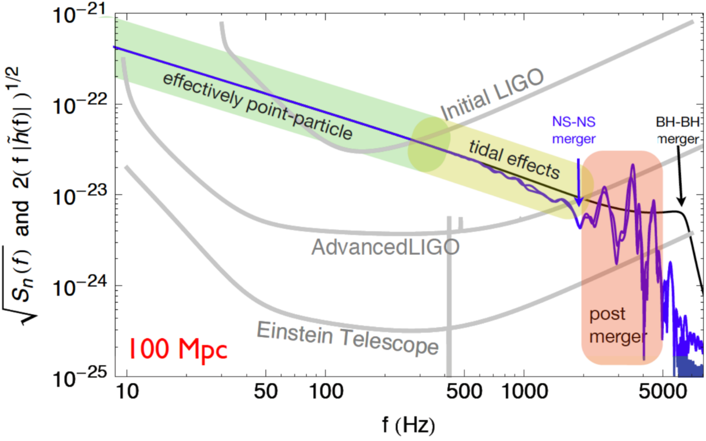
Postmerger GW

Λ probes the inspiral, what about (post)merger?
$\rightarrow$ Need sensitive detectors [2]!



Challenges

(Post)merger GW: needs expensive numerical relativity (NR) simulations, taking temperature into account!

- NR simulations: expensive, temperature is hard (?)
- Modelling GW signals: how to connect inspiral and (post)merger? Parameter estimation?
- Quasi-universal relations exist [3] – can they be improved?
- ALICE at high temperature – way to make connection?

Let us check out Ref. [4] as an example.

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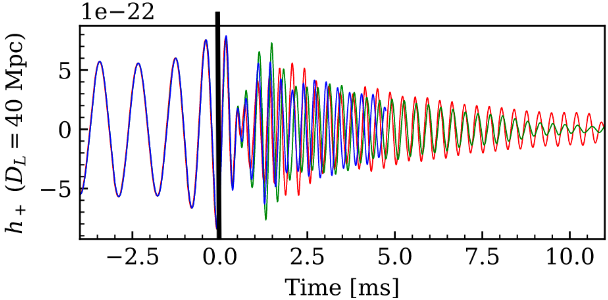
"Thermal Effects in Binary Neutron Star Mergers"

- Isolated neutron star: $T = 0$ MeV (cold); merger: $T \sim 100$ MeV
- Ref. [4]: temperature effects through modifying the specific heat capacity
- Perform parameter estimation with postmerger waveform from [5]



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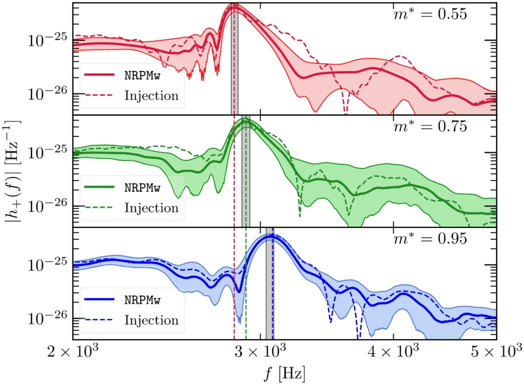
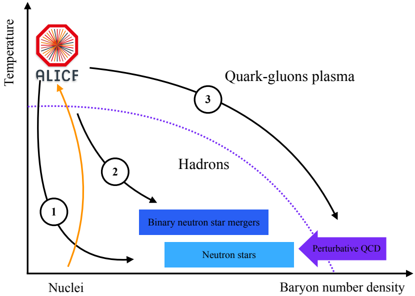


Conclusions

- Inspiral of neutron stars: tidal deformability $\rightarrow$ cold EOS constraints
- Future GW detectors will measure postmerger spectrum
- Temperature effects have to be taken into account: challenges and opportunities
- Finite temperature might lead to a connection with ALICE



References

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