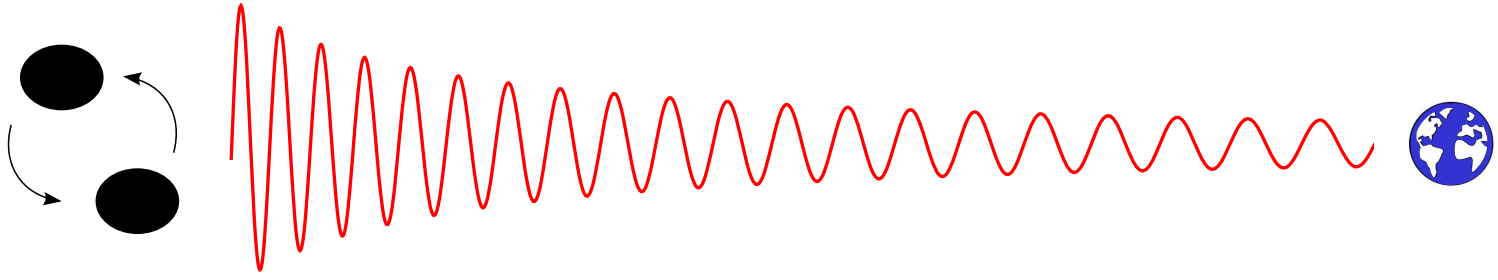
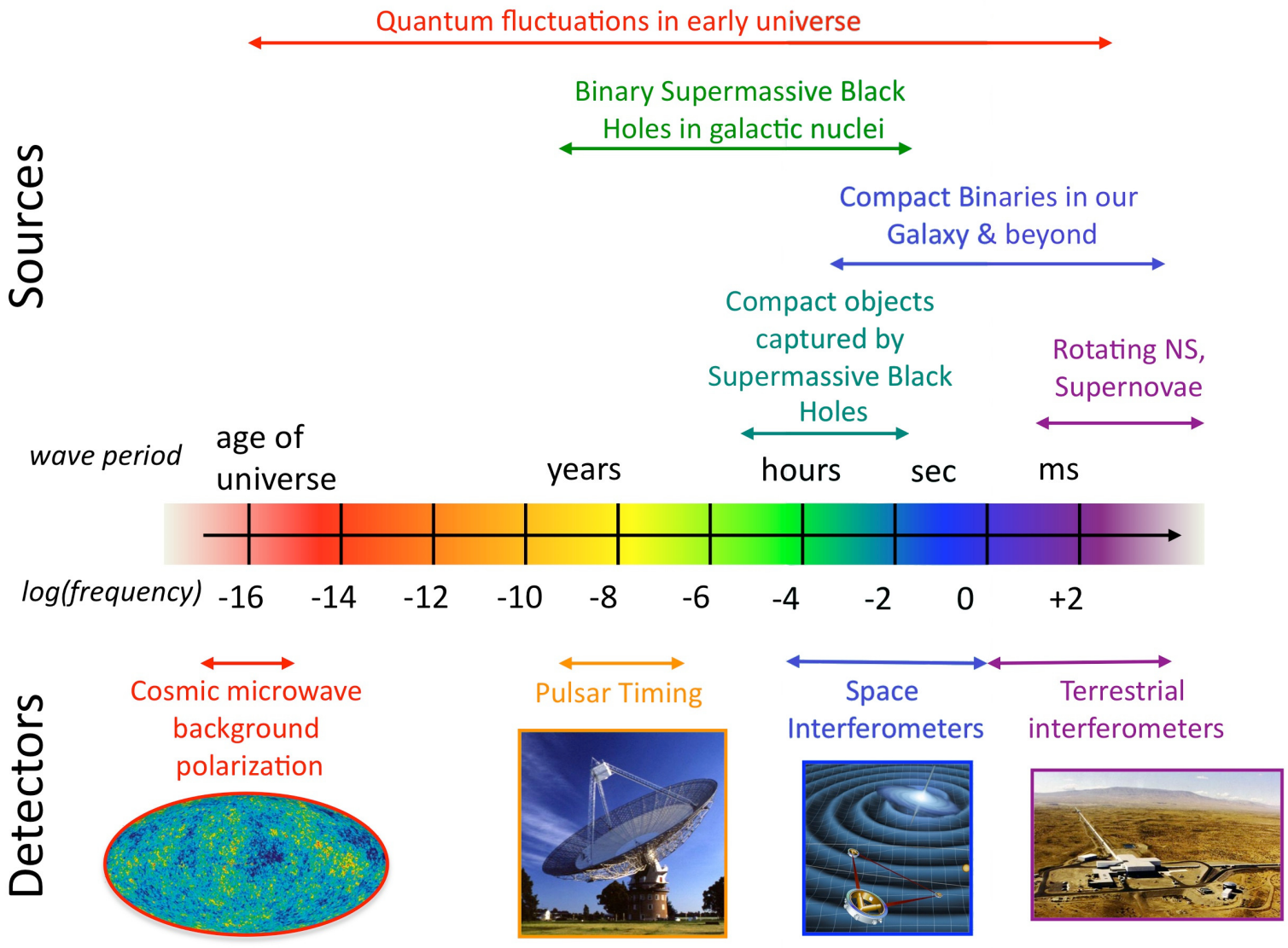
Recent developments on gravitational-wave science

Alexandre Le Tiec

Laboratoire Univers et Théories
Observatoire de Paris / CNRS

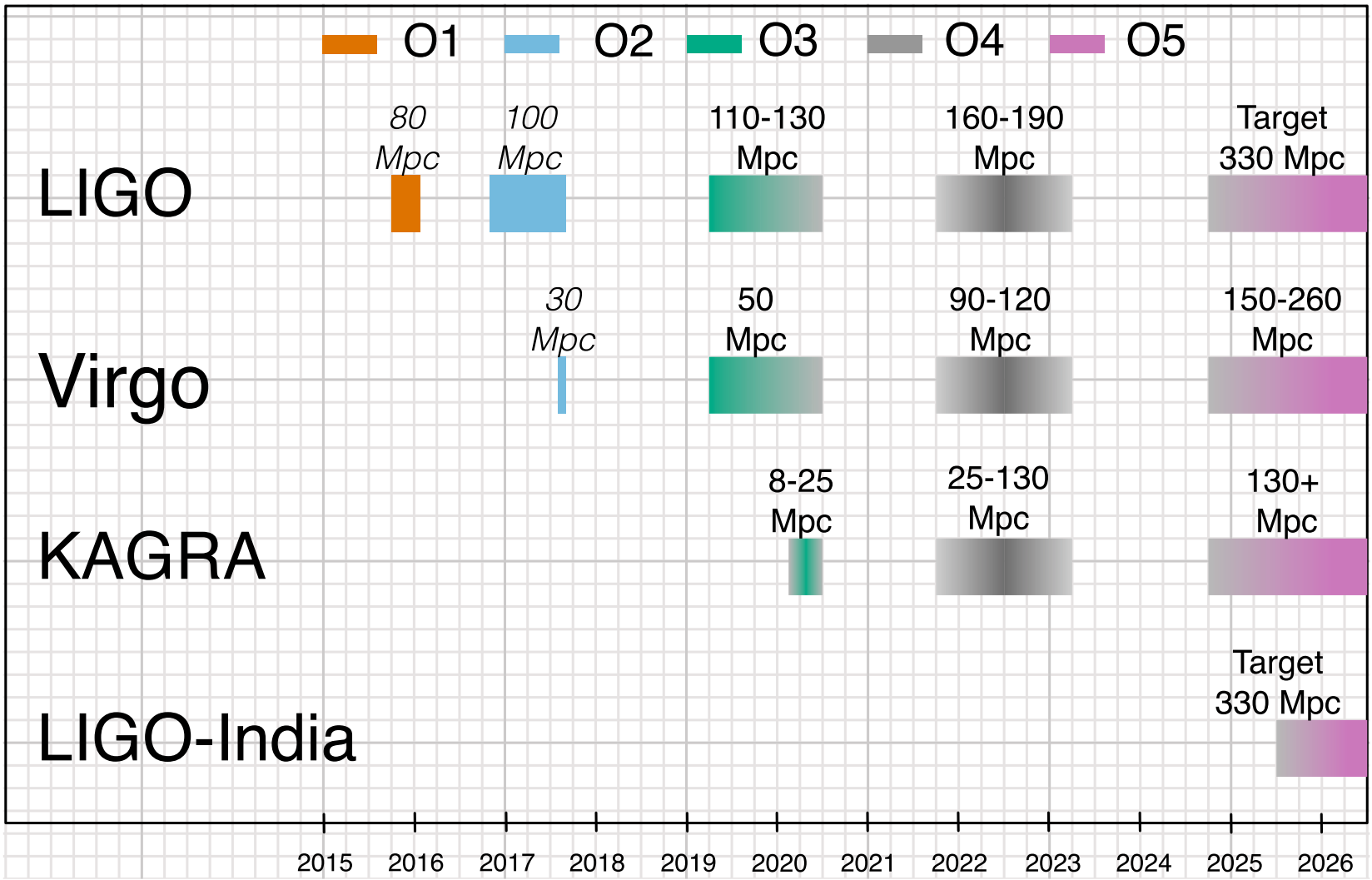


The gravitational-wave spectrum



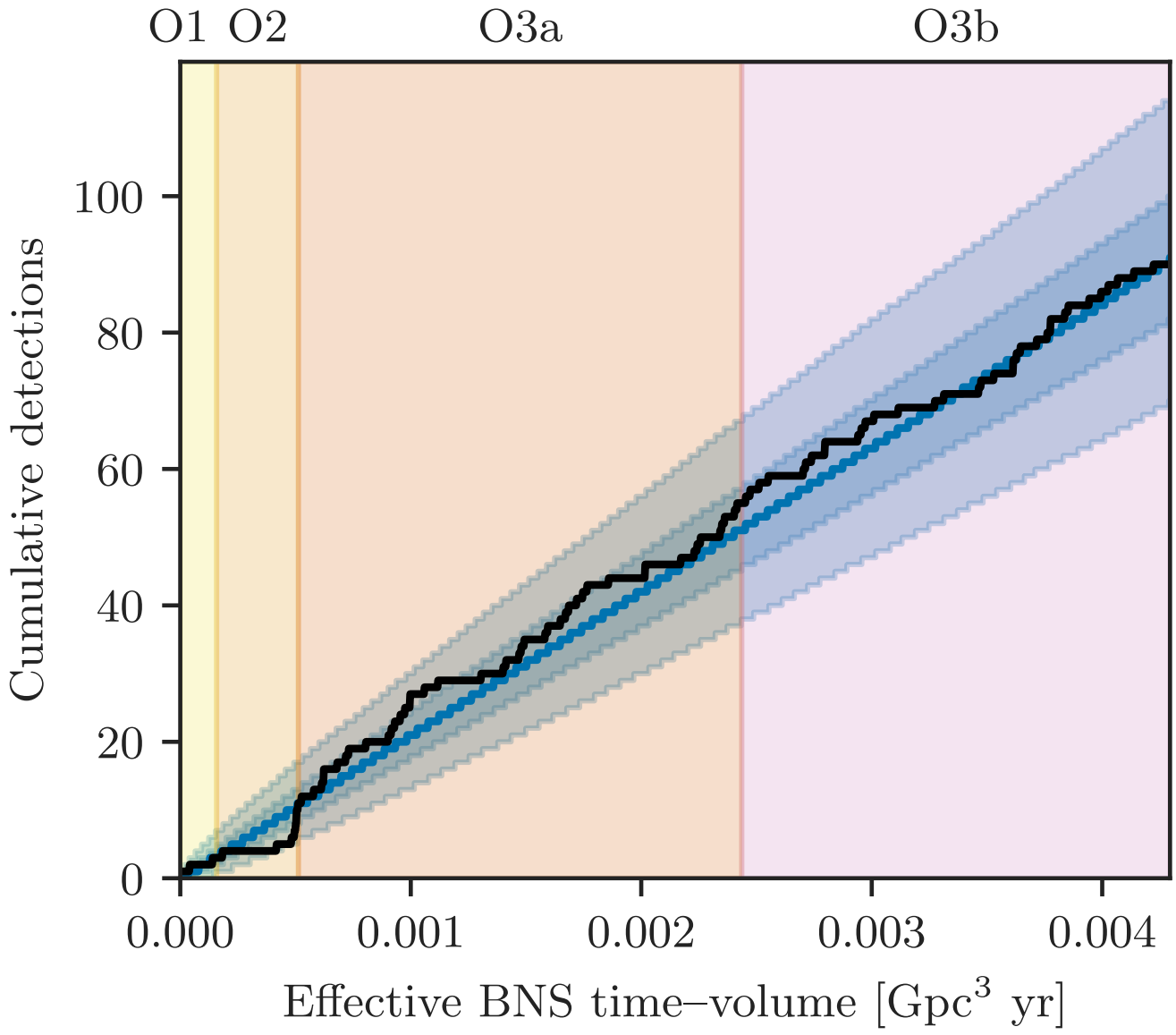
Ground-based interferometric detectors

Roadmap for ground-based detectors

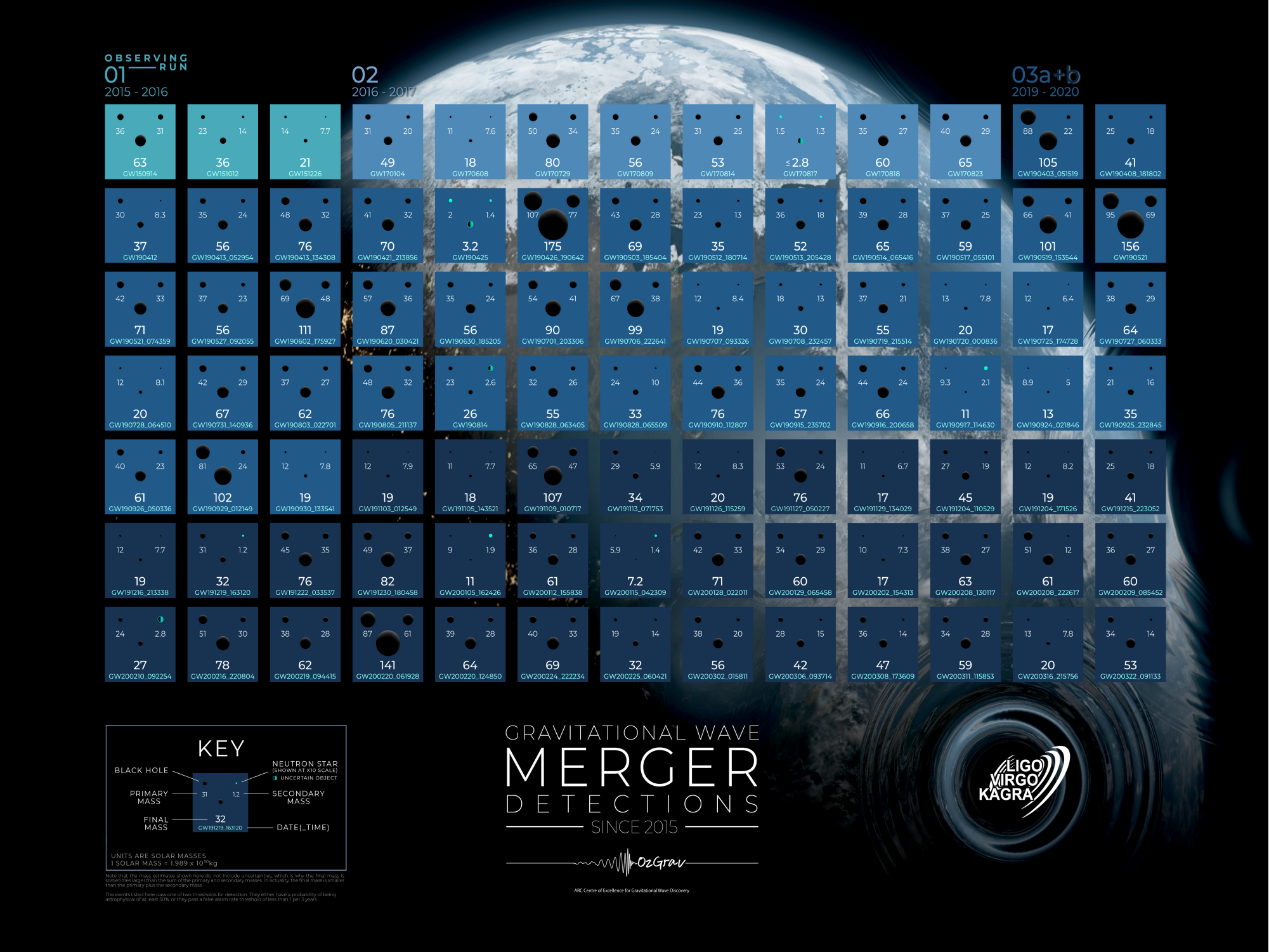


[LRR **23** (2020) 3]

Current gravitational-wave detections



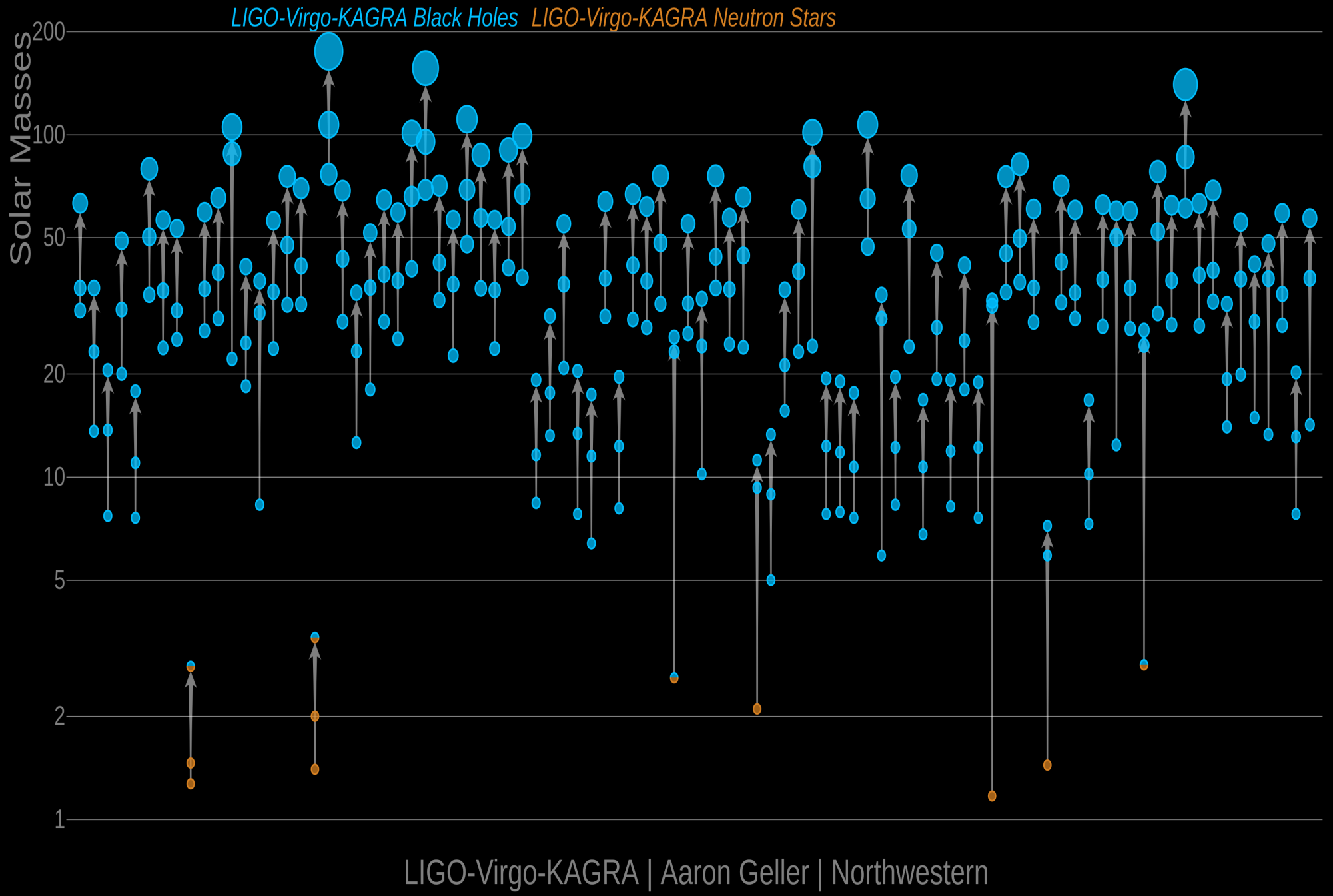
[LIGO-P2000318 (2021)]

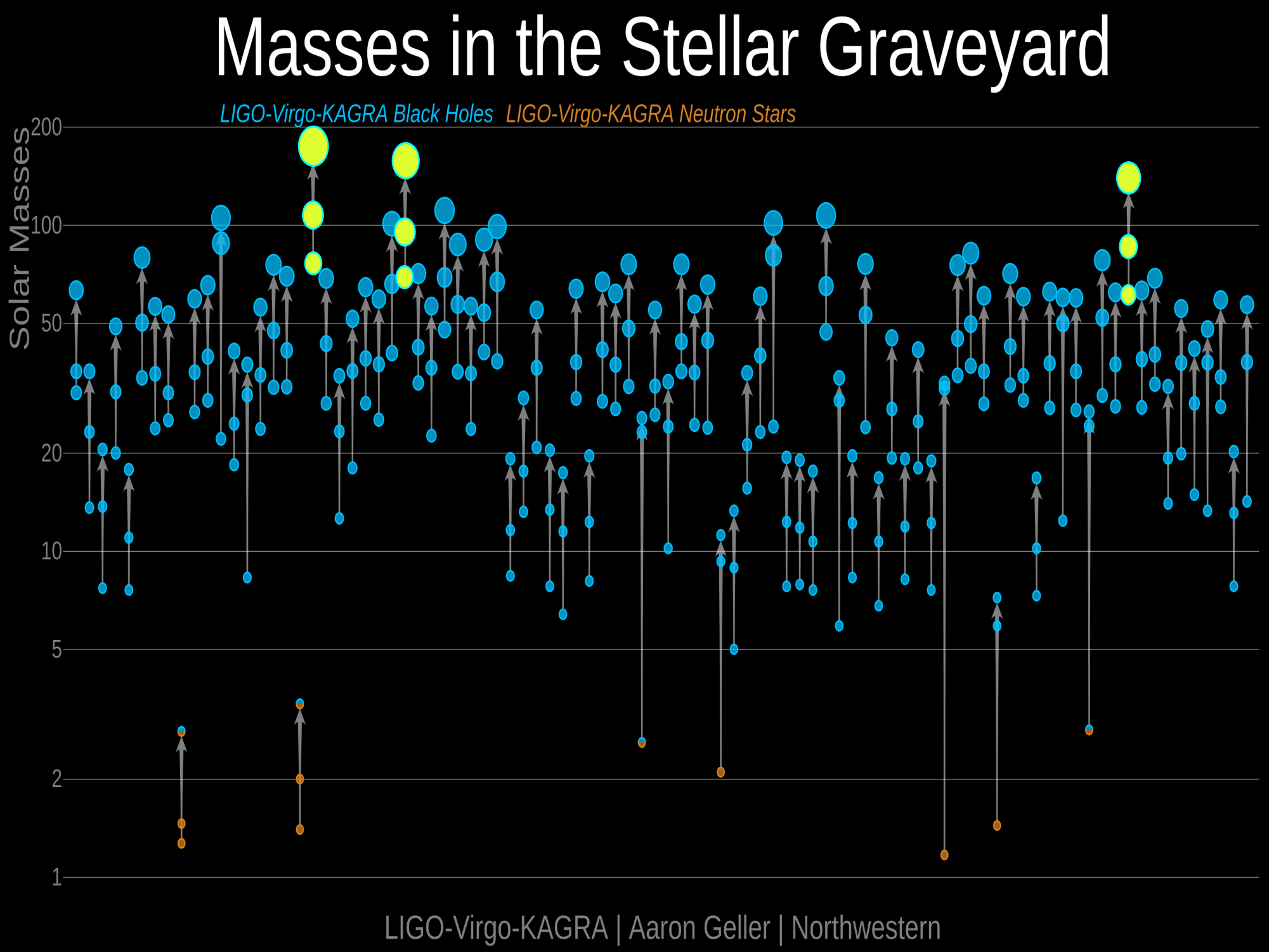


Note that the mass estimates shown here do not include uncertainties, which is why the final mass is sometimes larger than the sum of the primary and secondary masses. In actuality, the final mass is smaller than the primary plus the secondary mass.

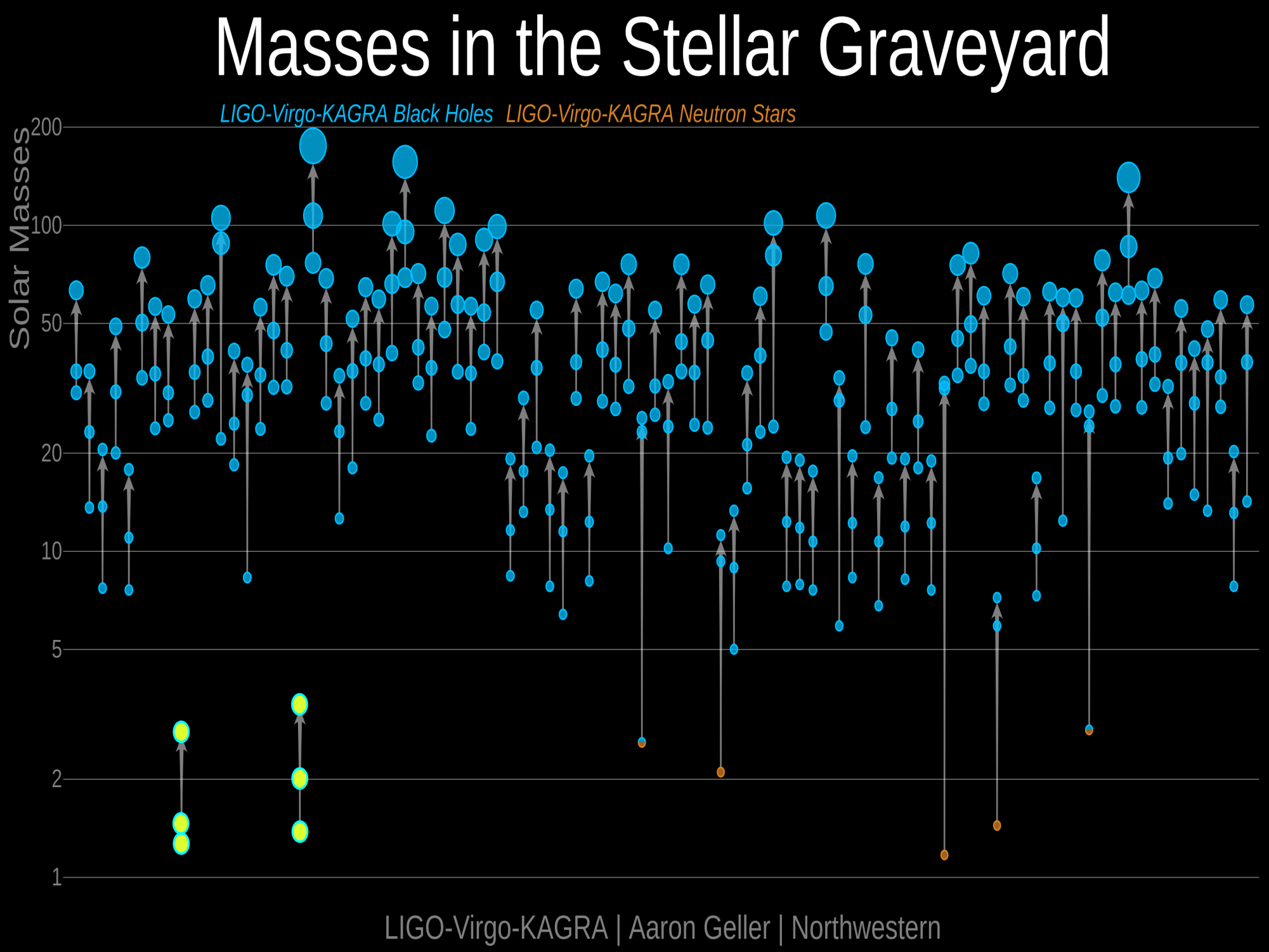
The events listed here pass one of two thresholds for detection. They either have a probability of being astrophysical of at least 50%, or they pass a false alarm rate threshold of less than 1 per 3 years.

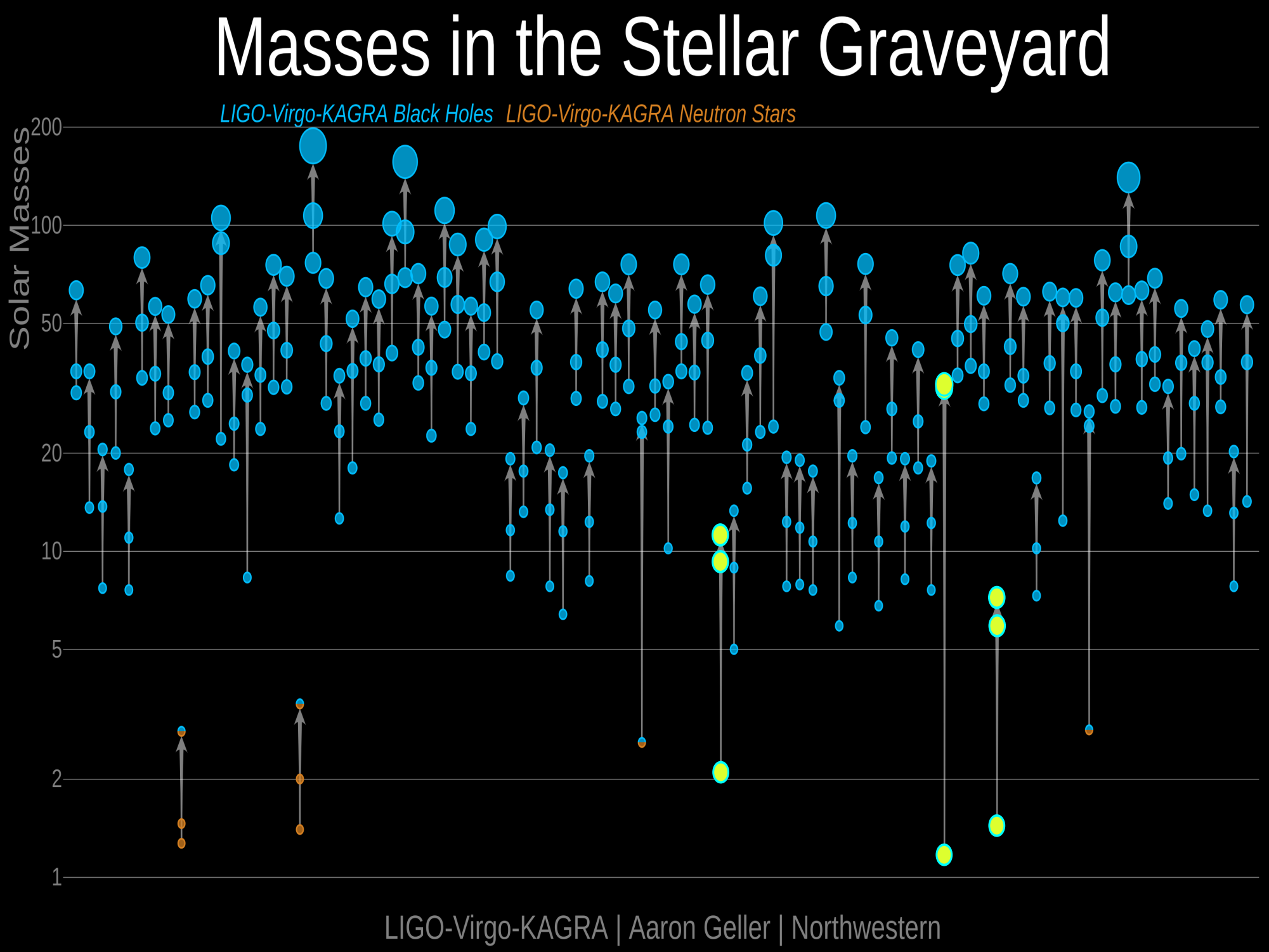
Masses in the Stellar Graveyard




Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

Masses in the Stellar Graveyard

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Gravitational-wave science

Fundamental physics

- Strong-field tests of GR
- Black hole no-hair theorem
- Cosmic censorship conjecture
- Dark energy equation of state
- Alternatives to general relativity

Astrophysics

- Formation and evolution of compact binaries
- Origin and mechanisms of γ-ray bursts
- Internal structure of neutron stars

Cosmology

- Cosmography and measure of Hubble's constant
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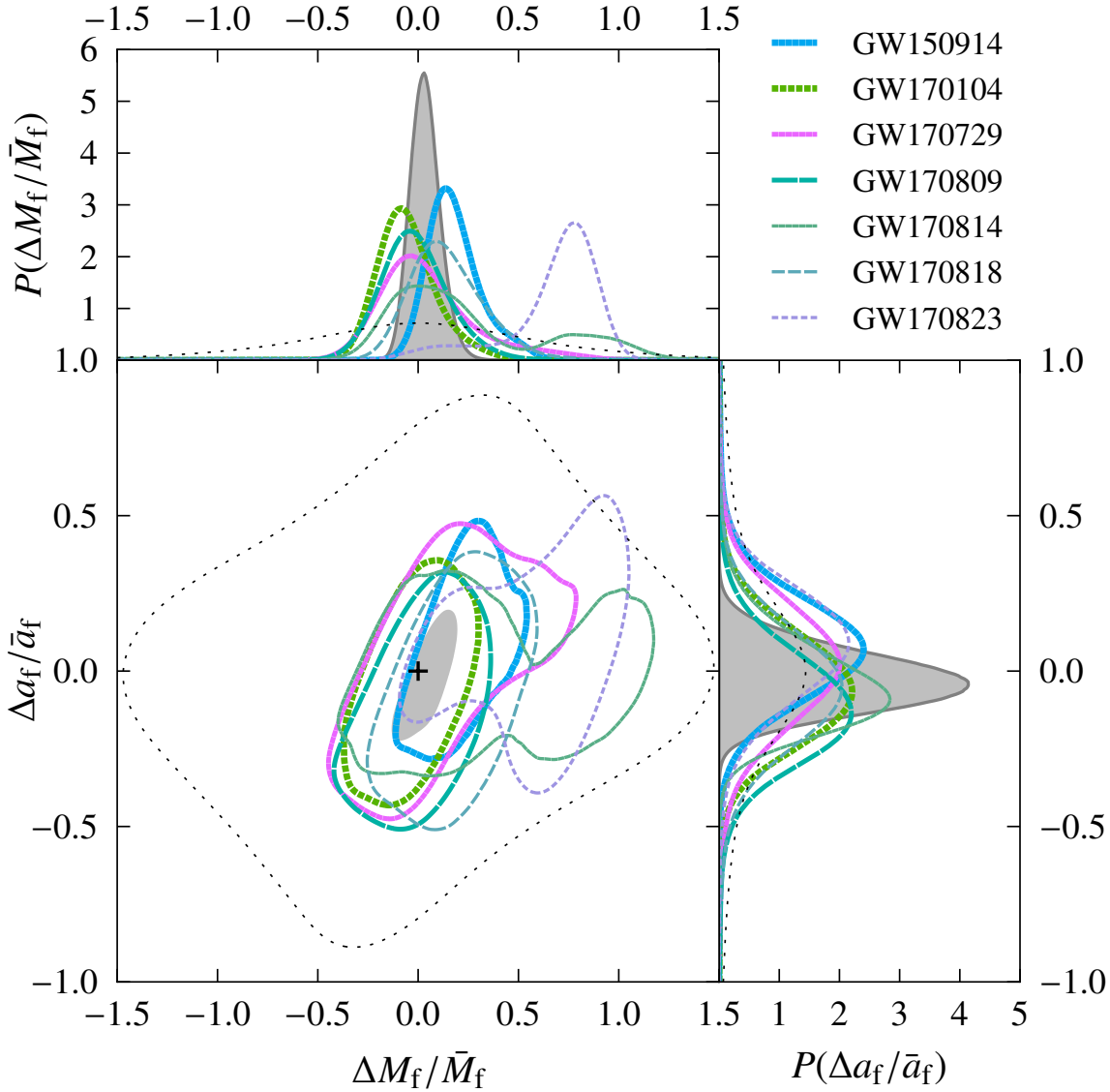
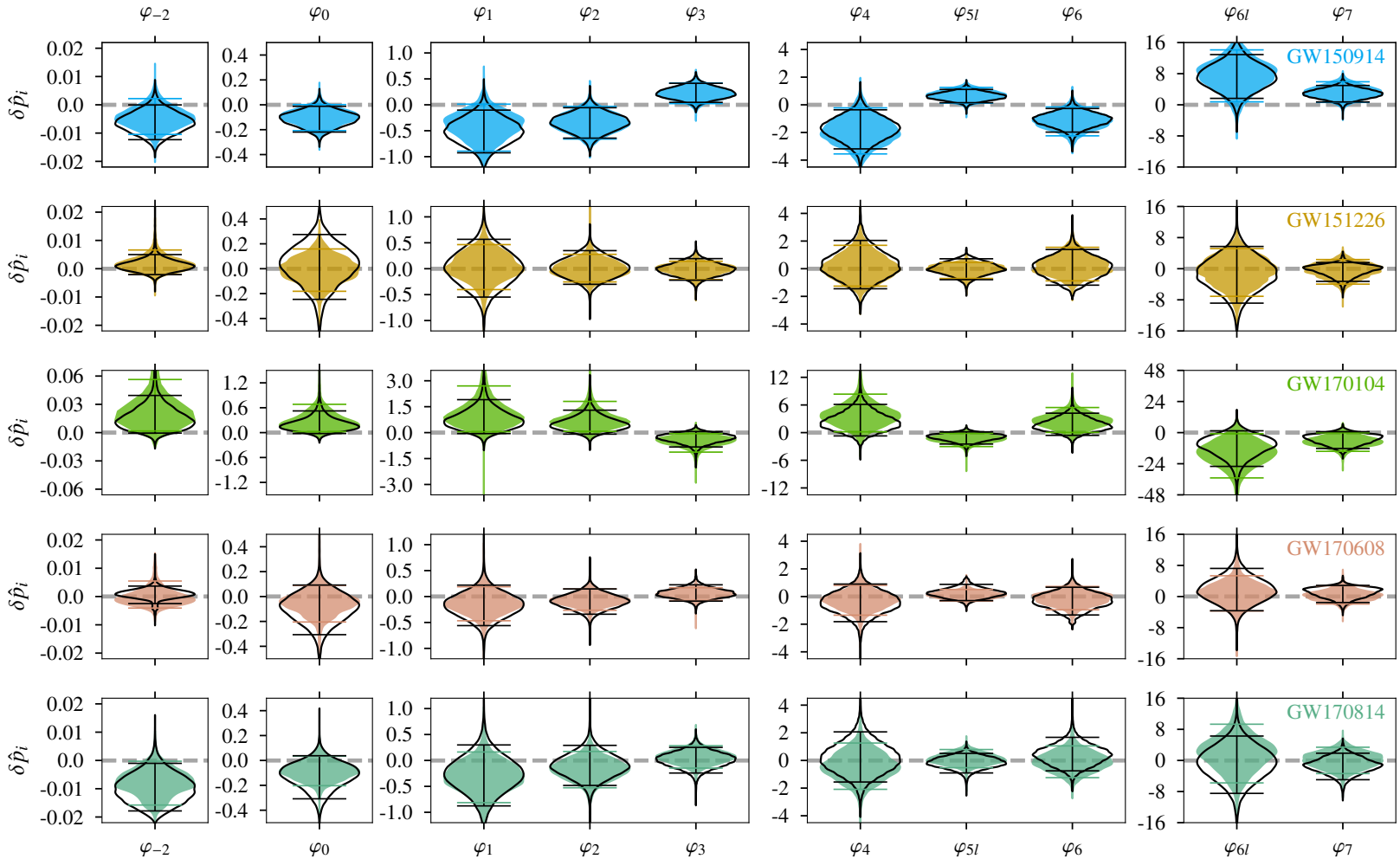
Consistency test for final mass and spin



[PRD **100** (2019) 104036]

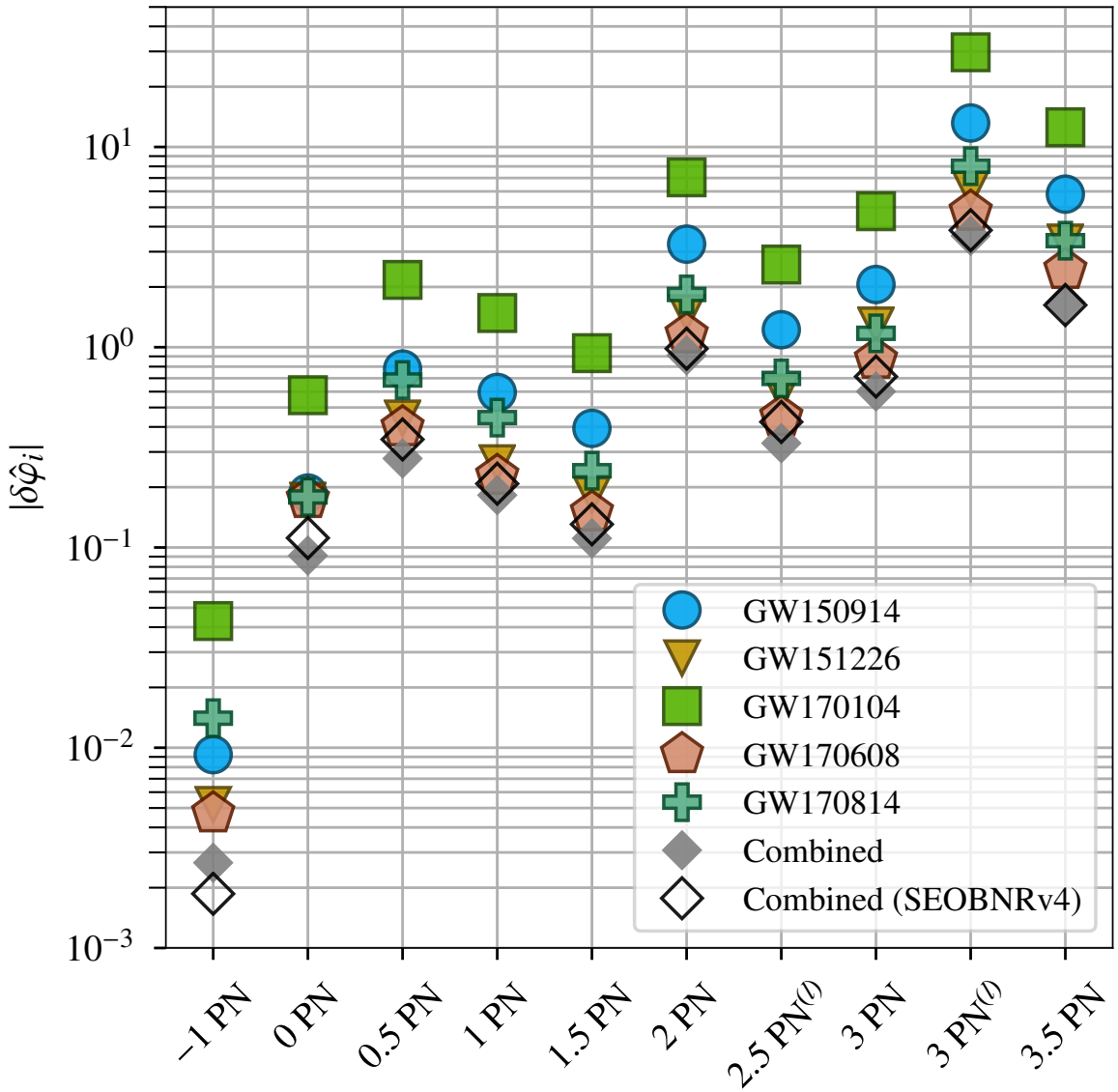
Constraining post-Newtonian parameters



$$\Phi(f) \propto \sum_{i=-2}^{7} \varphi_i \, f^{(i-5)/3}$$

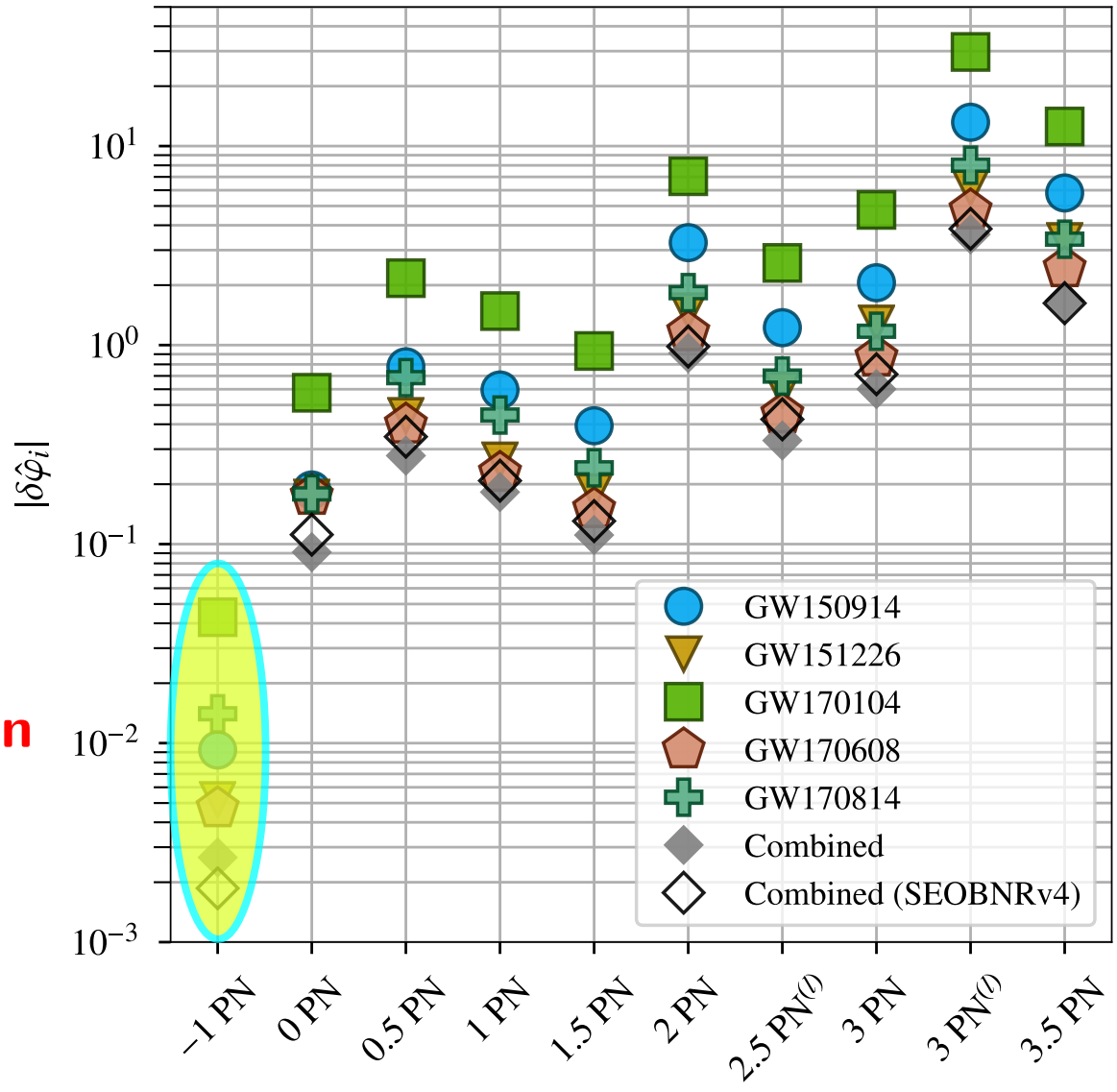
[PRD **100** (2019) 104036]

Constraining post-Newtonian parameters



[PRD **100** (2019) 104036]

Constraining post-Newtonian parameters

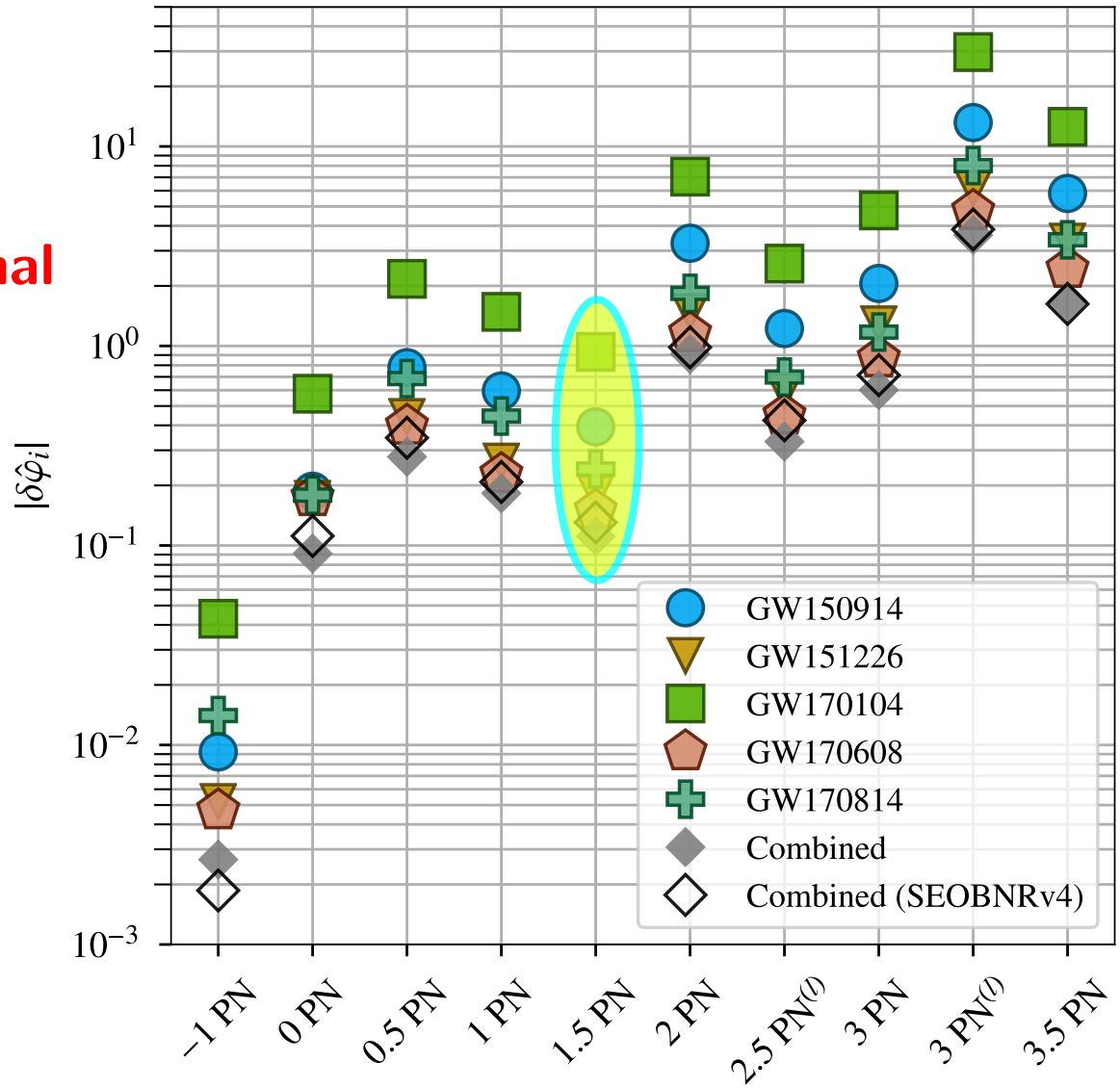


dipolar radiation

[PRD **100** (2019) 104036]

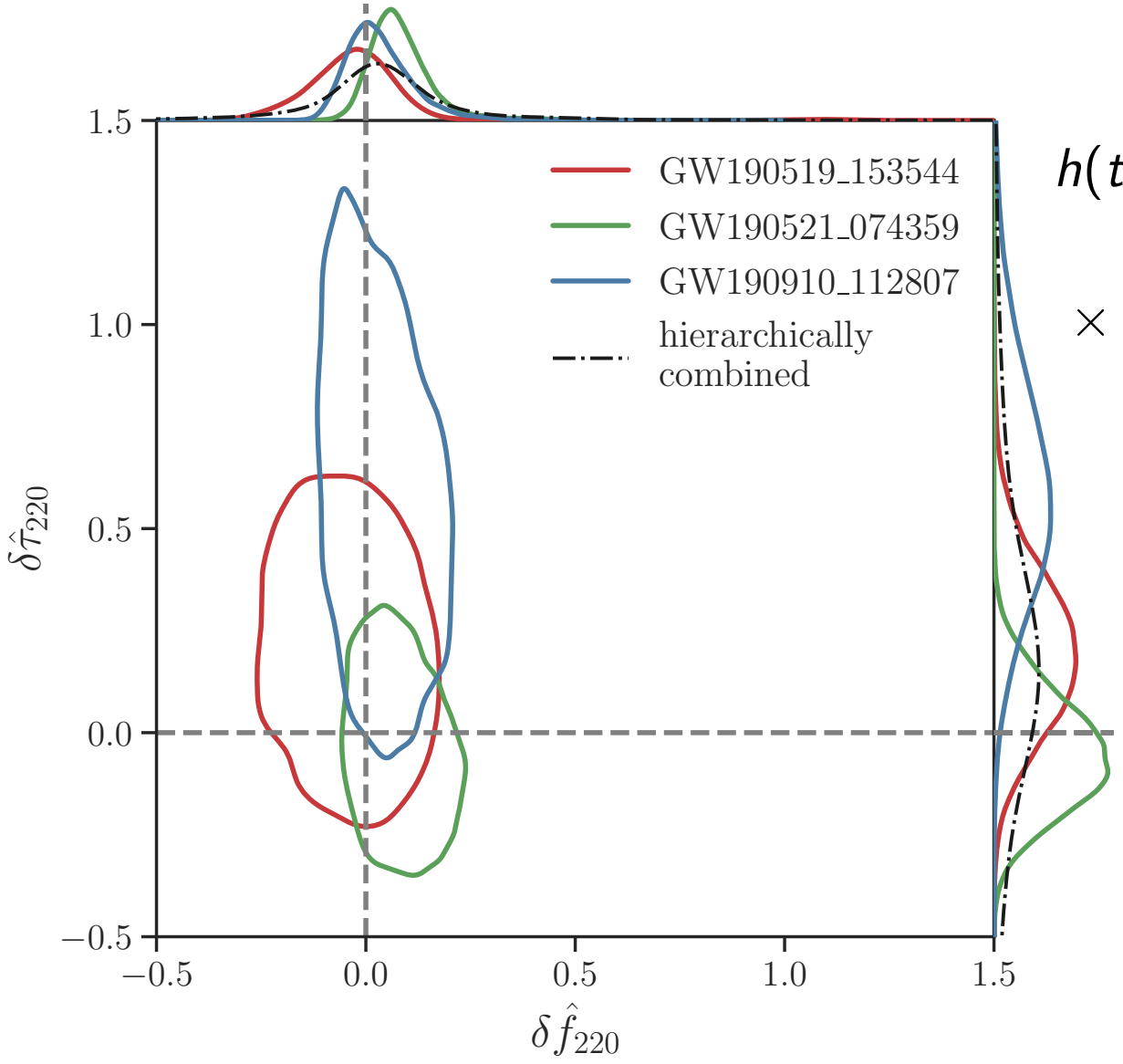
Constraining post-Newtonian parameters

gravitational wave tail



[PRD **100** (2019) 104036]

Null test for Kerr black hole ringdown



$$h(t) \propto \sum_{lmn} e^{-t/\tau_{lmn}} \times \cos(2\pi f_{lmn} t + \phi_{lmn})$$

[PRD **103** (2021) 122002]

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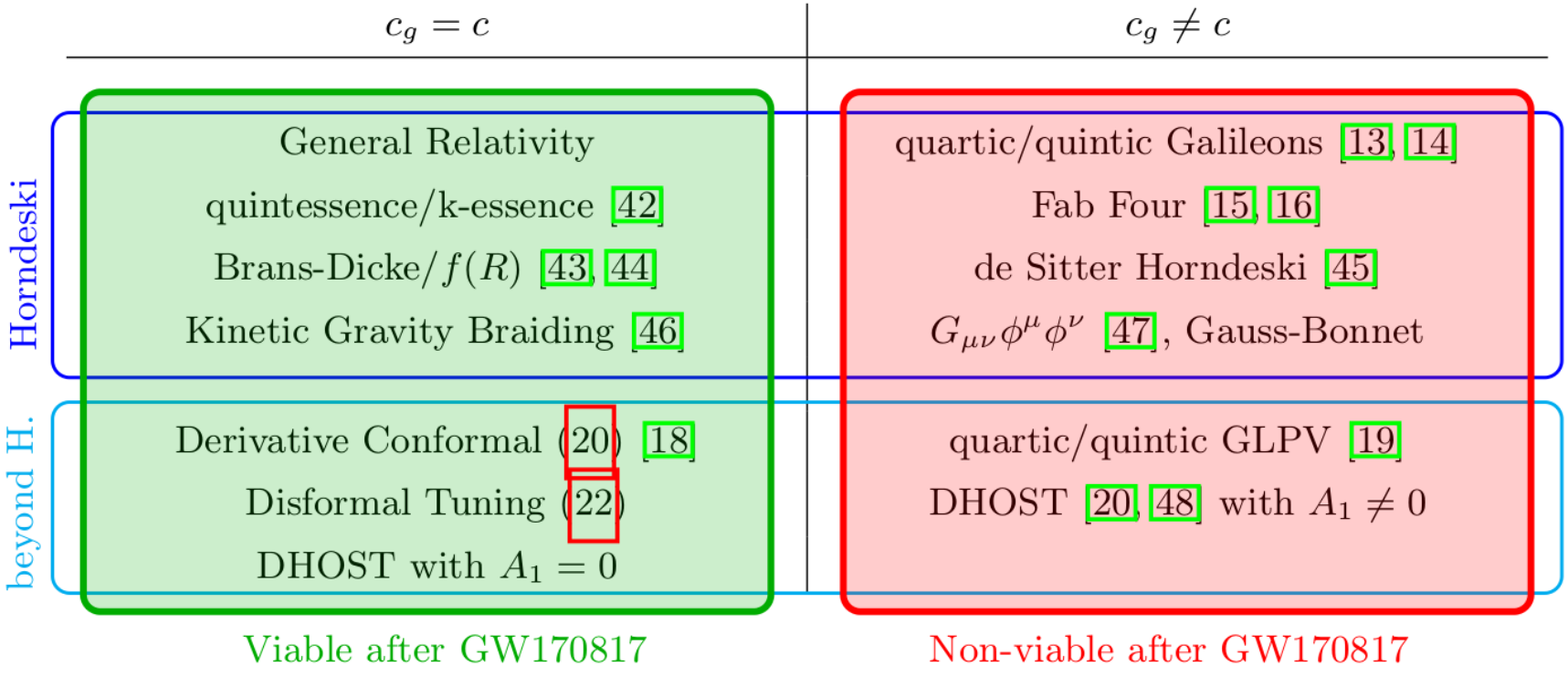
Falsifying scalar-tensor theories



$$|c_g/c - 1| < 10^{-15}$$

[PRL **119** (2017) 251304]

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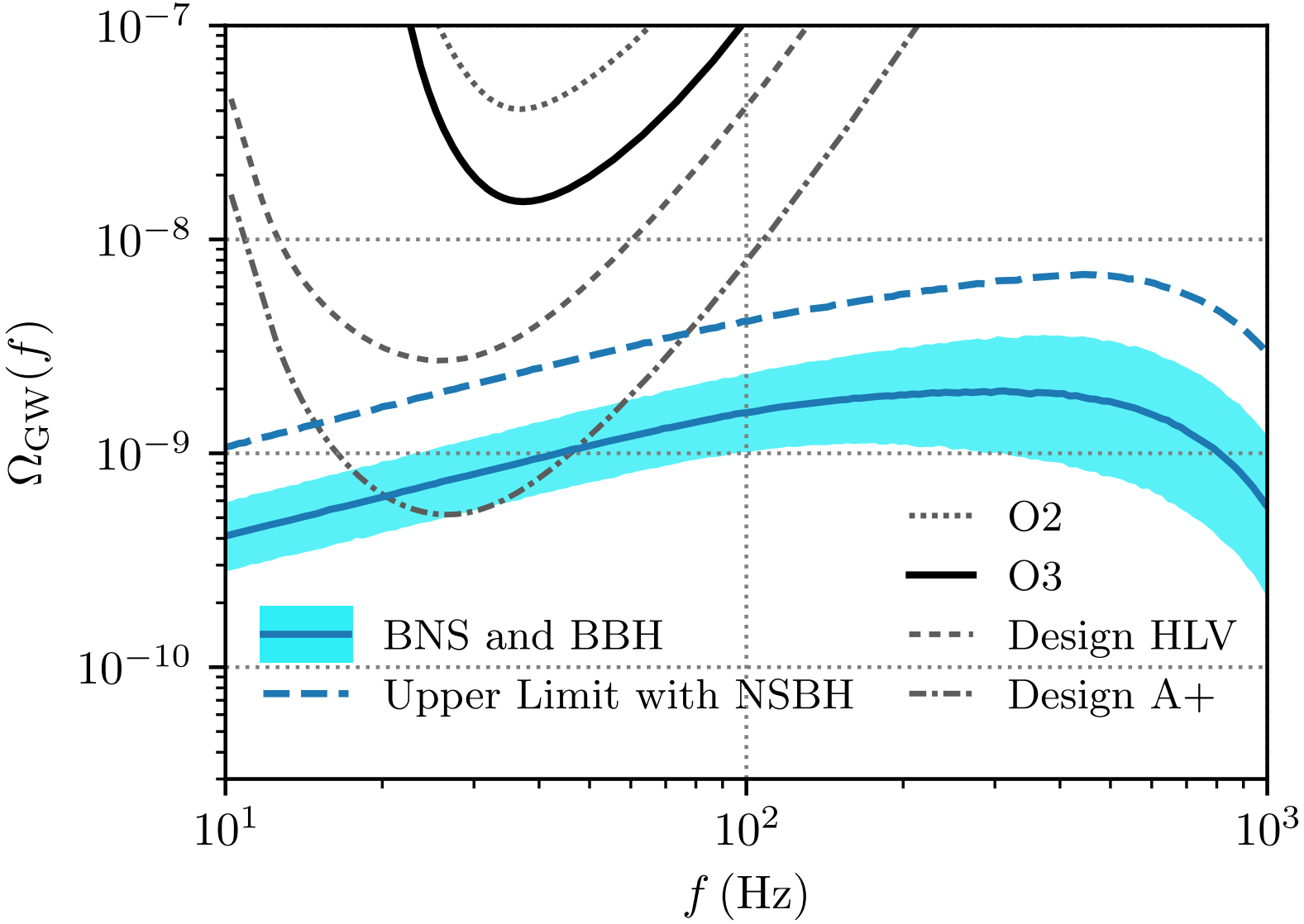
Isotropic gravitational-wave background



[PRD **104** (2021) 022004]

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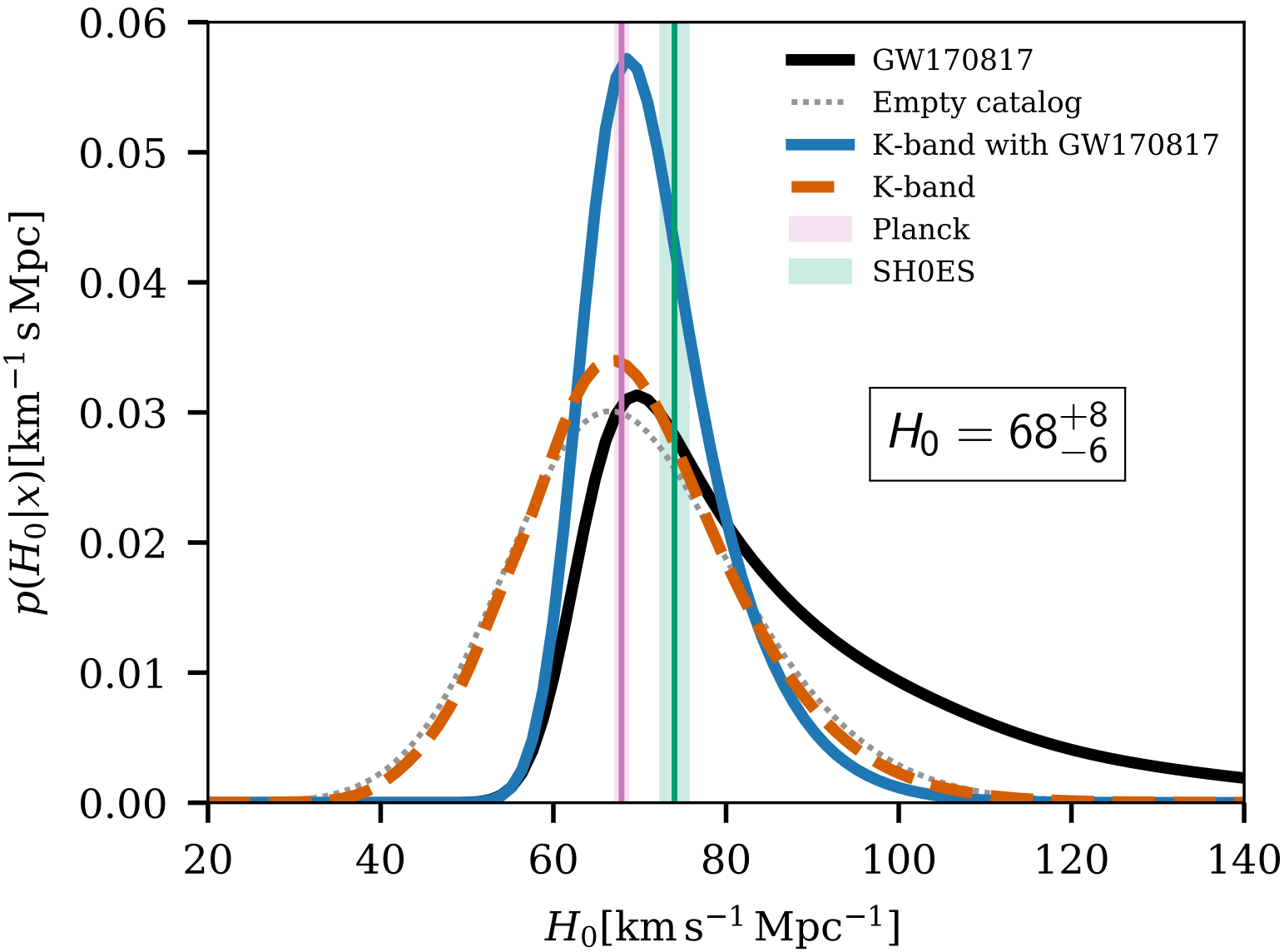
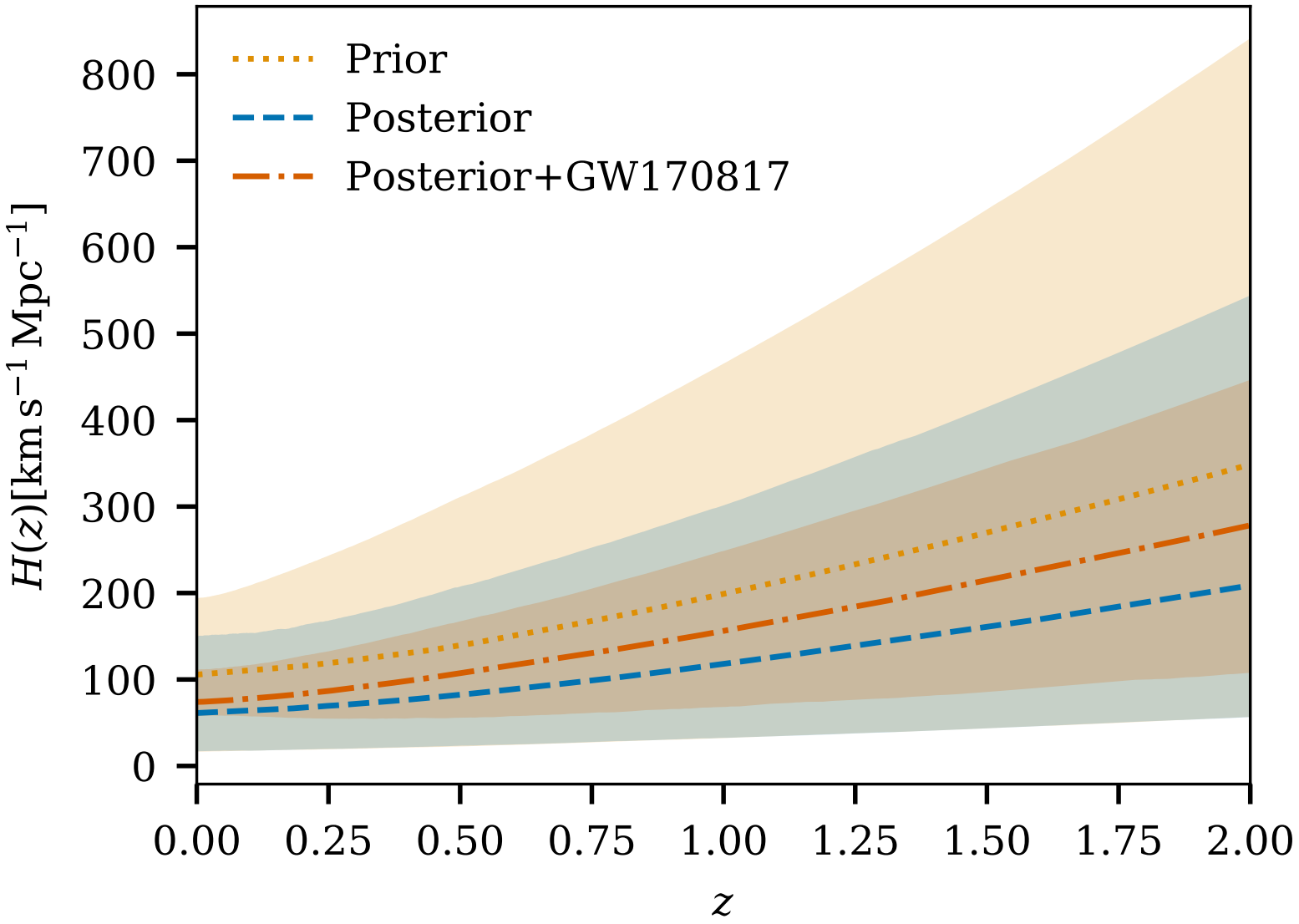
Independent measure of Hubble's constant



[LIGO-P2100185 (2021)]

Evolution of the Hubble parameter



[LIGO-P2100185 (2021)]

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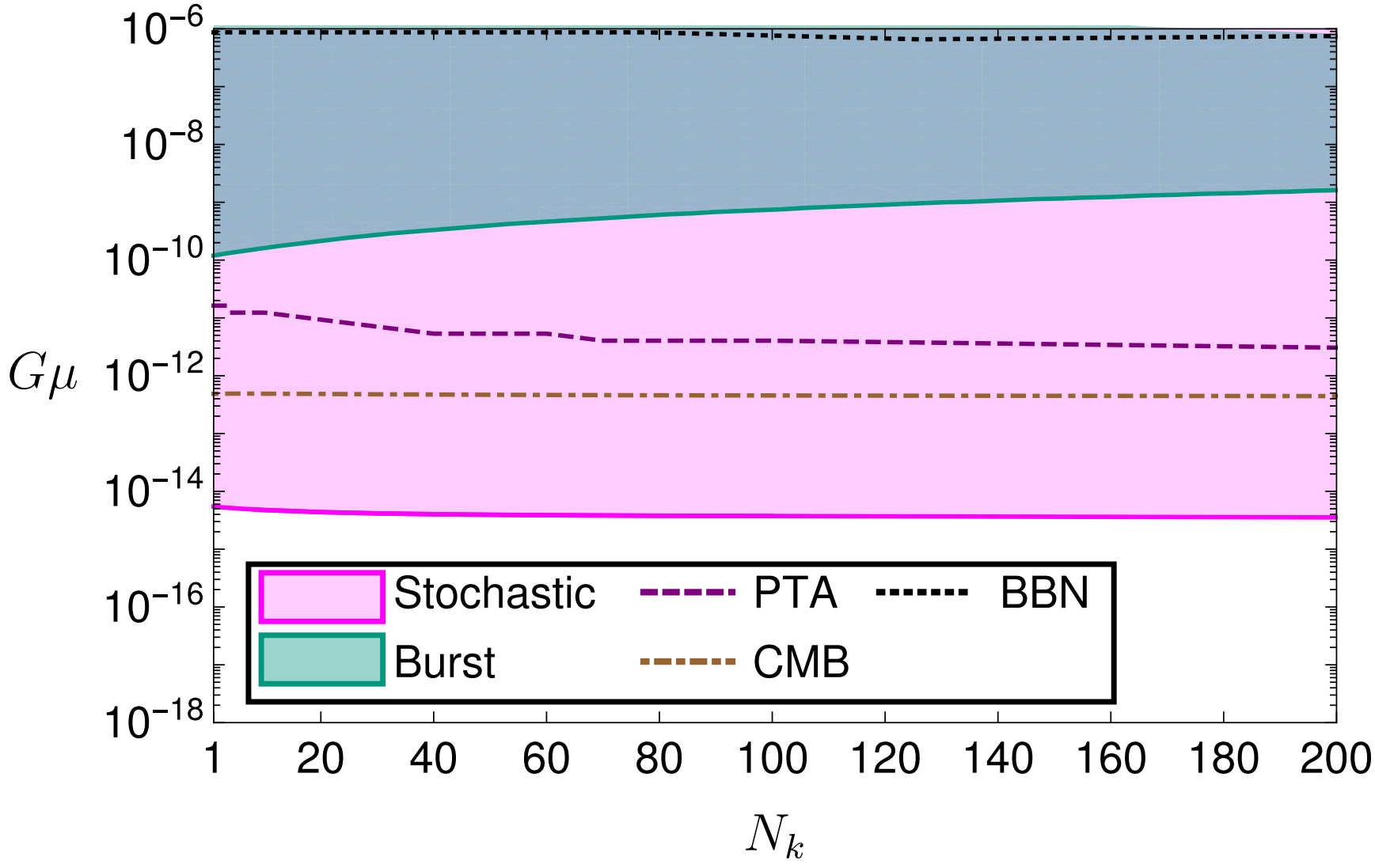
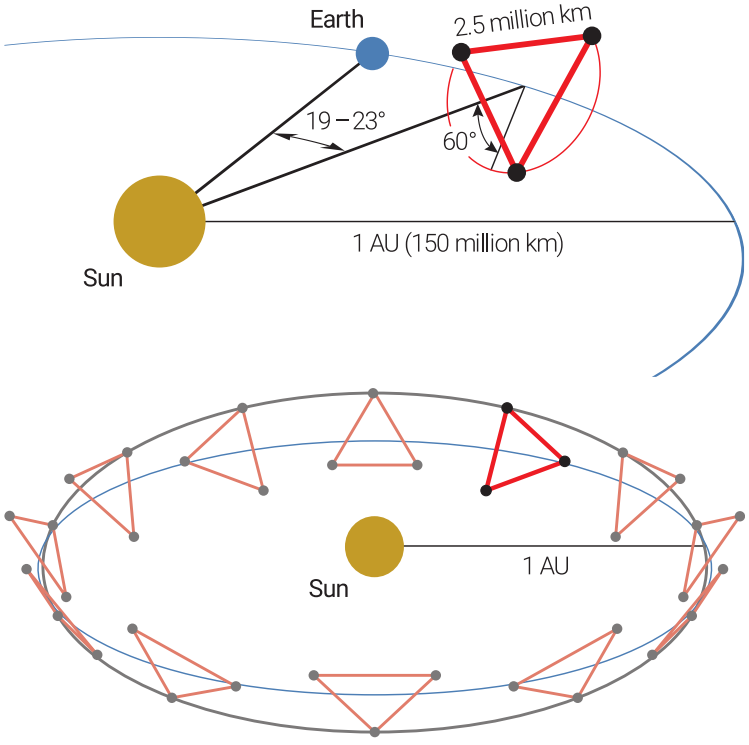
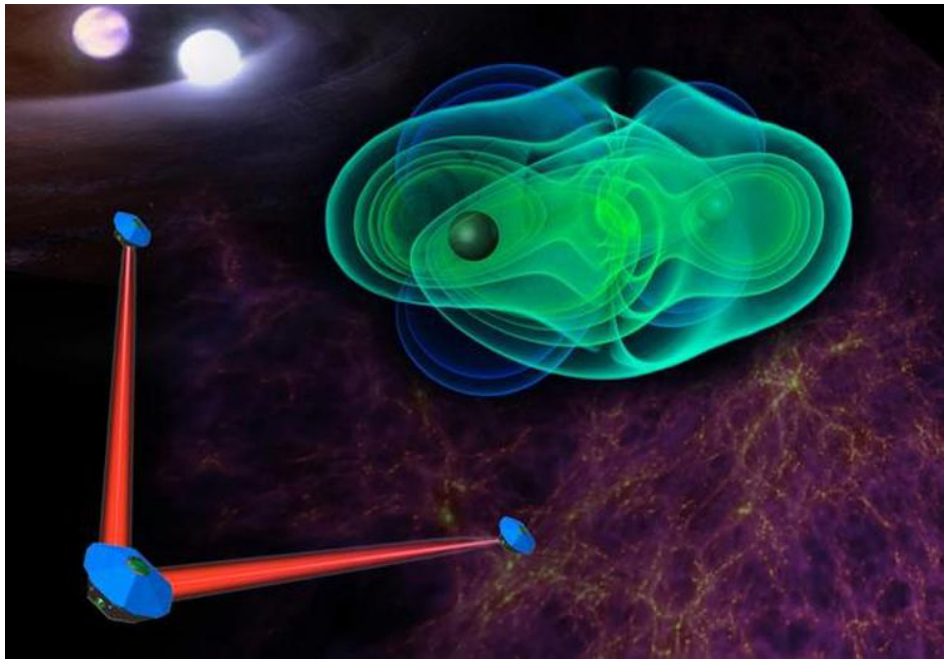
Constraints on cosmic strings



[PRL **126** (2021) 241102]

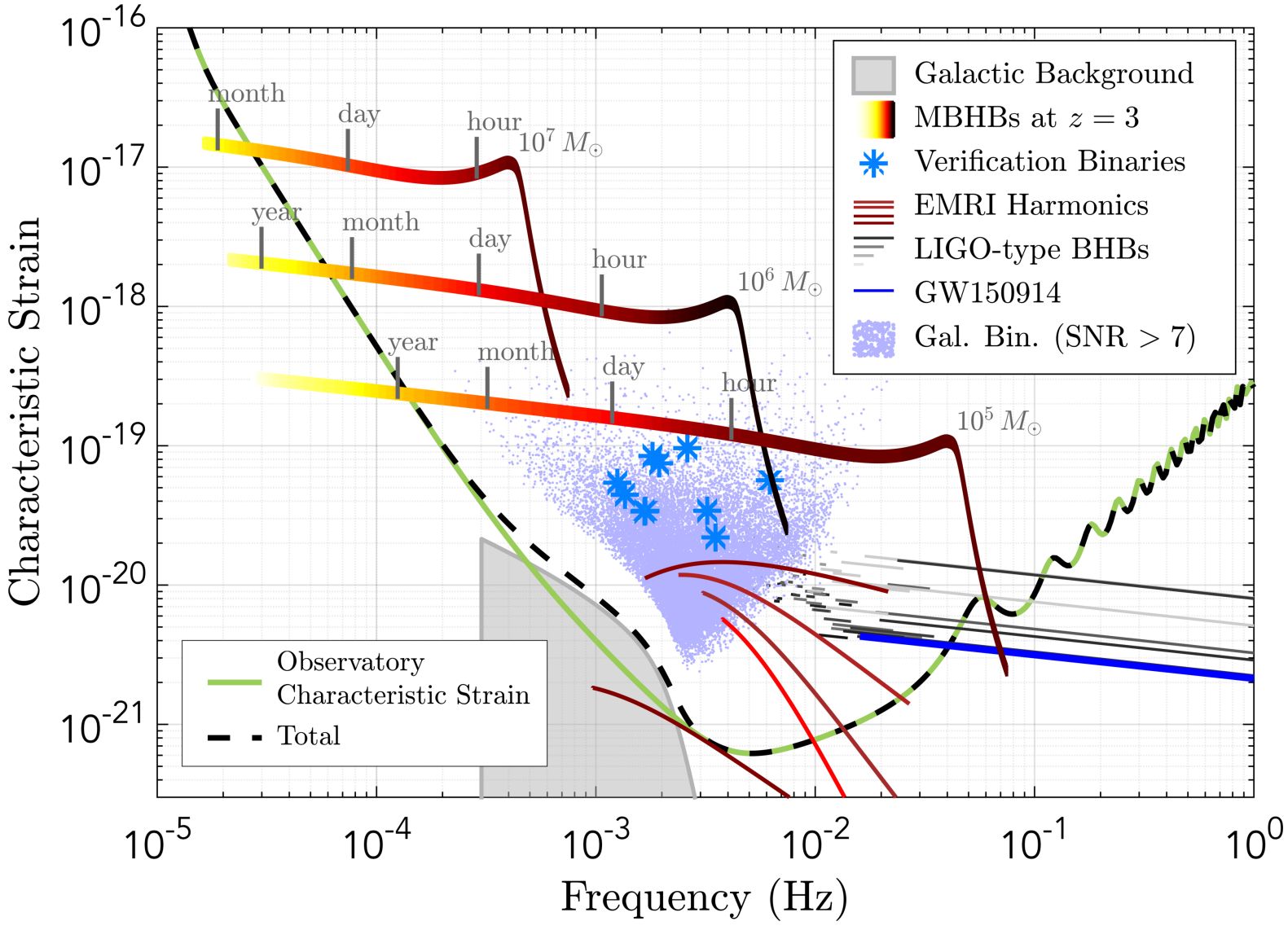
LISA: a gravitational antenna in space



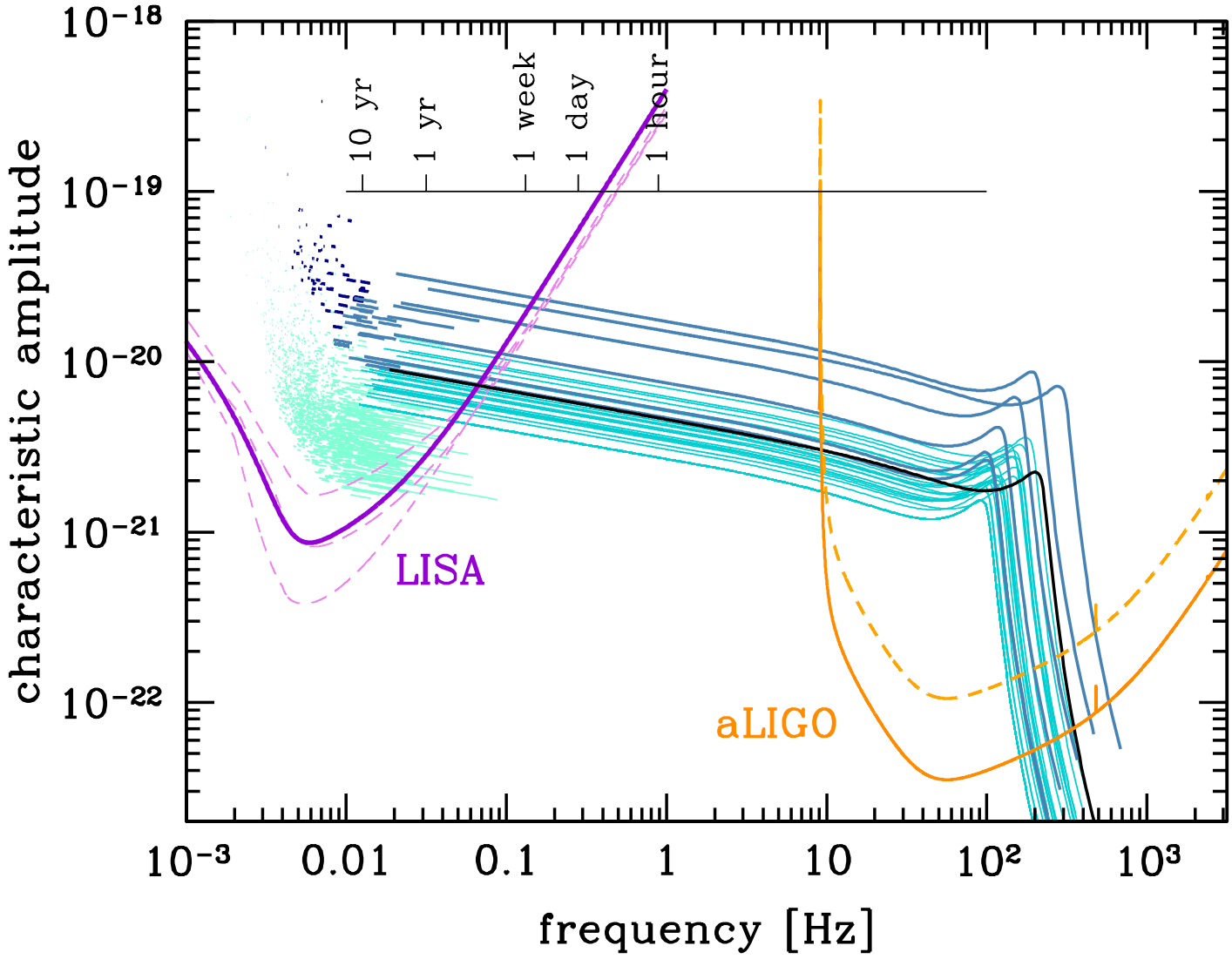


The *LISA mission* proposal was accepted by ESA in 2017 for L3 slot, with a launch planned for 2034 [http://www.lisamission.org]

LISA sources of gravitational waves



Multi-band gravitational-wave astronomy



[PRL **116** (2016) 231102]

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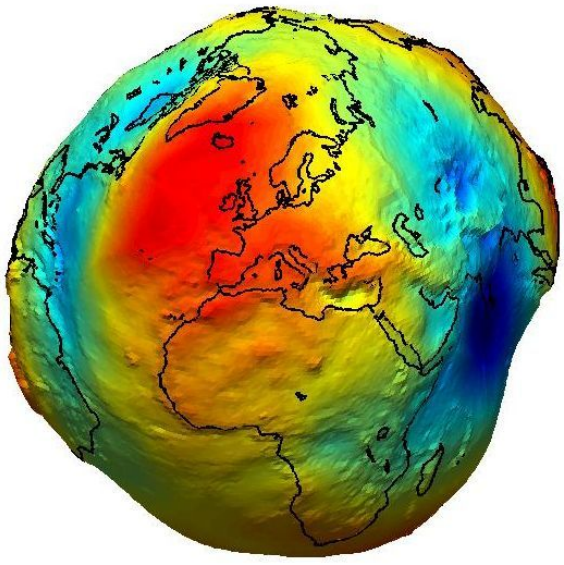
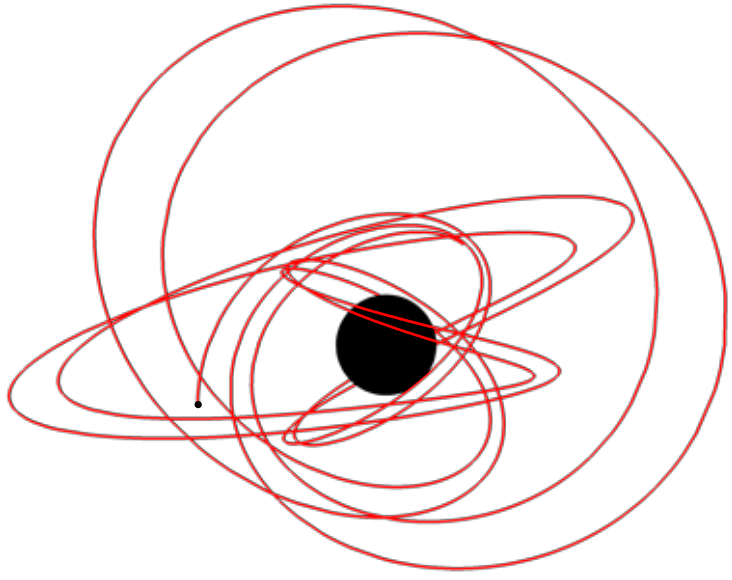
Do black holes have hair?

Geodesy



M_ℓ arbitrary

Botromeladesy



$M_\ell + iS_\ell = M(ia)^\ell$

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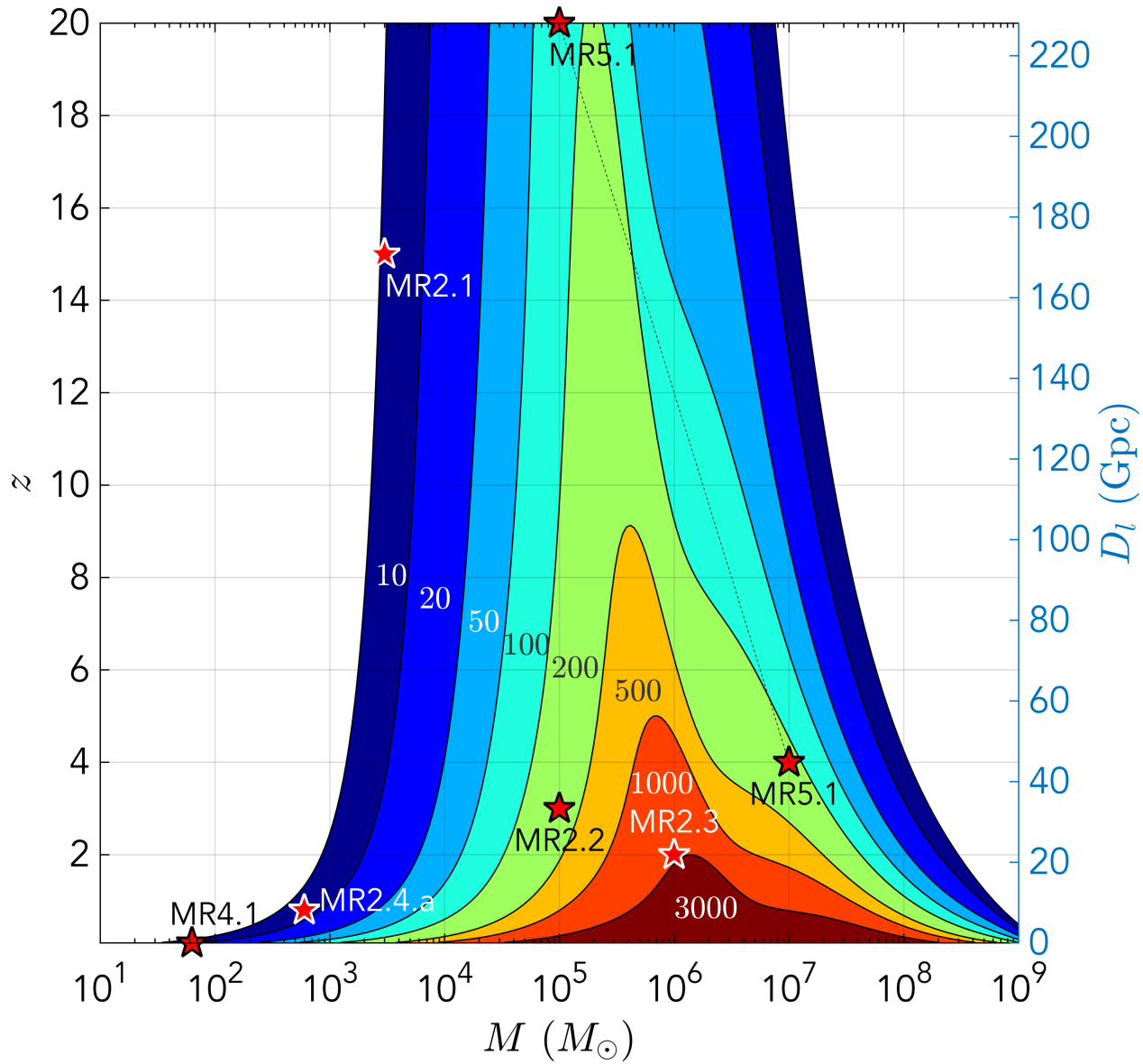
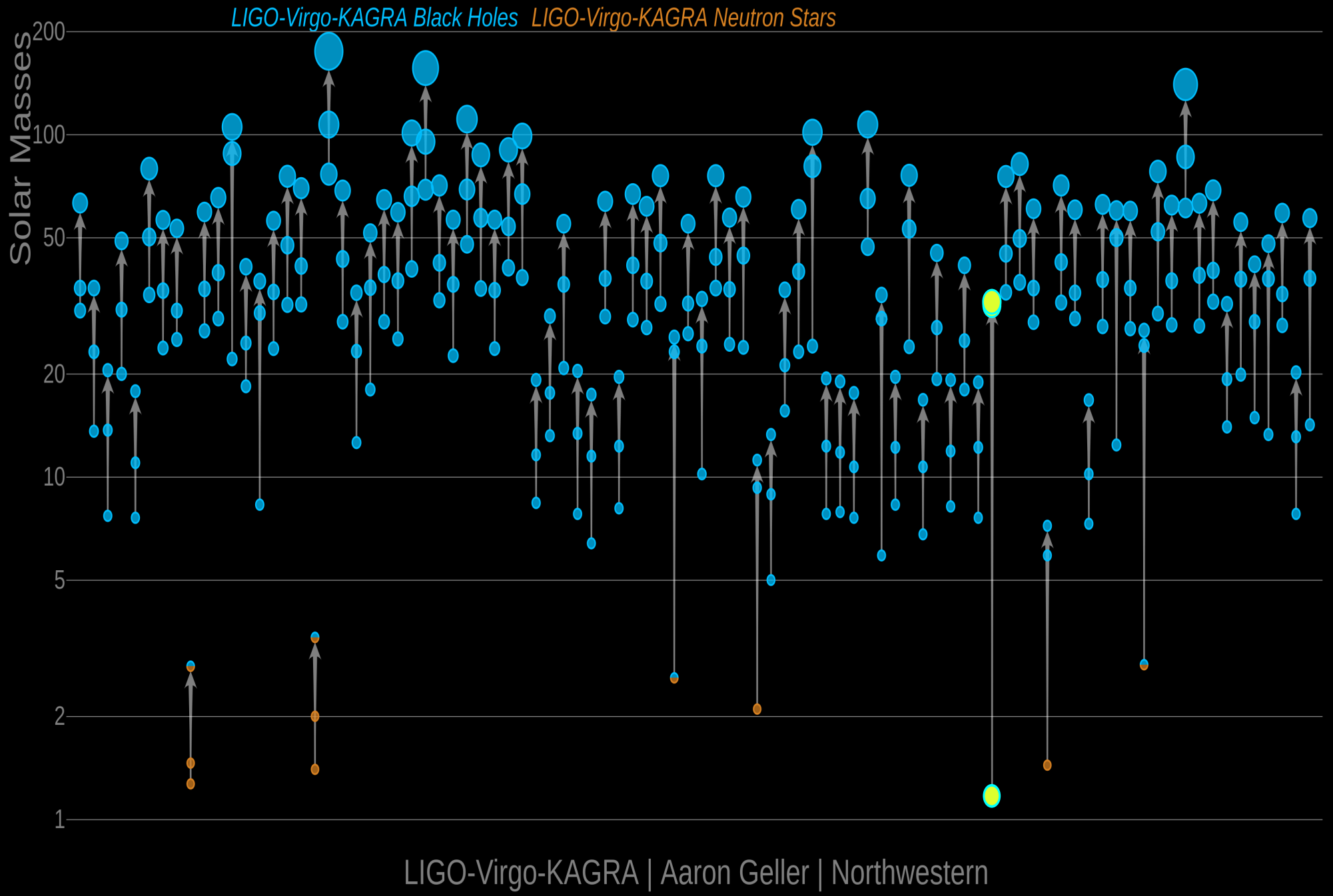
How do massive black holes form?



Masses in the Stellar Graveyard



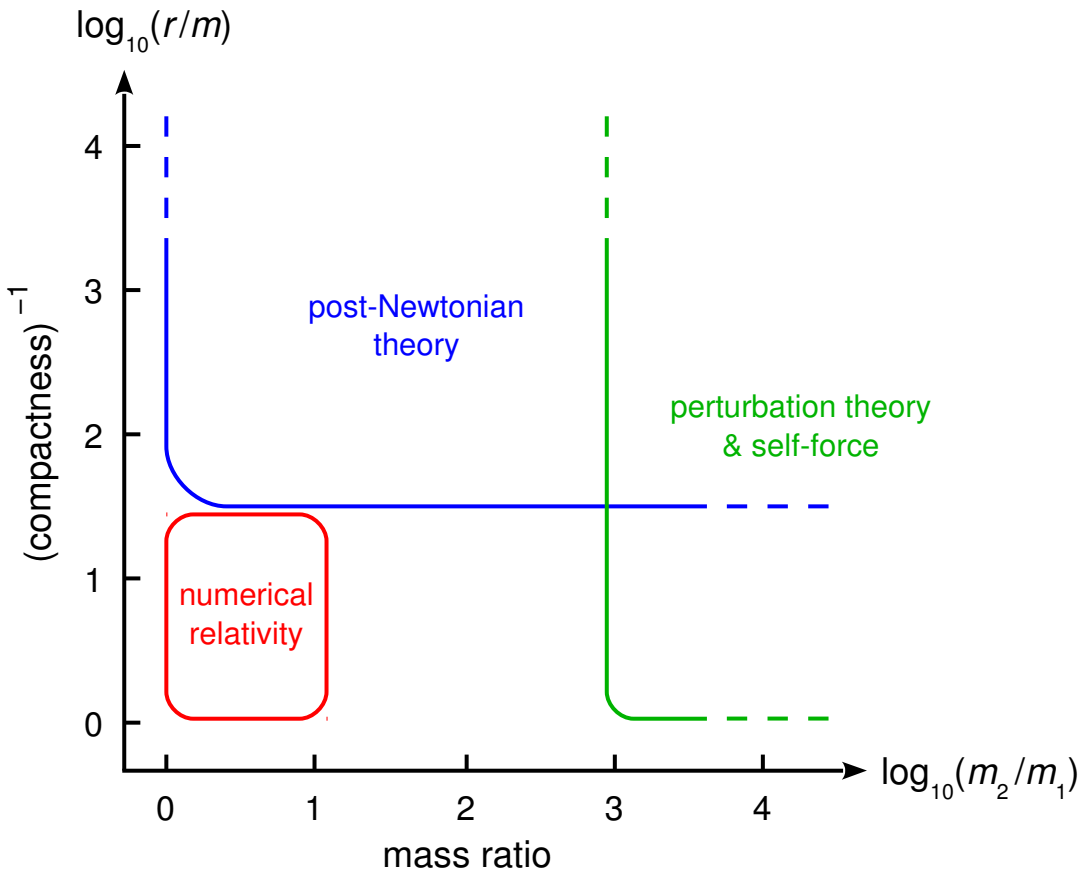
Systematic uncertainties in modeling IMRIs

The mass ratio of GW191219_163120's source is inferred to be $q = 0.038 \pm 0.005$, *which is extremely challenging for waveform modeling, and thus there may be systematic uncertainties in results for this candidate.*

Modeling of higher-order multipole moments is particularly important for inferring the properties of systems with unequal masses, and may impact inference of parameters including the mass ratio, inclination and distance.

[LIGO-P2000318 (2021)]

Modeling coalescing compact binaries



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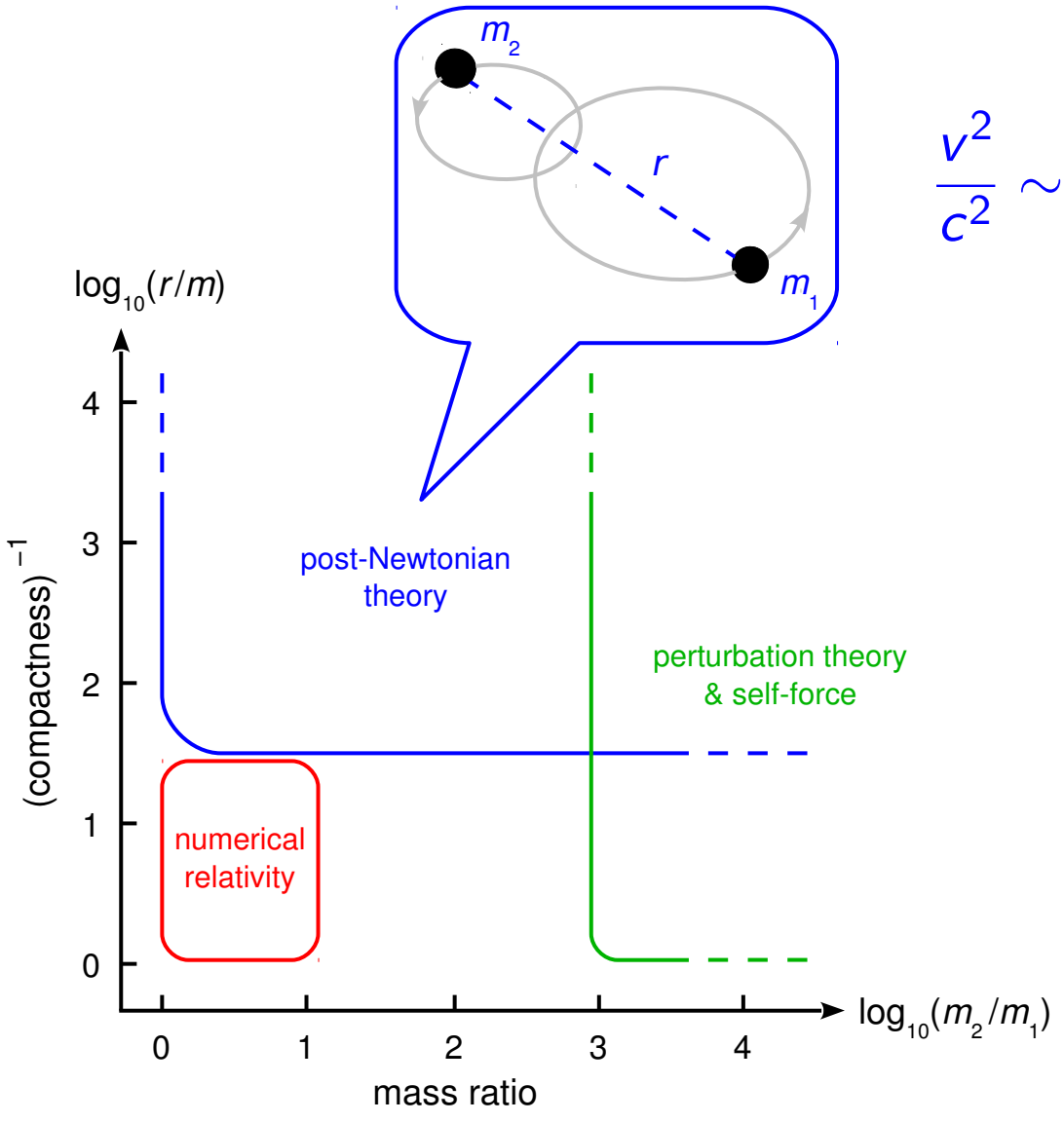
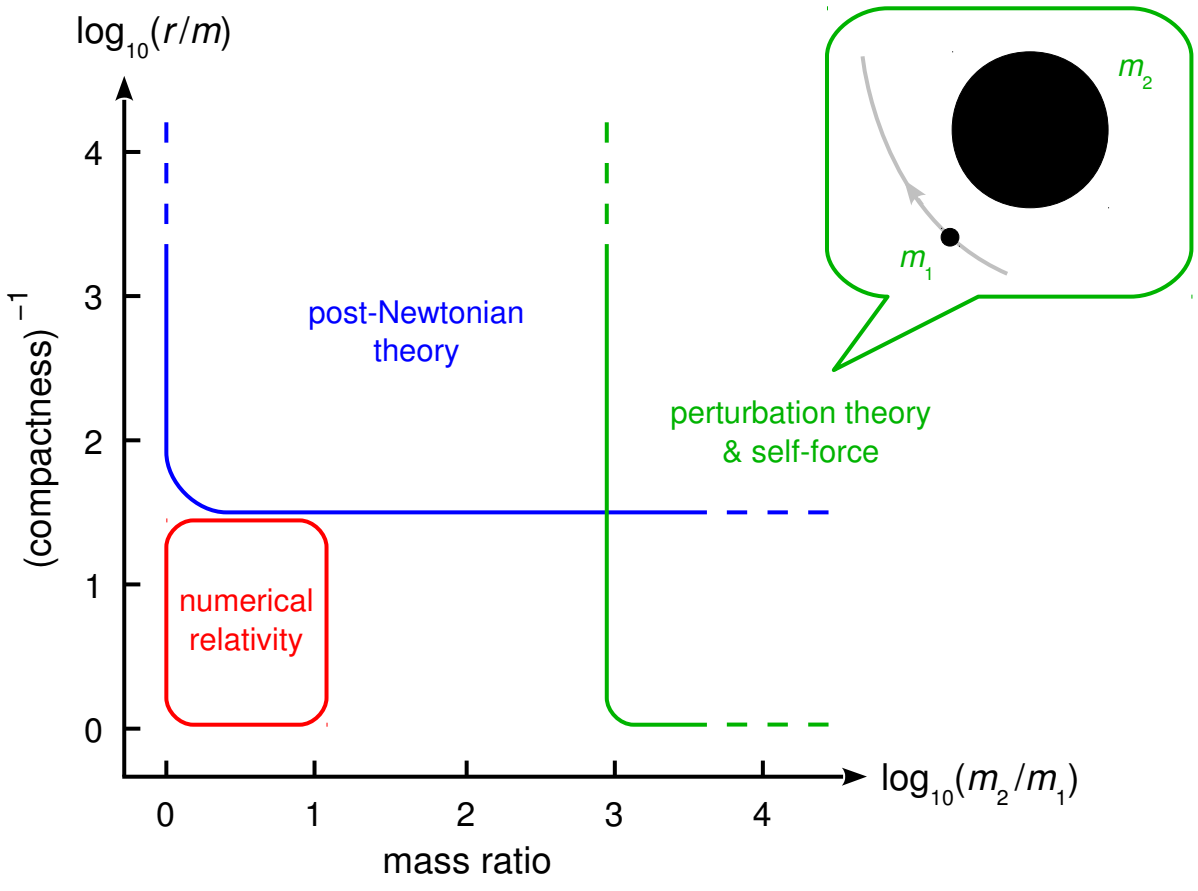


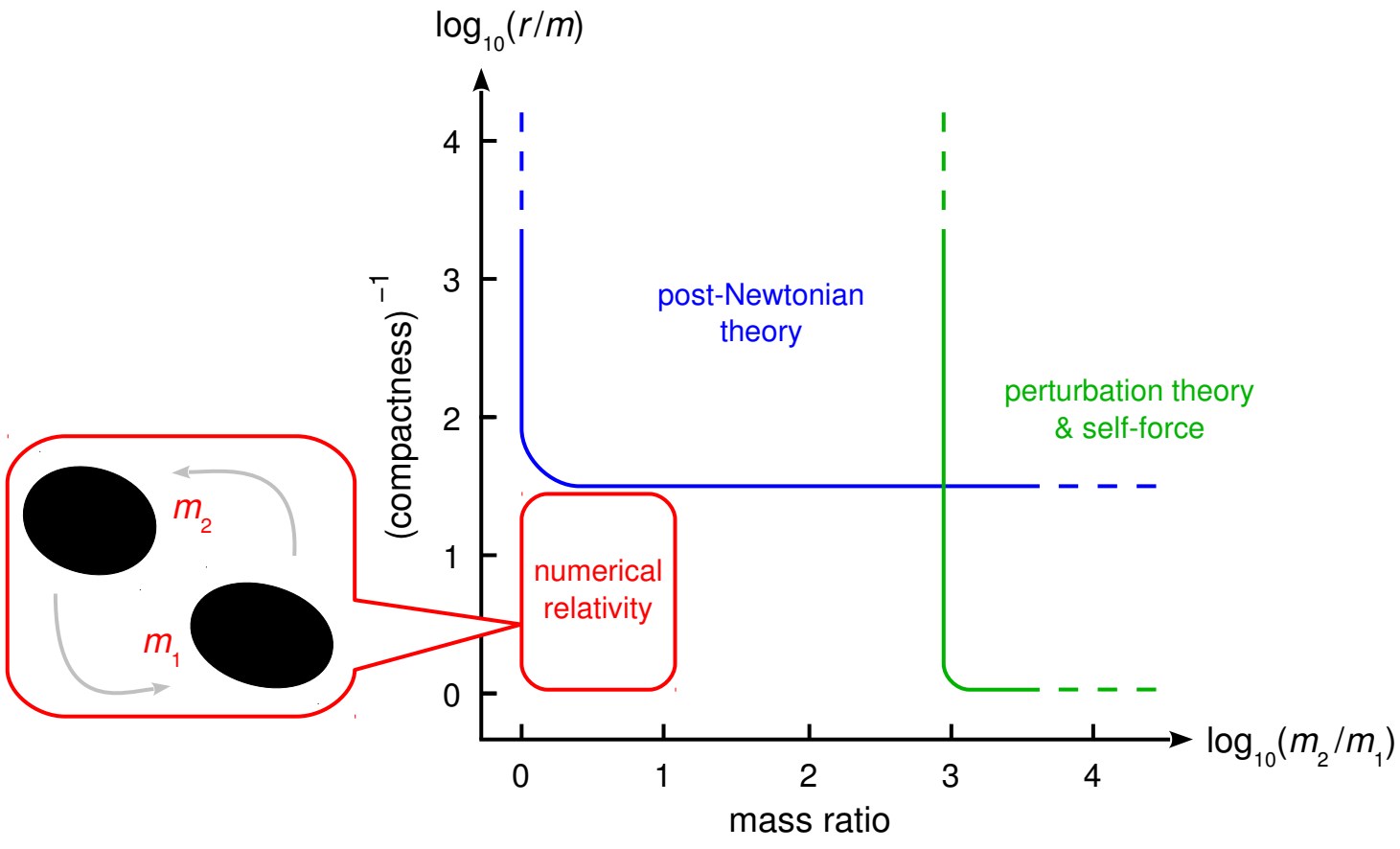
$$\frac{v^2}{c^2} \sim \frac{Gm}{c^2 r} \ll 1$$

Modeling coalescing compact binaries

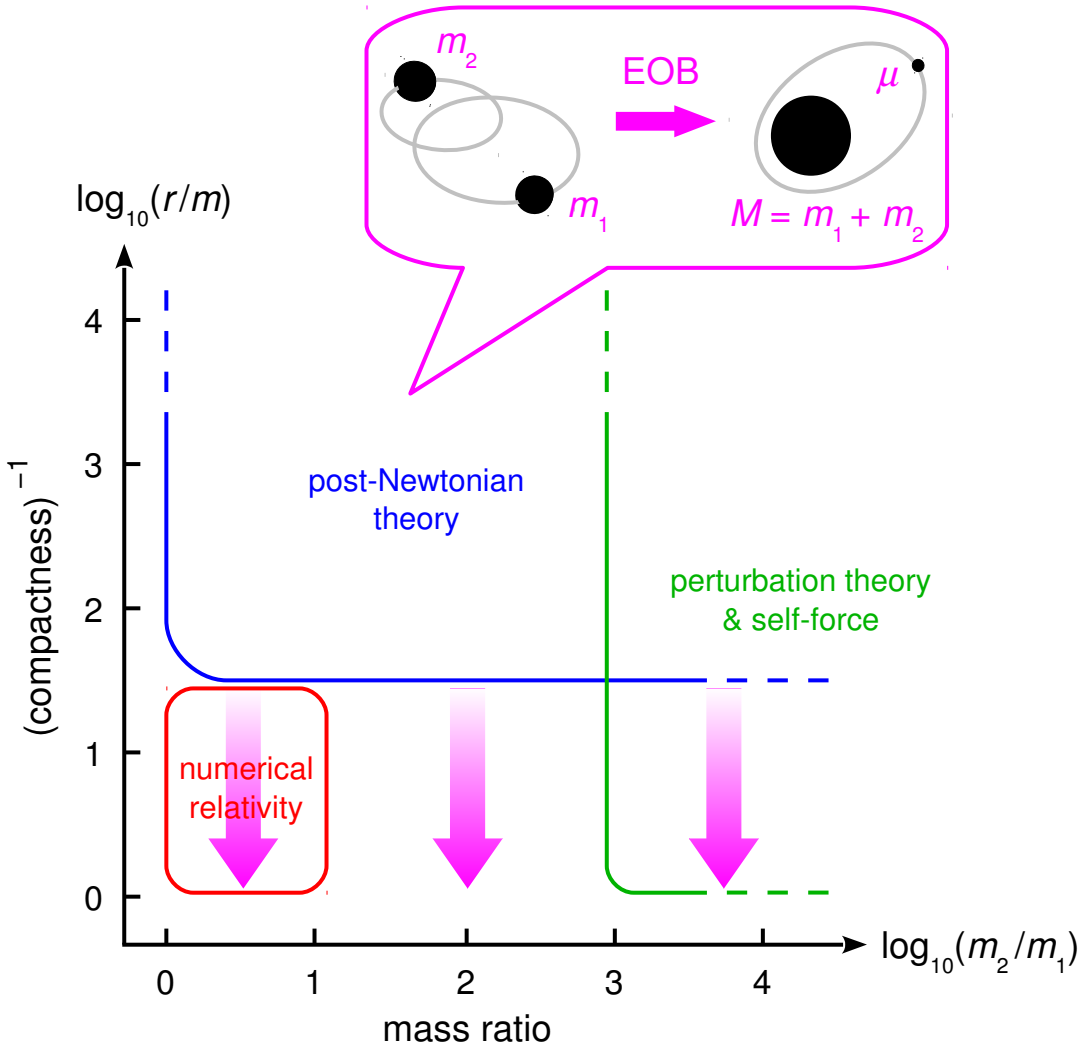
$$q \equiv \frac{m_1}{m_2} \ll 1$$



Modeling coalescing compact binaries

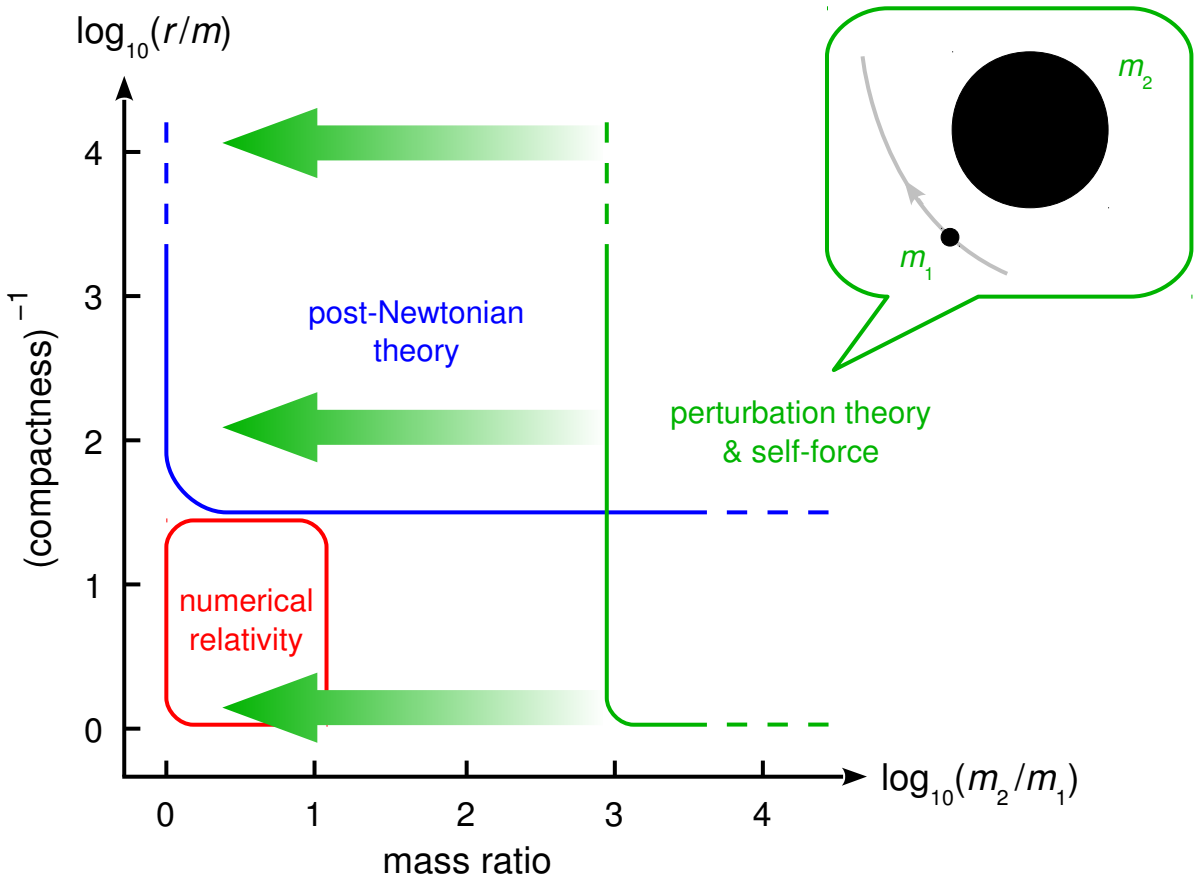


Modeling coalescing compact binaries

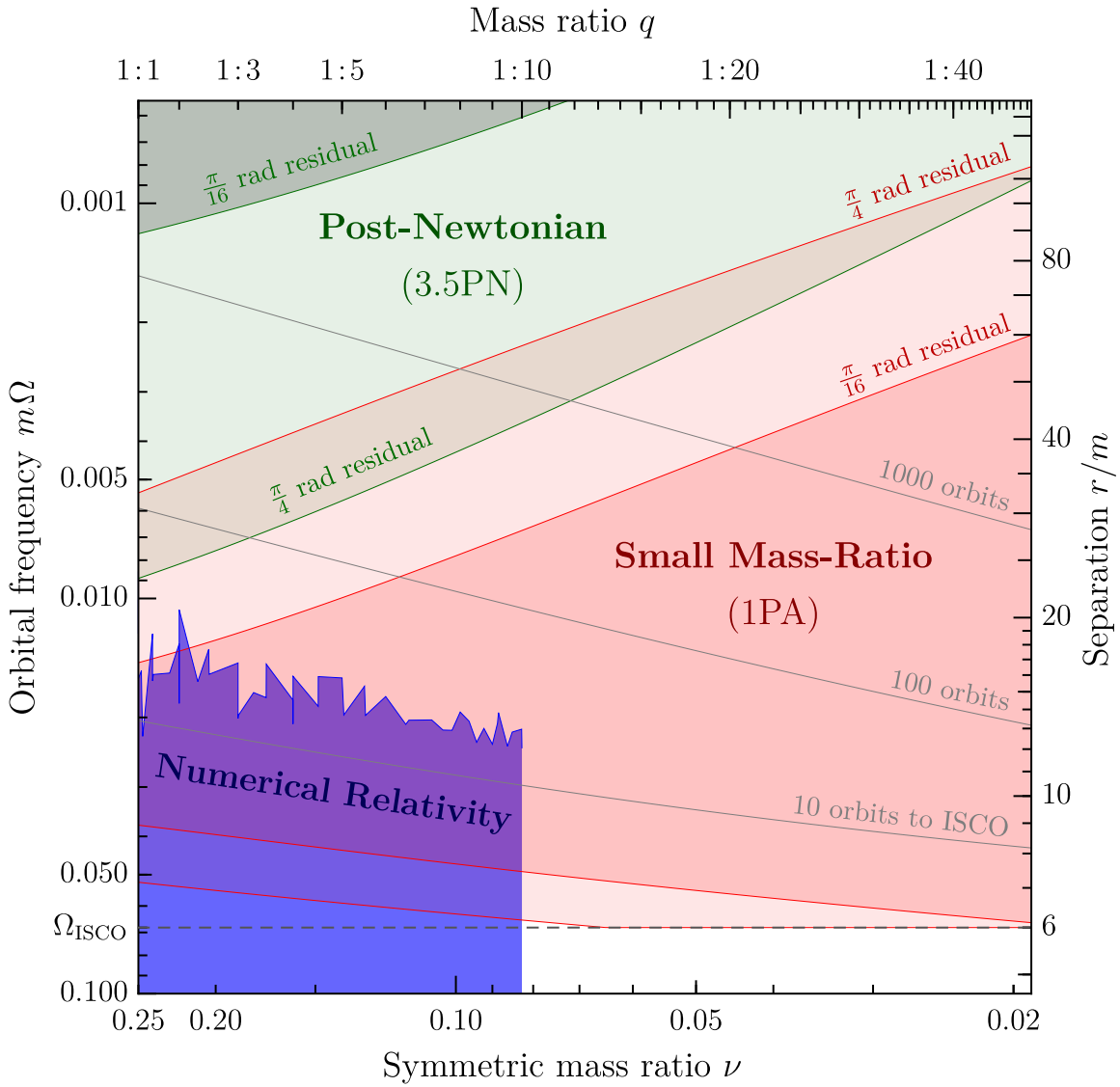


Modeling coalescing compact binaries

$$q \equiv \frac{m_1}{m_2} \quad \rightarrow \quad \nu \equiv \frac{m_1 m_2}{m^2}$$



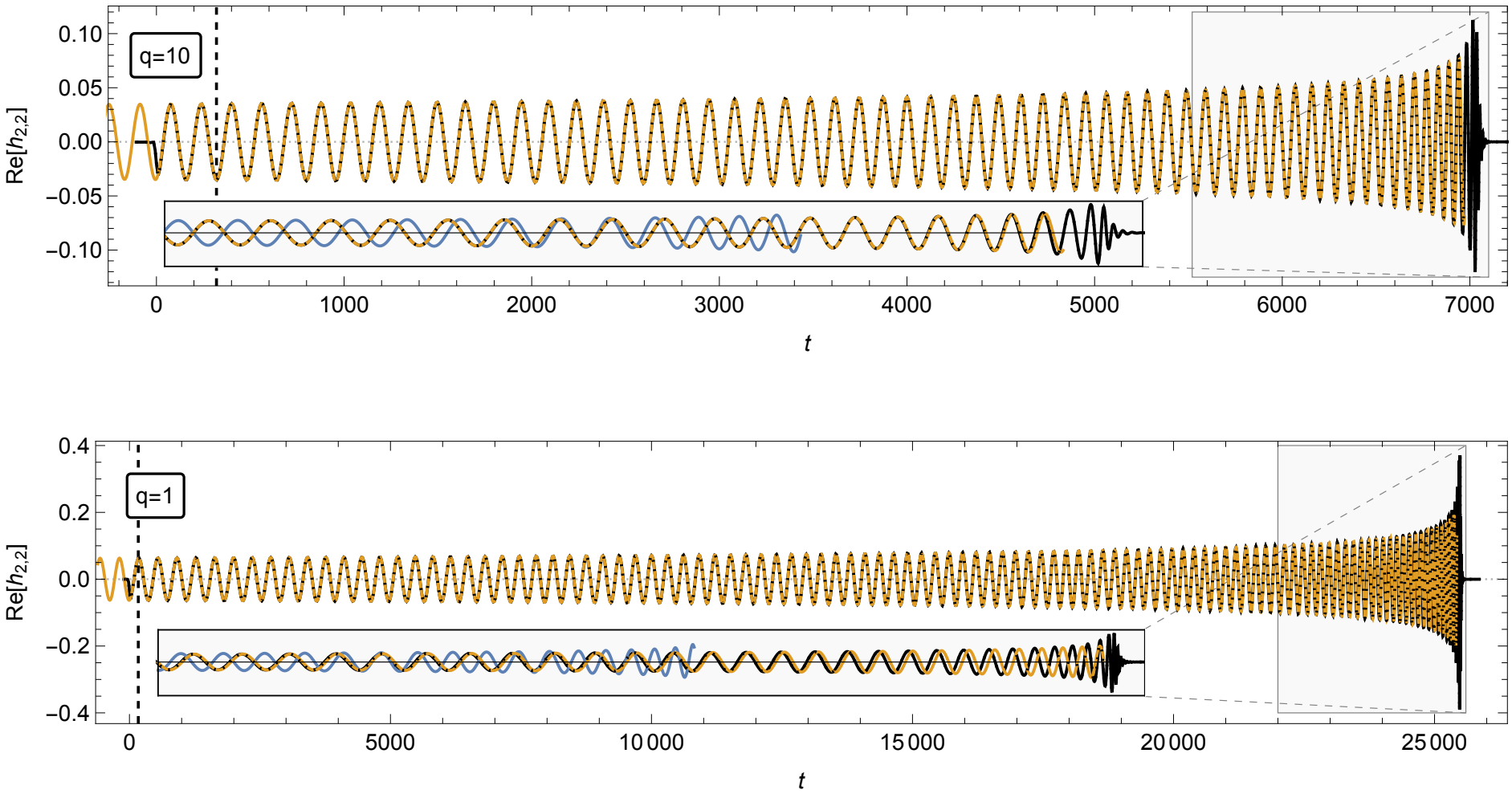
Perturbation theory for comparable masses



[PRL **125** (2020) 181101]

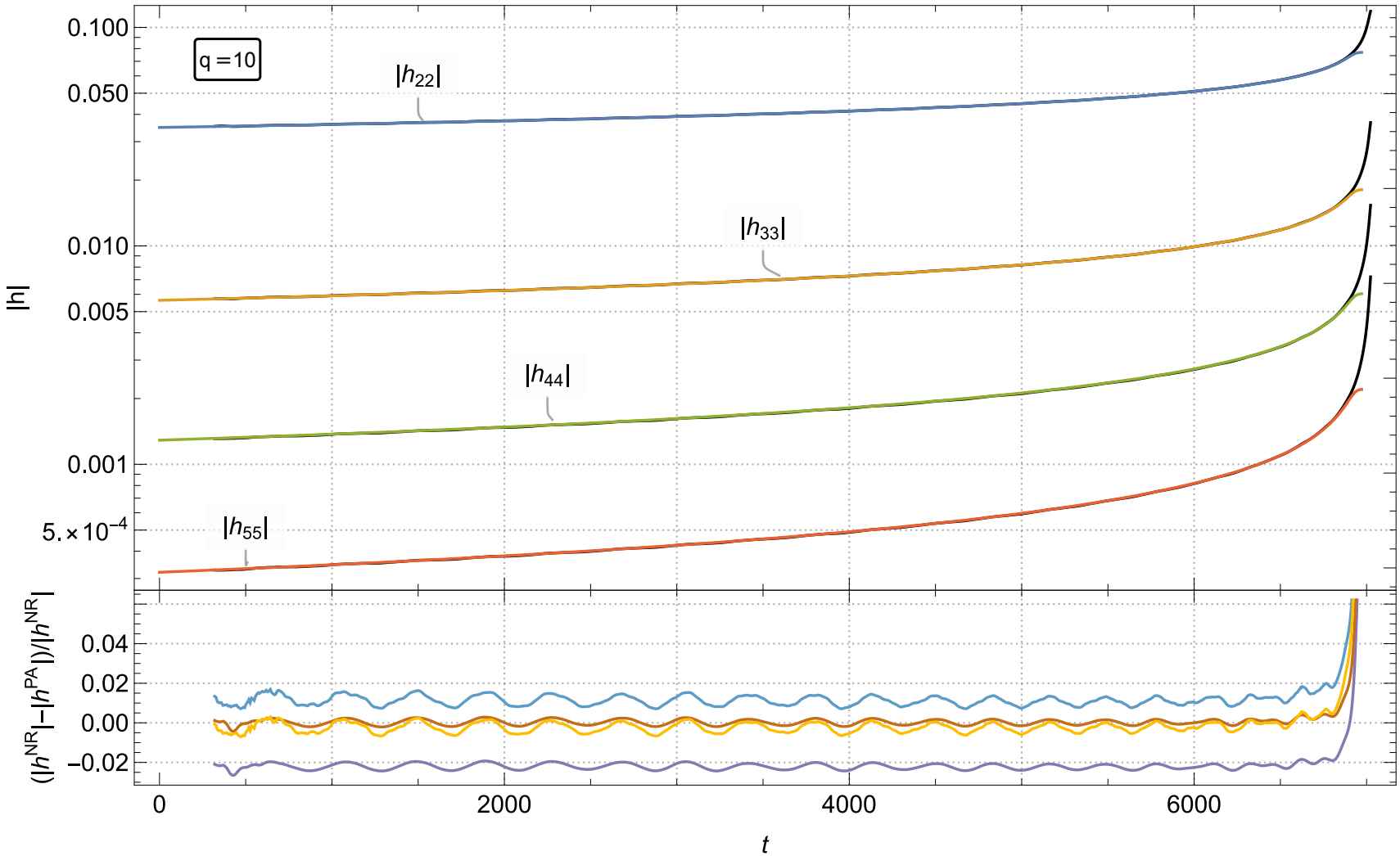
Gravitational waveforms

[Wardell *et al.* 2021]



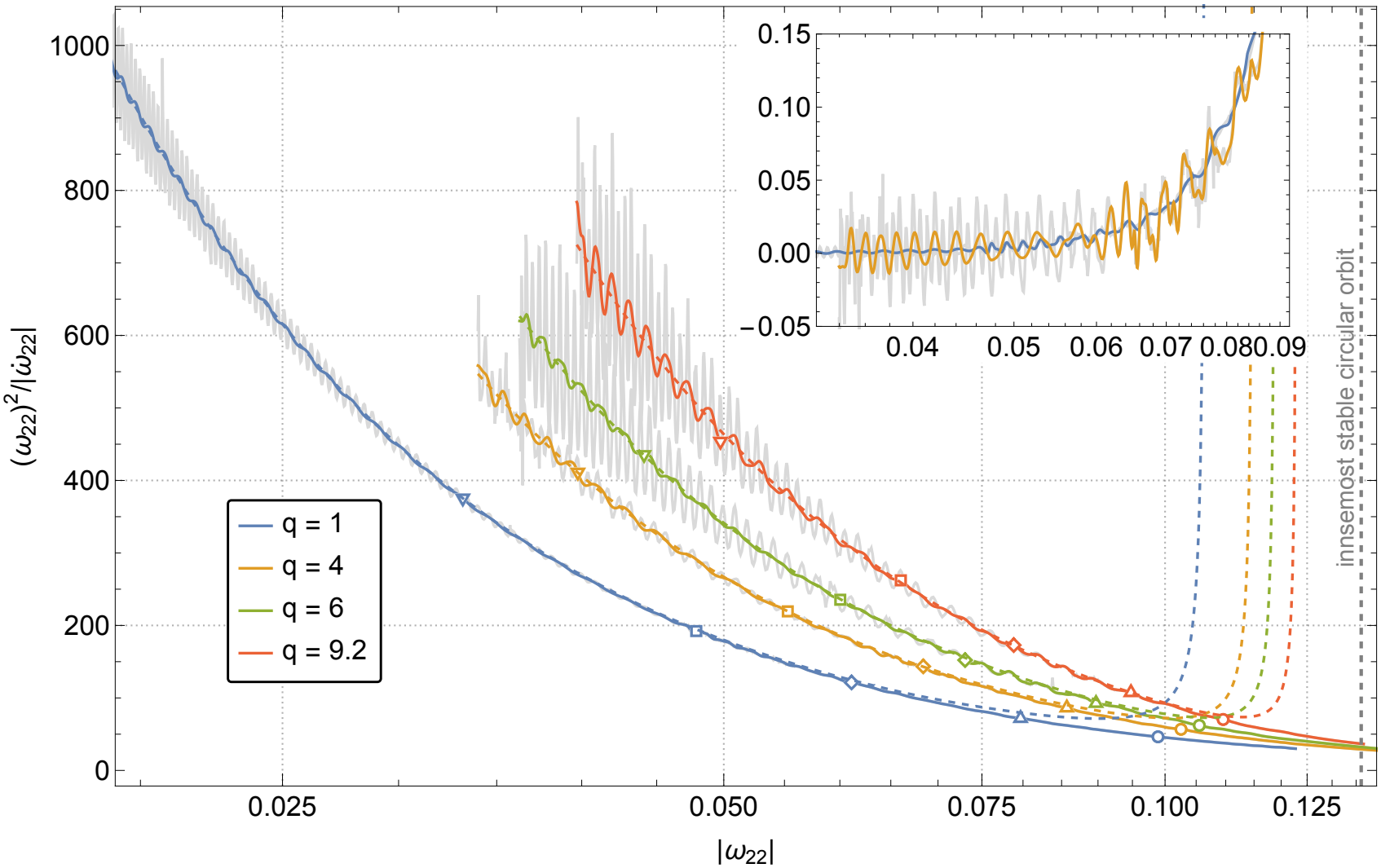
Mode waveform amplitudes

[Wardell *et al.* 2021]



Waveforms frequency evolution

[Wardell *et al.* 2021]



Accumulated dephasing

[Wardell *et al.* 2021]