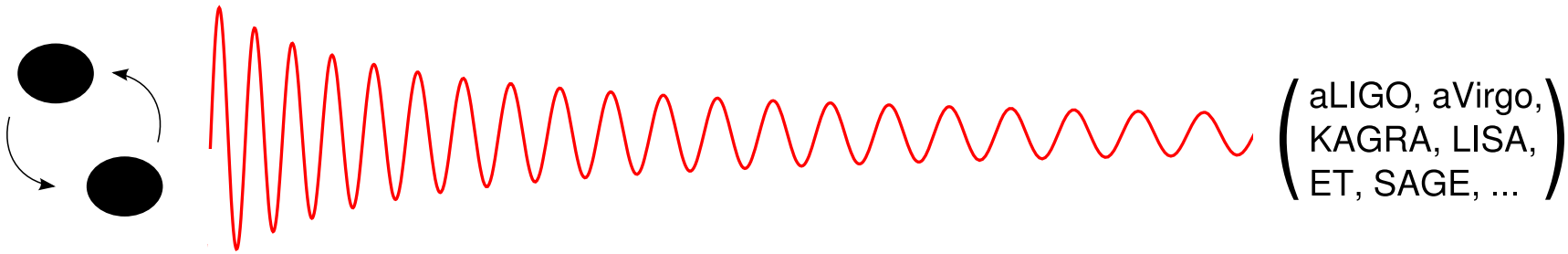
Quelles perspectives théoriques pour l'astrophysique des ondes gravitationnelles ?

Alexandre Le Tiec

Laboratoire Univers et Théories
Observatoire de Paris / CNRS



Outline

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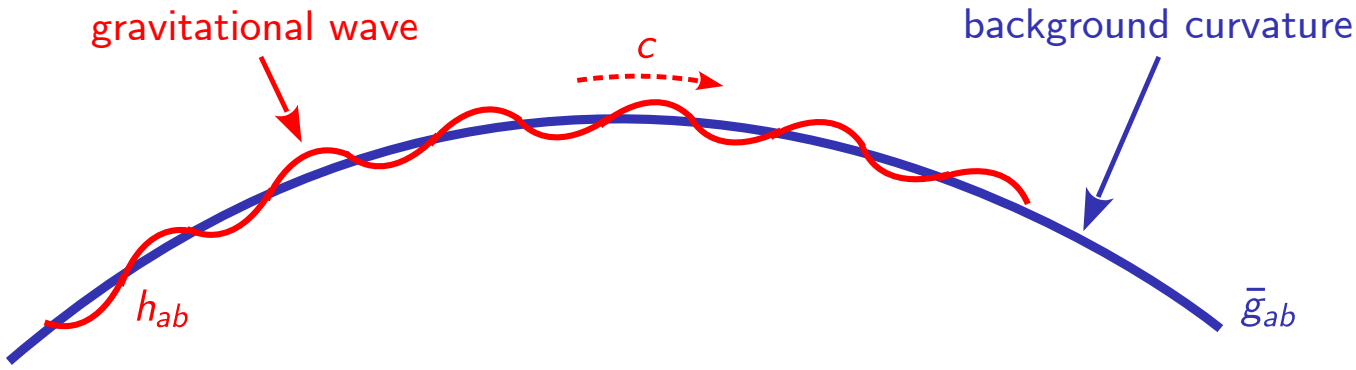
What is a gravitational wave ?

A gravitational wave is a tiny ripple in the curvature of spacetime that propagates at the vacuum speed of light



$$\Box h_{ab} + 2\bar{R}_{abcd}\, h^{cd} = -16\pi\, T_{ab}$$

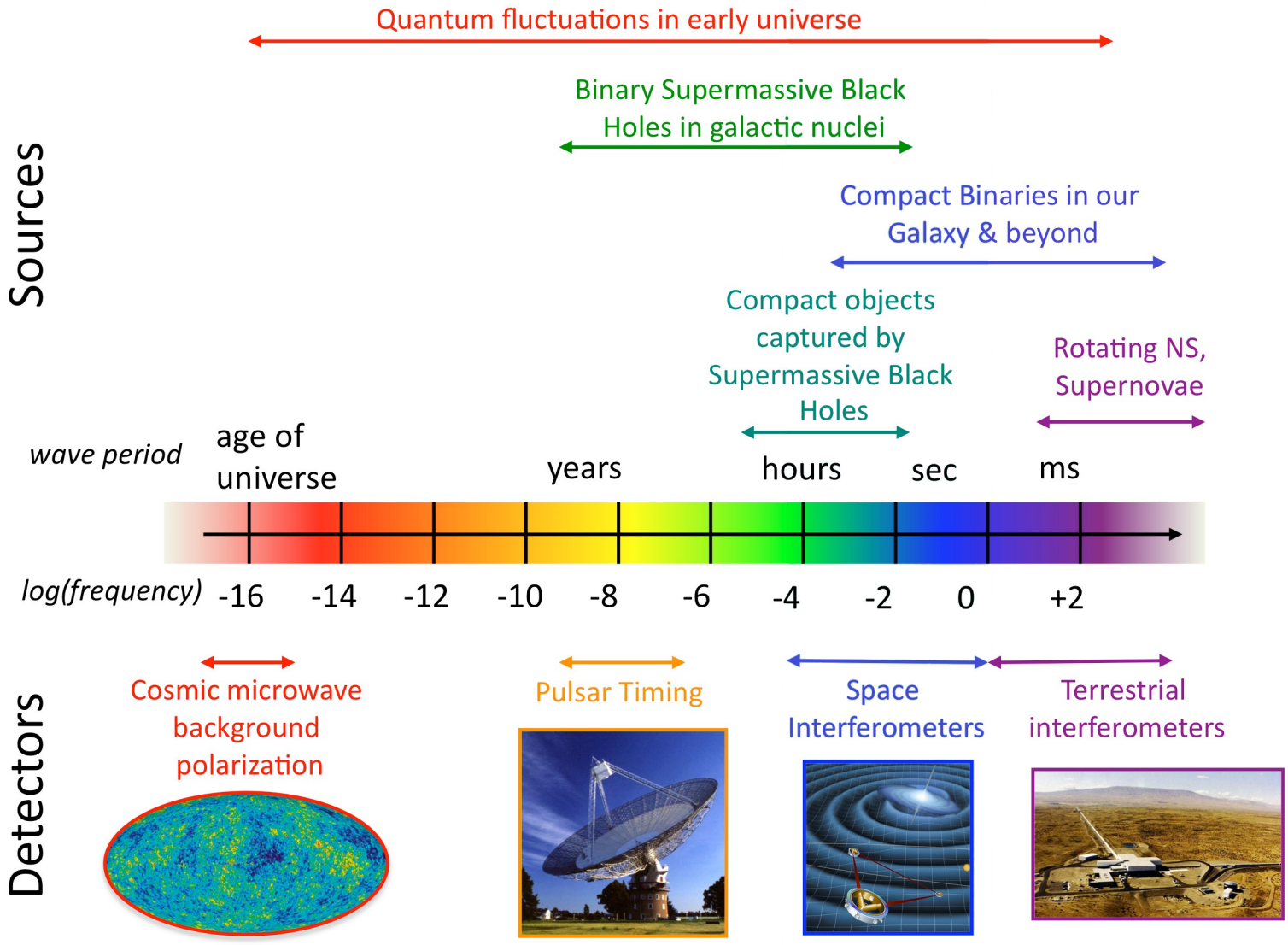
Key prediction of Einstein's general theory of relativity

Electromagnetic *vs* gravitational waves

	Electromagnetic waves	Gravitational waves
Origin	electromagnetic field	spacetime curvature
Nature	waves in spacetime	waves of spacetime
Sources	accelerated charges	accelerated masses
Wavelength	$\ll$ size of source	$\gtrsim$ size of source
Structure	dipolar	quadrupolar
Coherence	low	high
Interaction	strong	weak
Detection	power	amplitude
Analogy	vision	audition

Complementary sources of information about the Universe

The gravitational-wave spectrum



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

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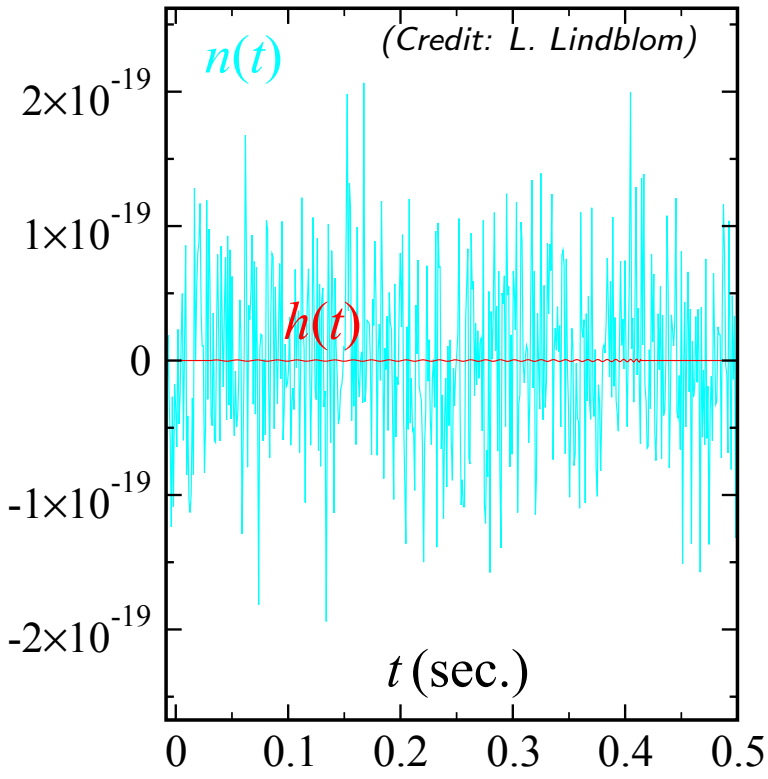
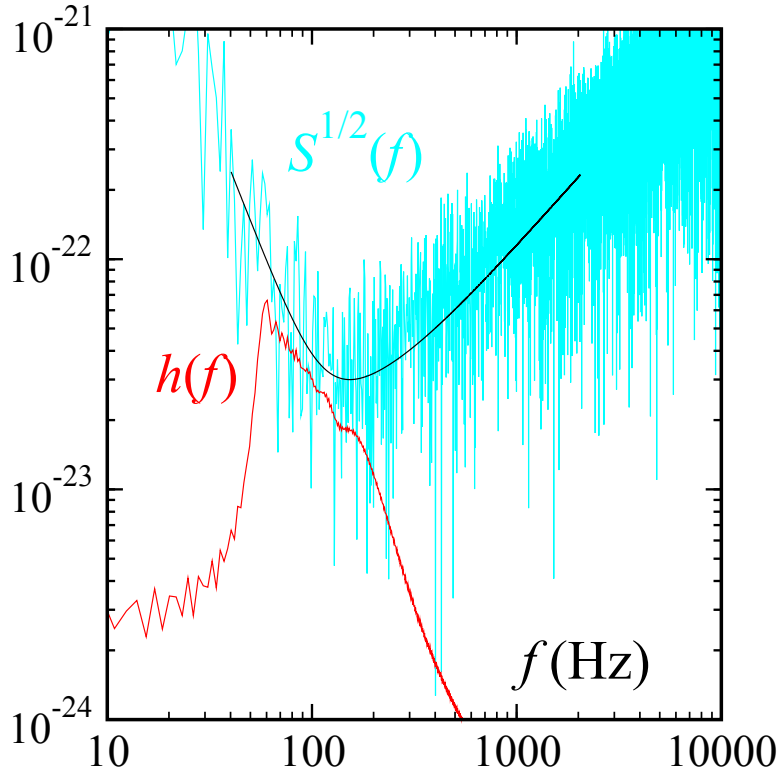
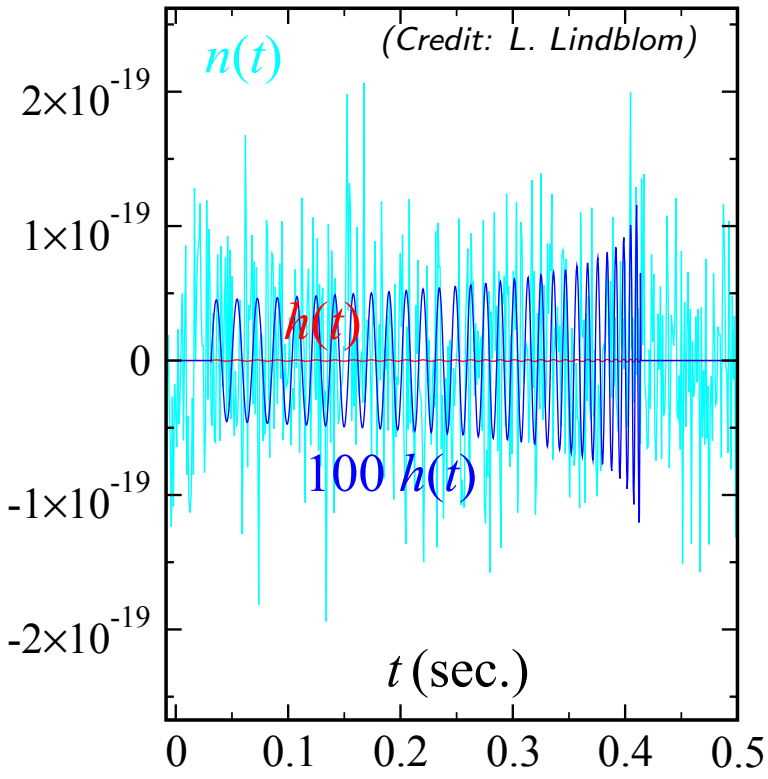
Need for accurate template waveforms

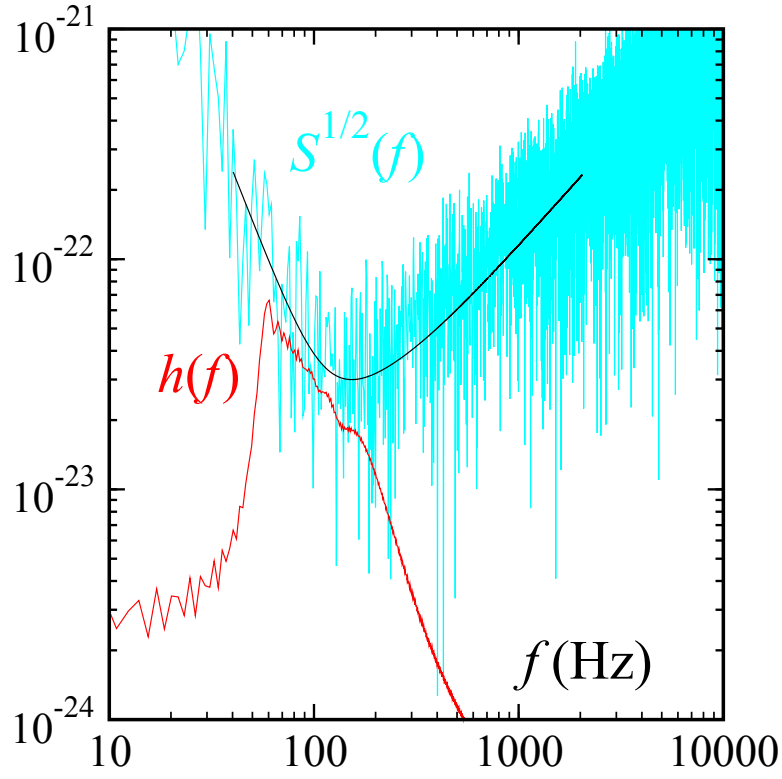




If the expected signal is *known in advance* then $n(t)$ can be filtered and $h(t)$ recovered by matched filtering $\longrightarrow$ **template waveforms**

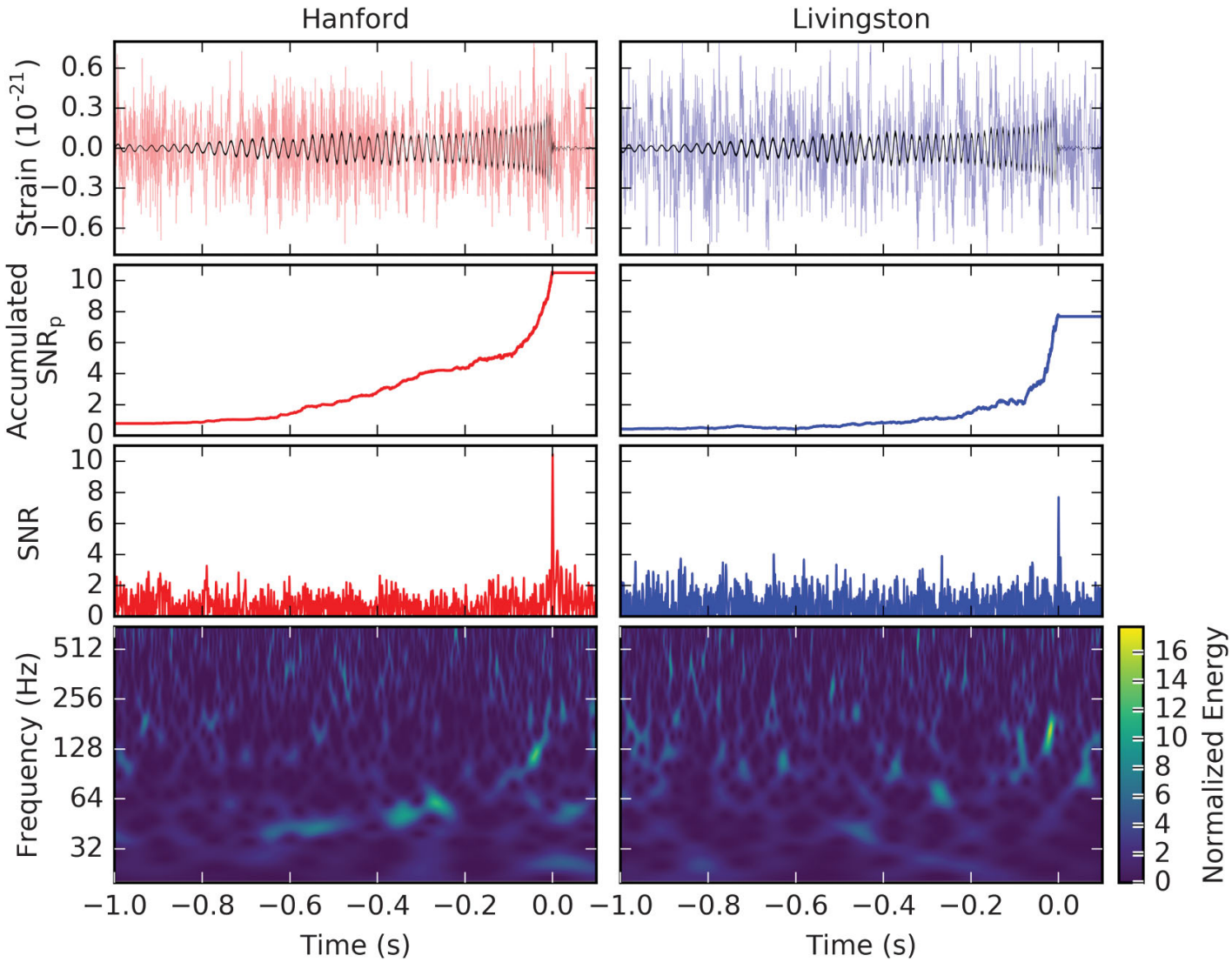
Need for accurate template waveforms





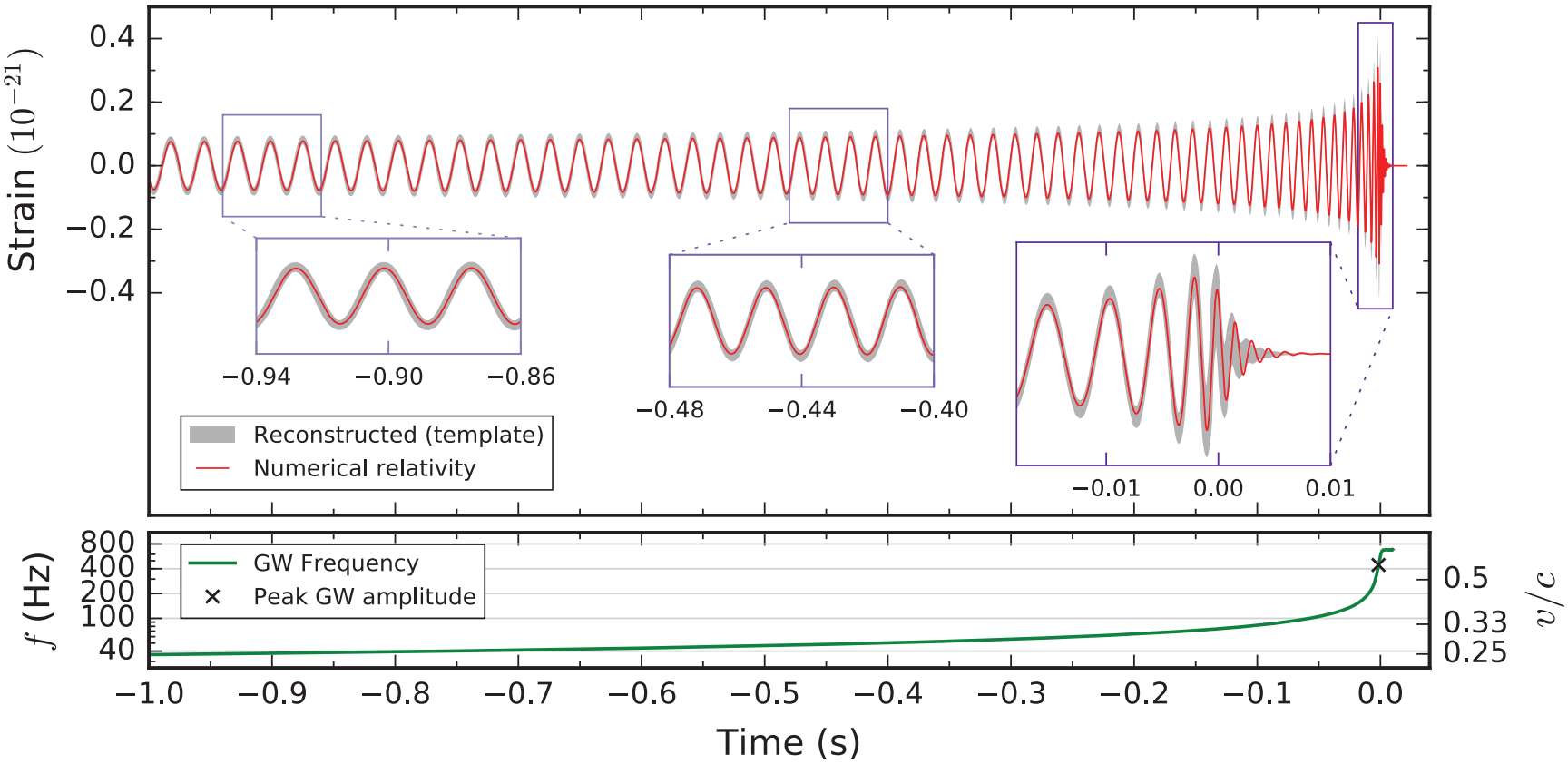
If the expected signal is *known in advance* then $n(t)$ can be filtered and $h(t)$ recovered by matched filtering $\longrightarrow$ **template waveforms**

A recent example: the event GW151226



[PRL **116** (2016) 241103]

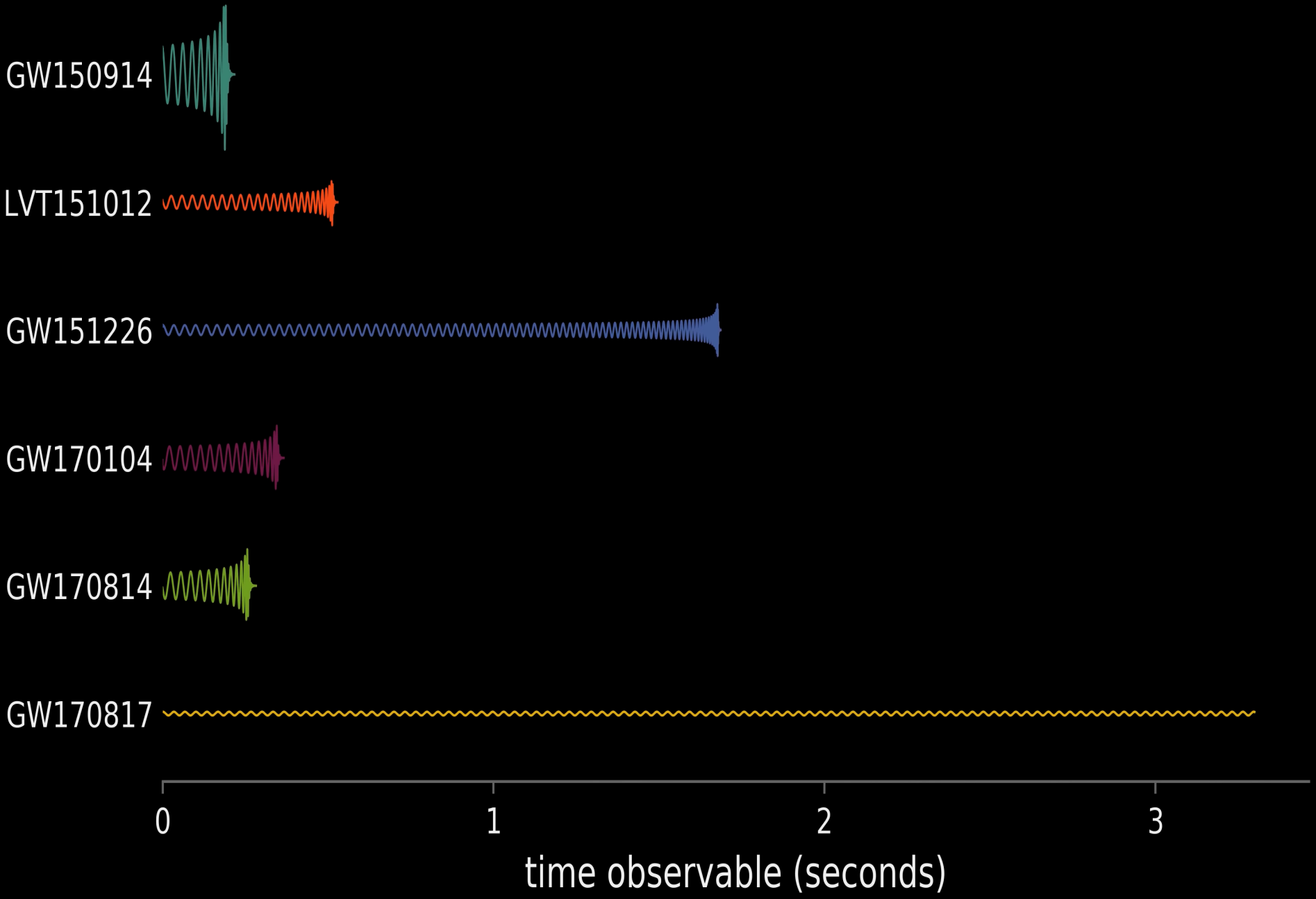
A long inspiral to merger to ringdown



[PRL **116** (2016) 241103]

Outline

Ground-based interferometric detectors


GW150914
LVT151012
GW151226
GW170104
GW170814
GW170817
0
1
2
3
time observable (seconds)
LIGO/University of Oregon/Ben Farr

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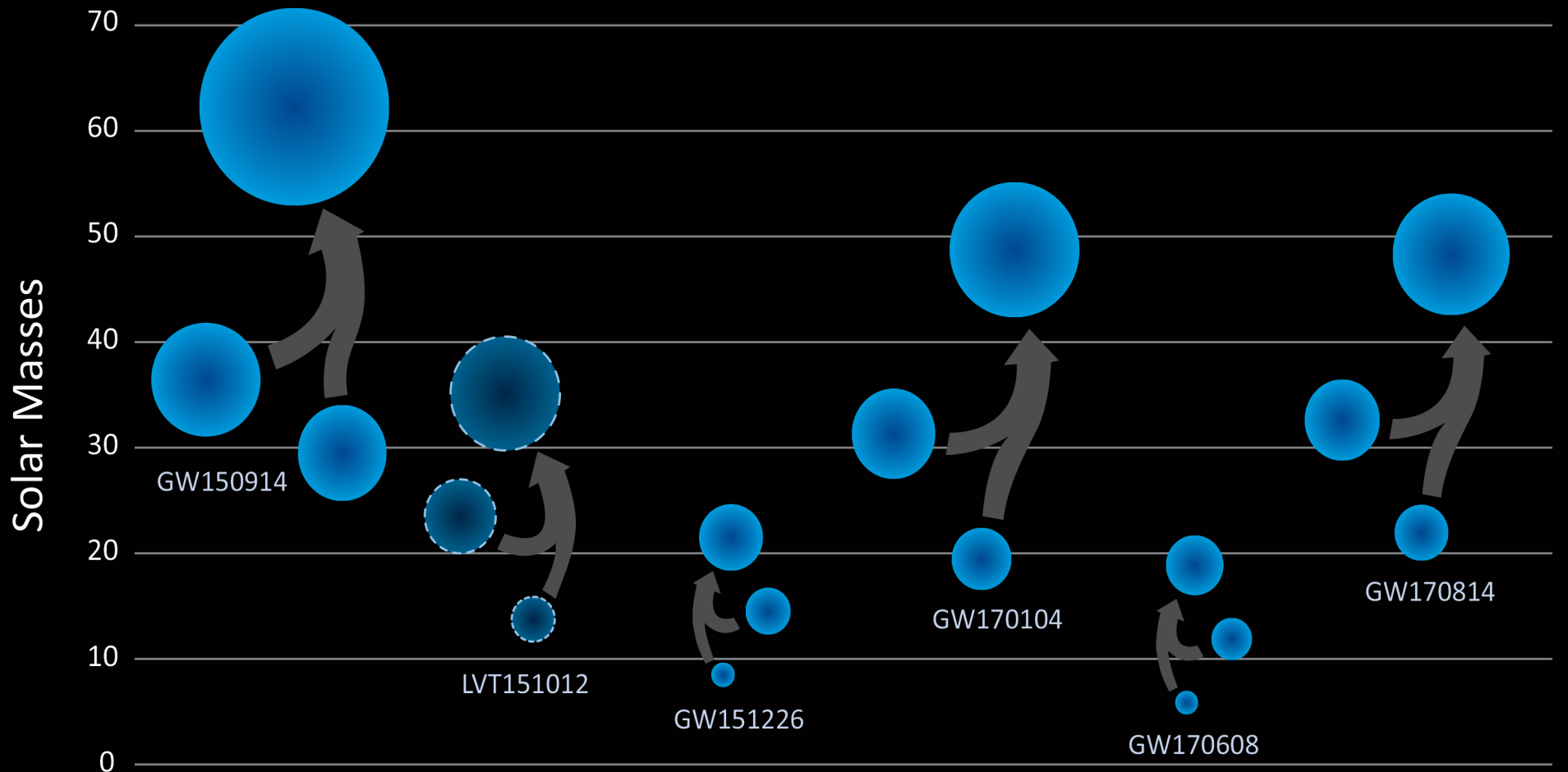
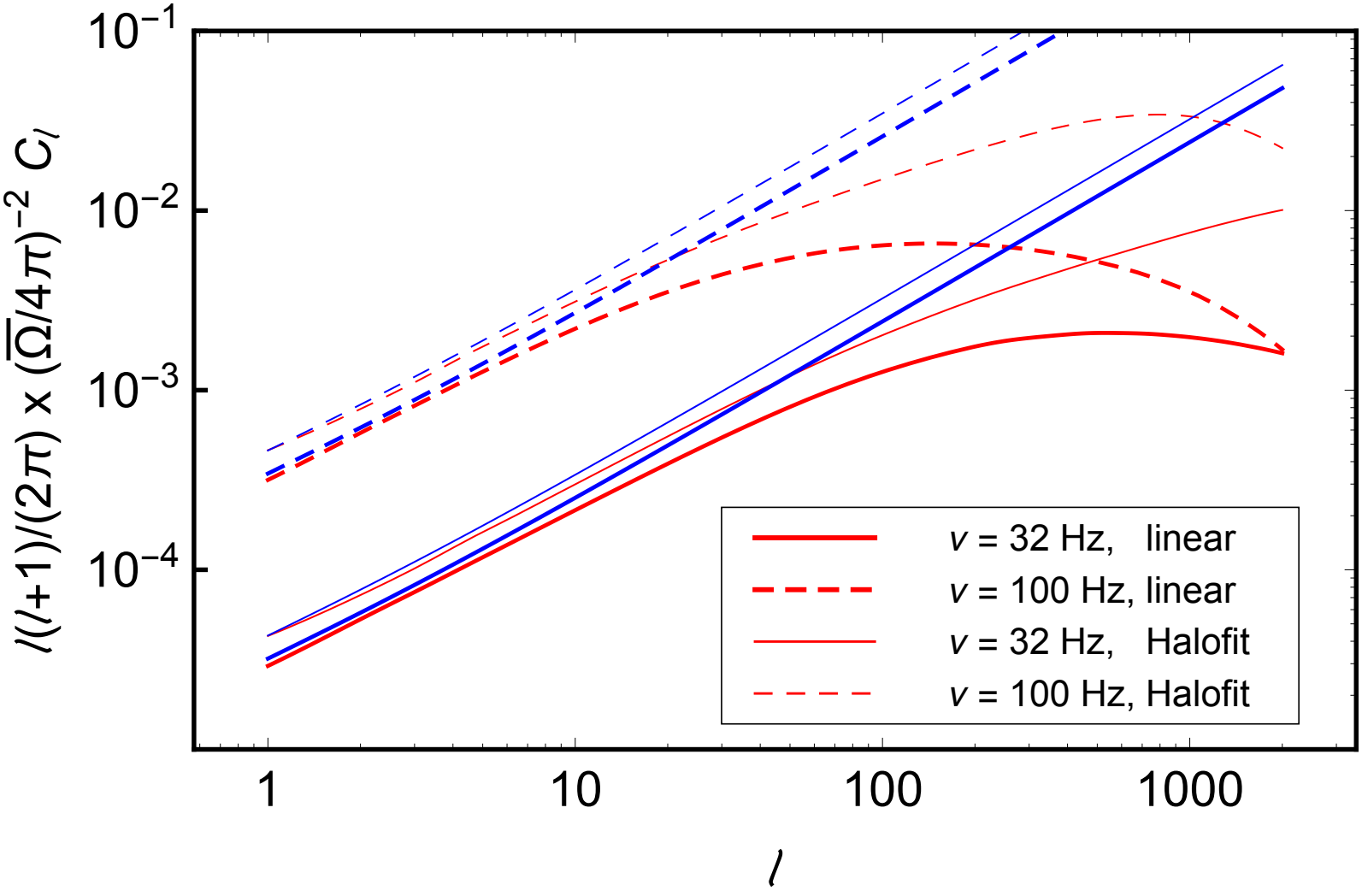
Black Holes of Known Mass



LIGO/VIRGO

Angular power spectrum of AGWB



[PRL **120** (2018) 231101]

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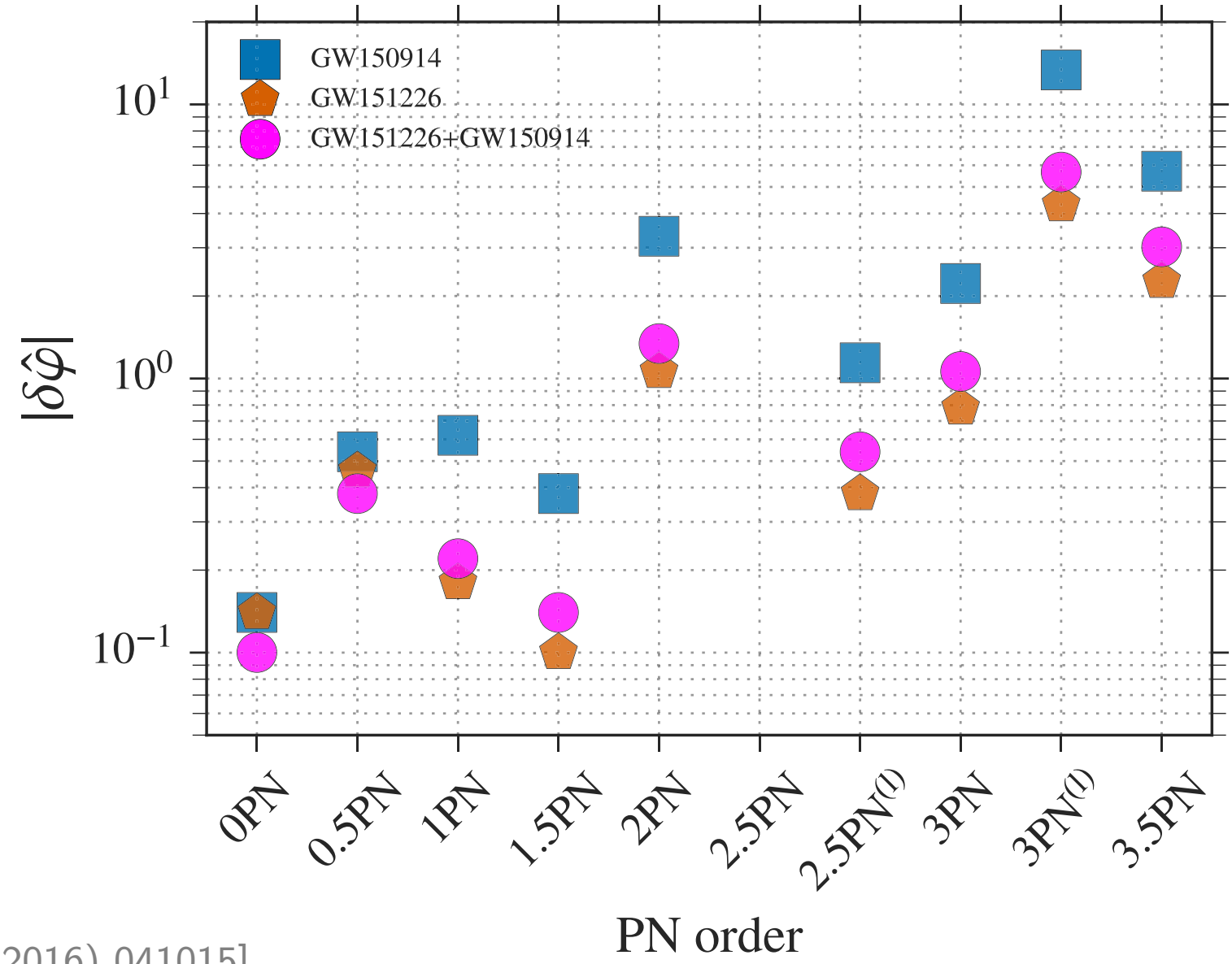
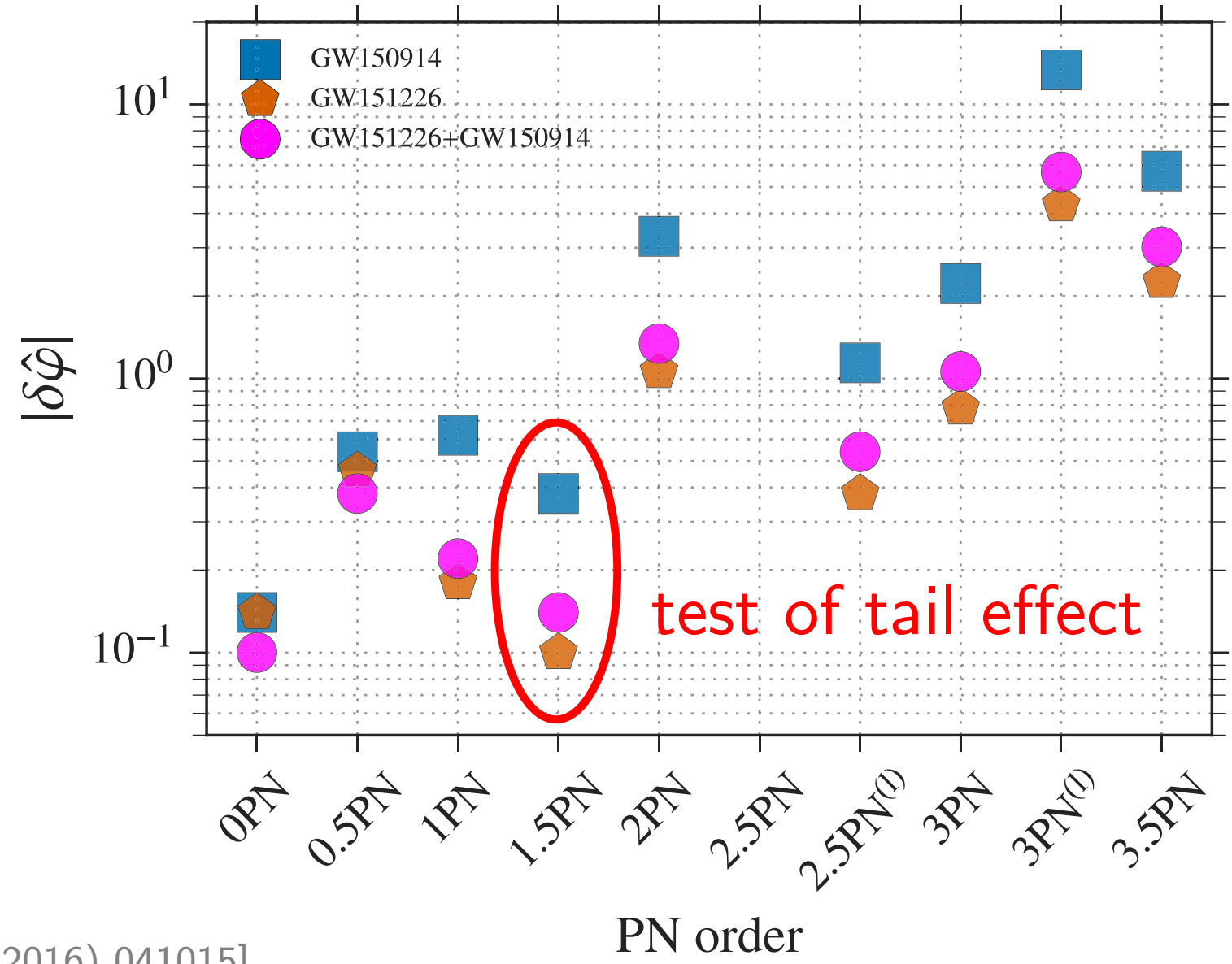
Measurement of PN parameters



[PRX **6** (2016) 041015]

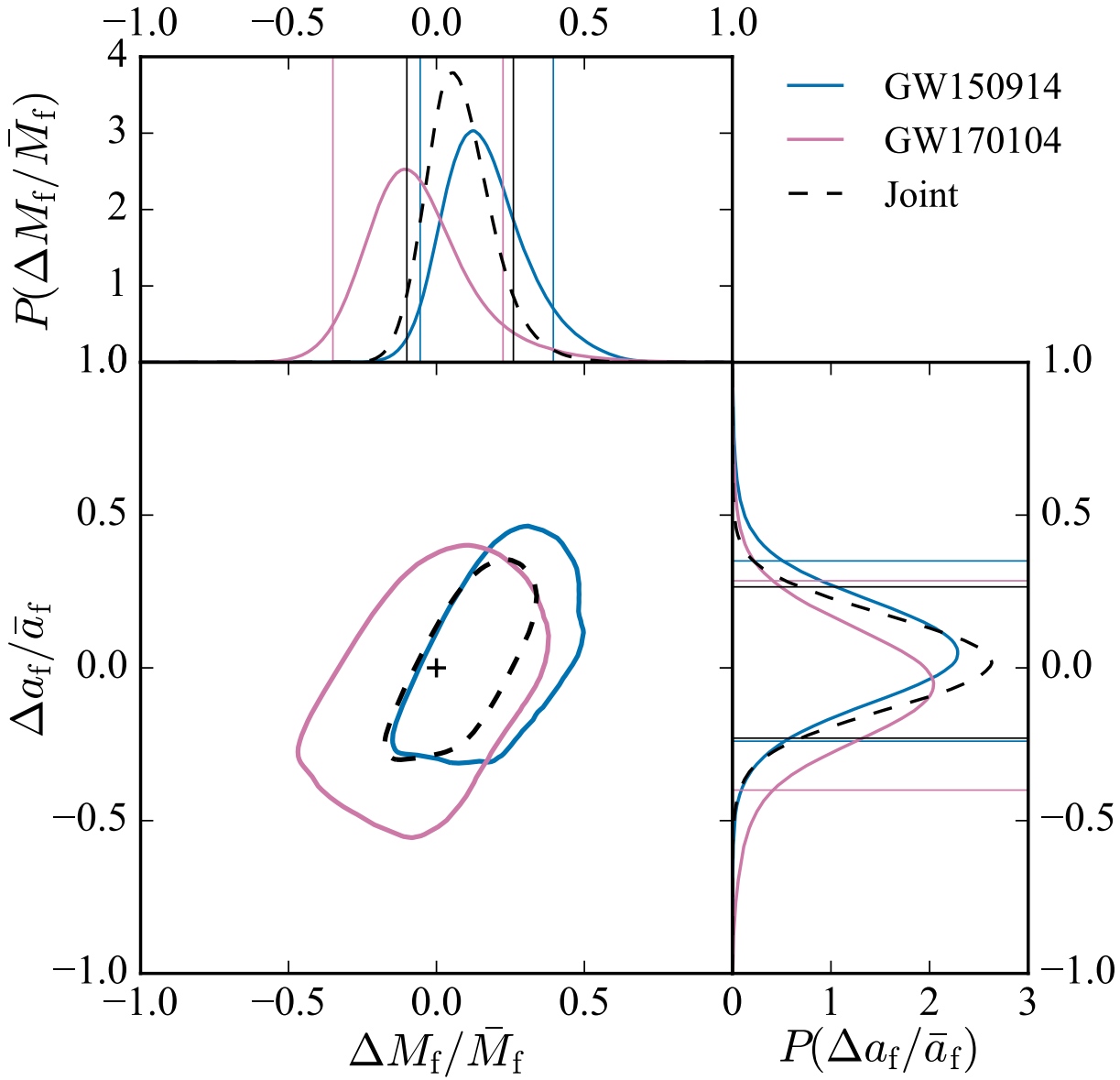
Measurement of PN parameters



[PRX **6** (2016) 041015]

[PRL **118** (2017) 221101]

IMR consistency tests



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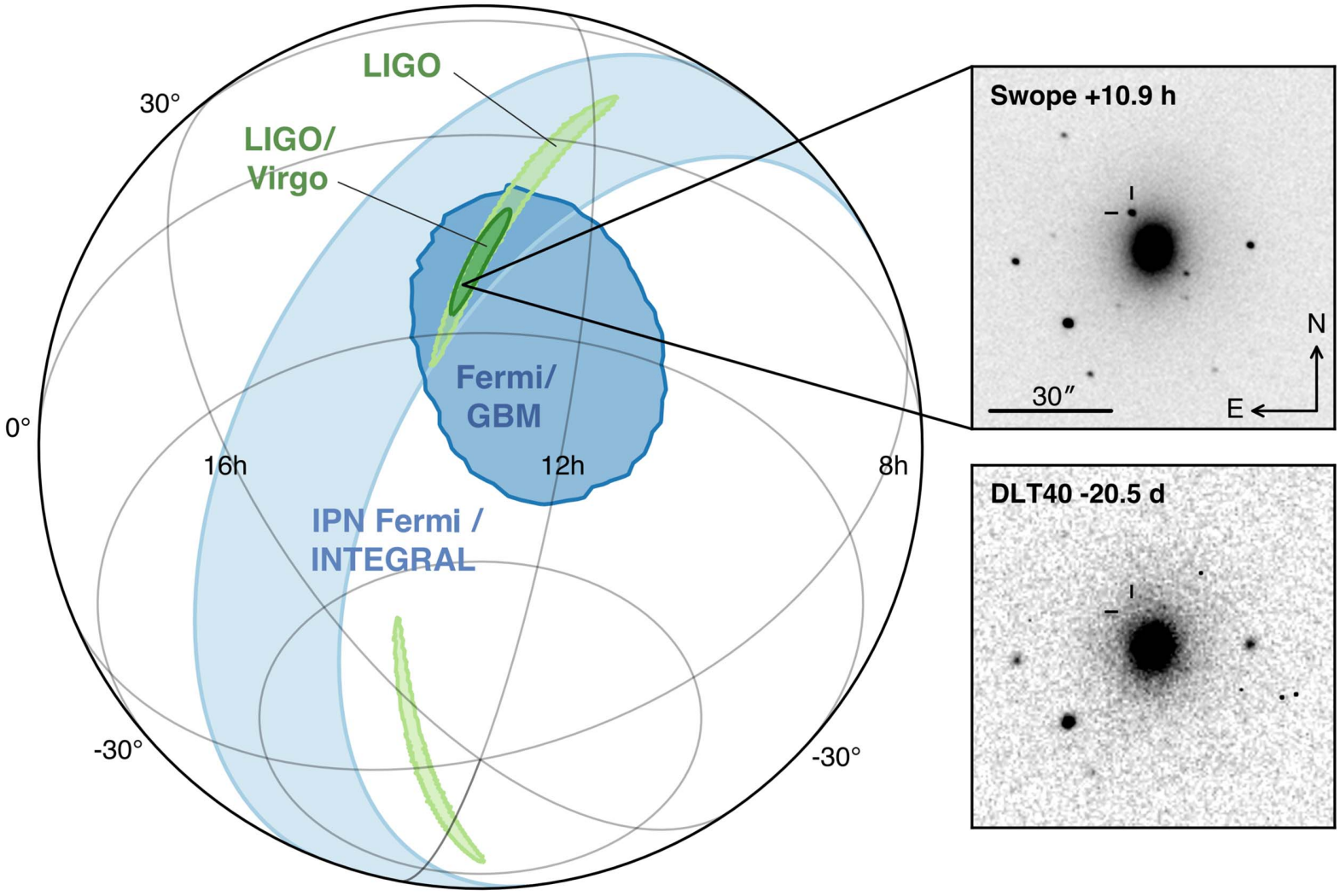
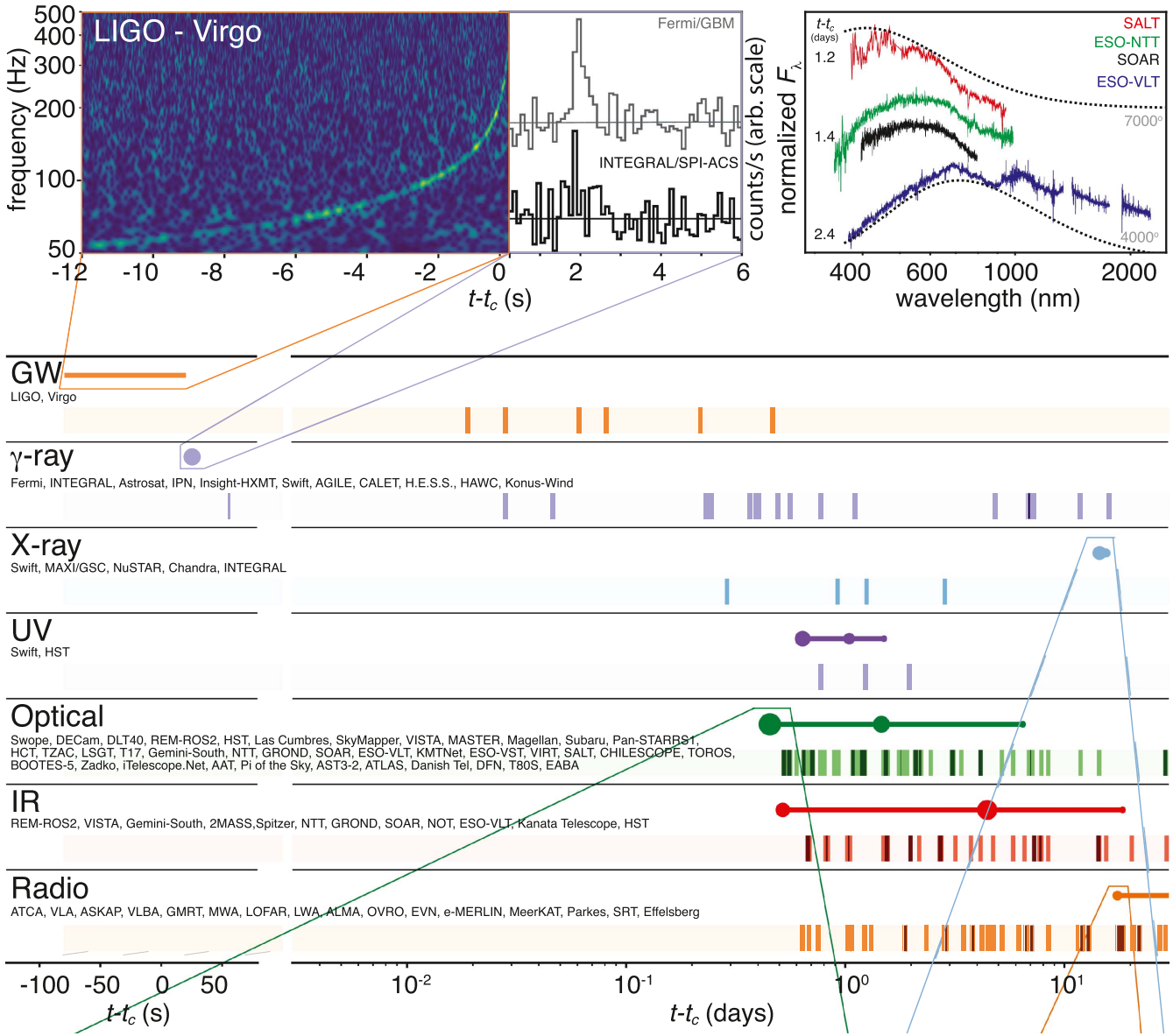
[ApJ **848** (2017) L12]

A binary neutron star merger



[ApJ **848** (2017) L12]

Multi-messenger astronomy



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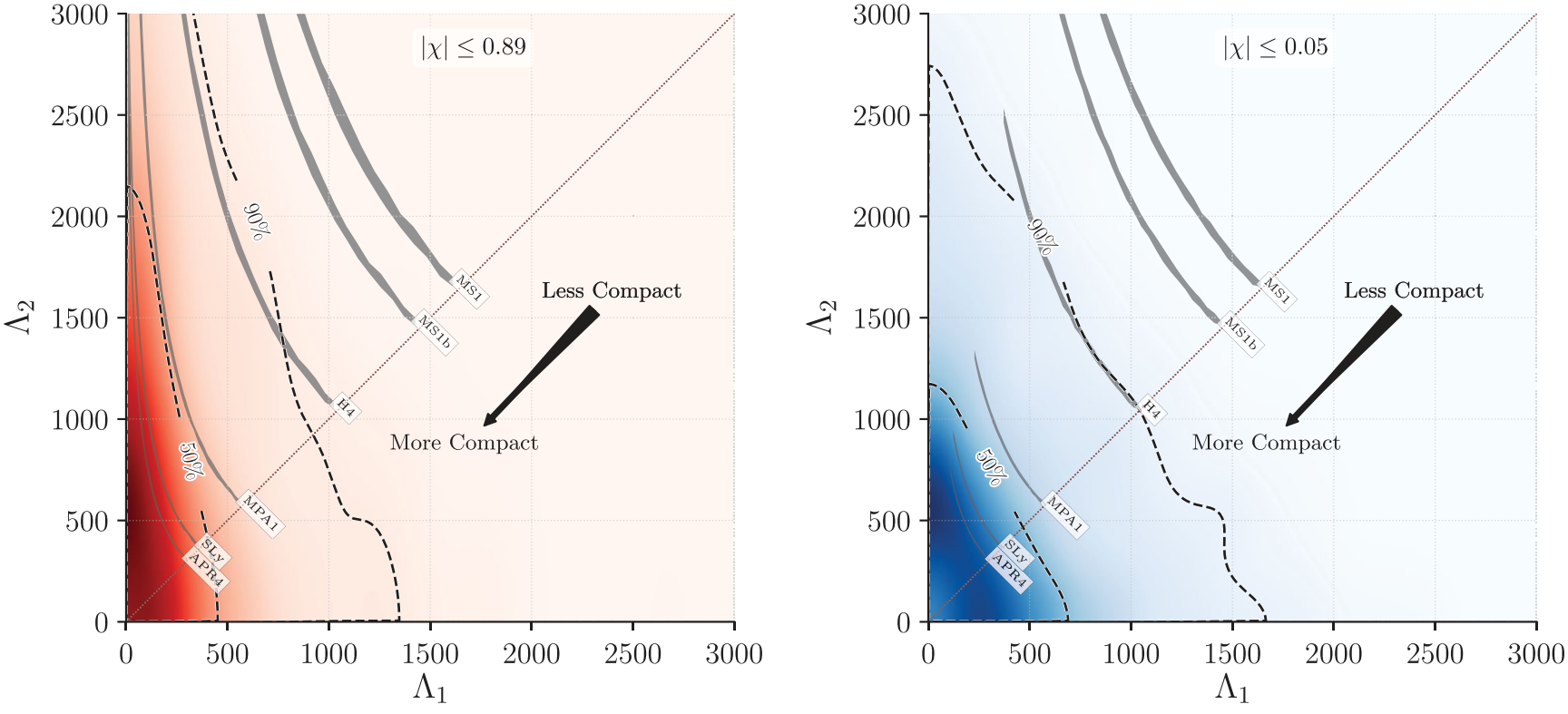
[PRL **119** (2017) 161101]

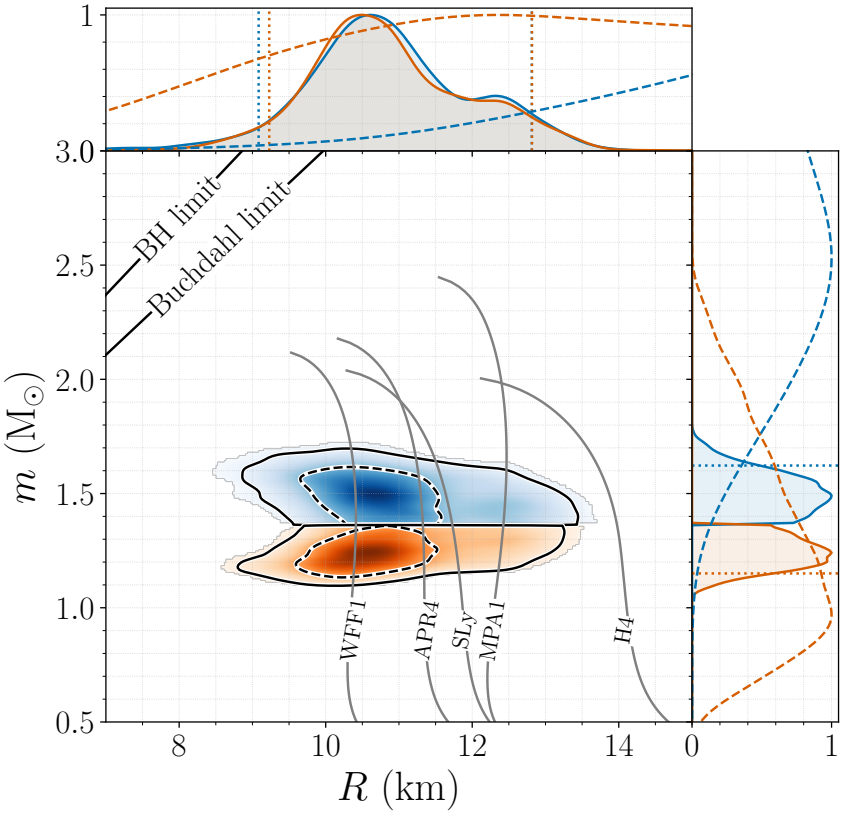
Tidal deformability

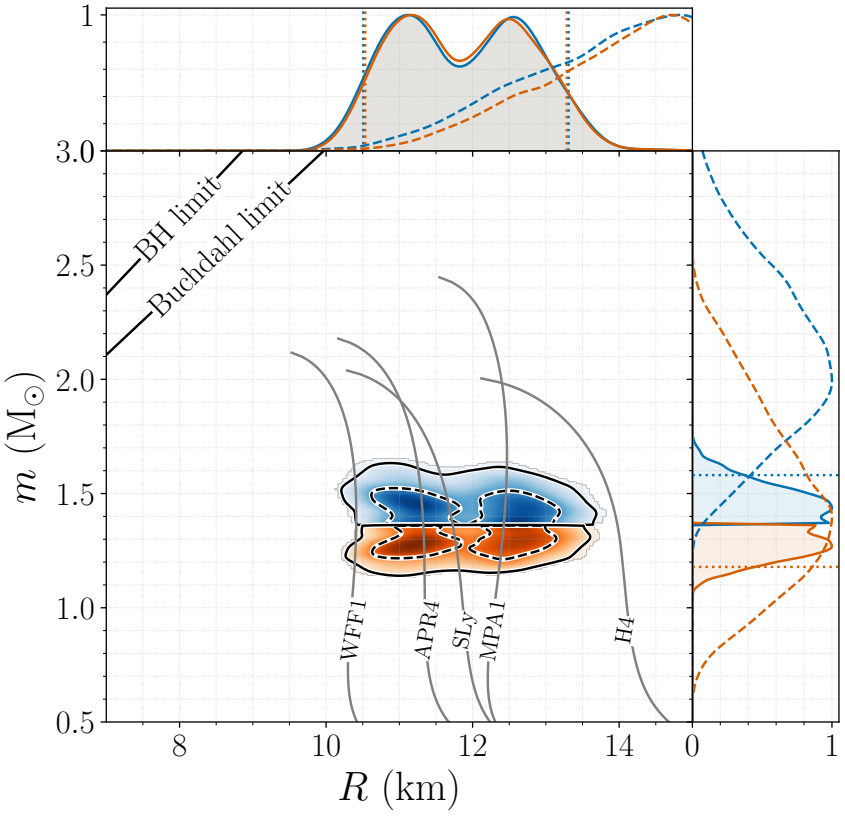


$$\Lambda_i \propto \left(\frac{c^2 R_i}{G m_i}\right)^5$$

[LIGO-P1800115 (2018)]

Mass, radius and EOS





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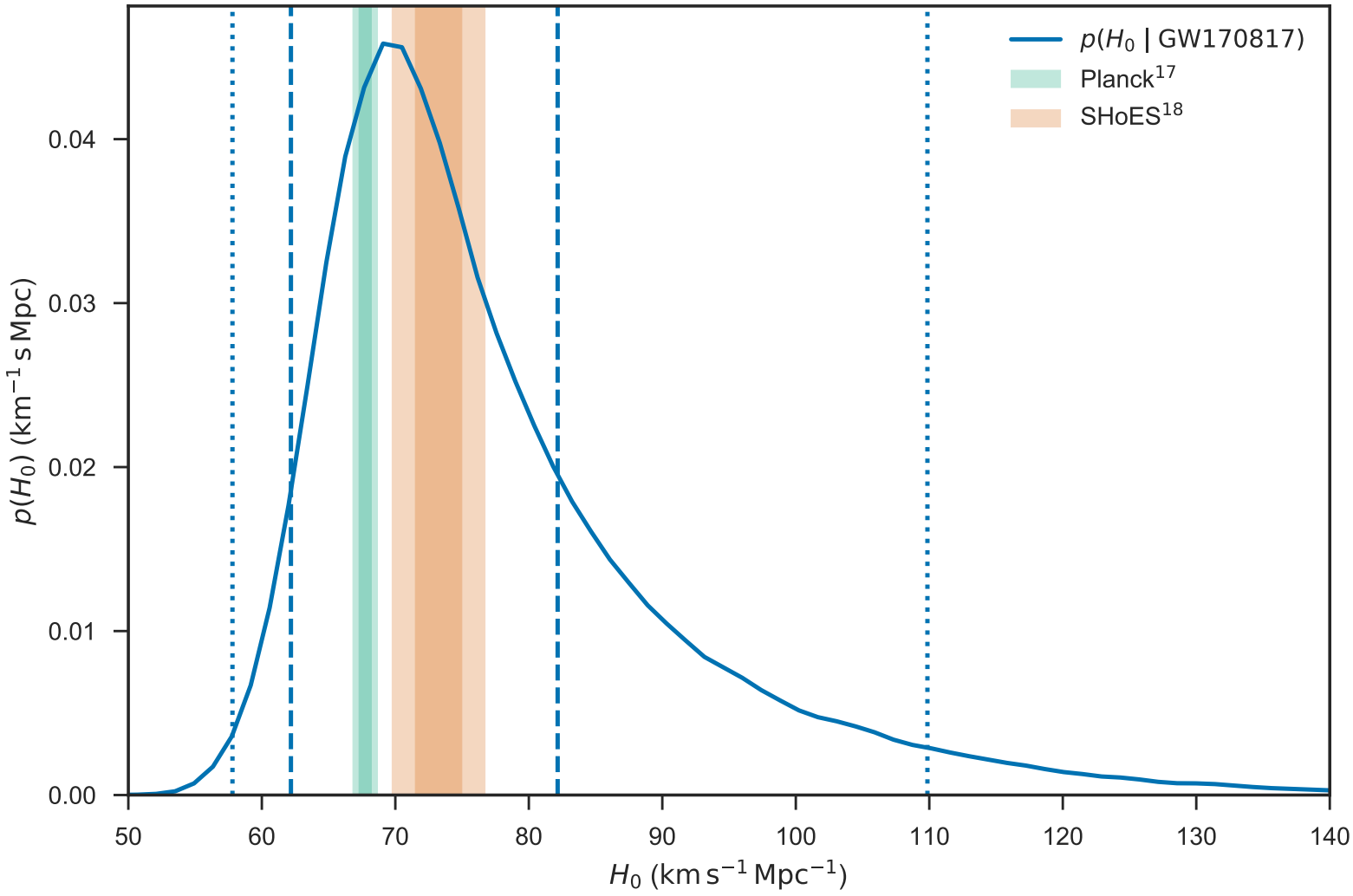
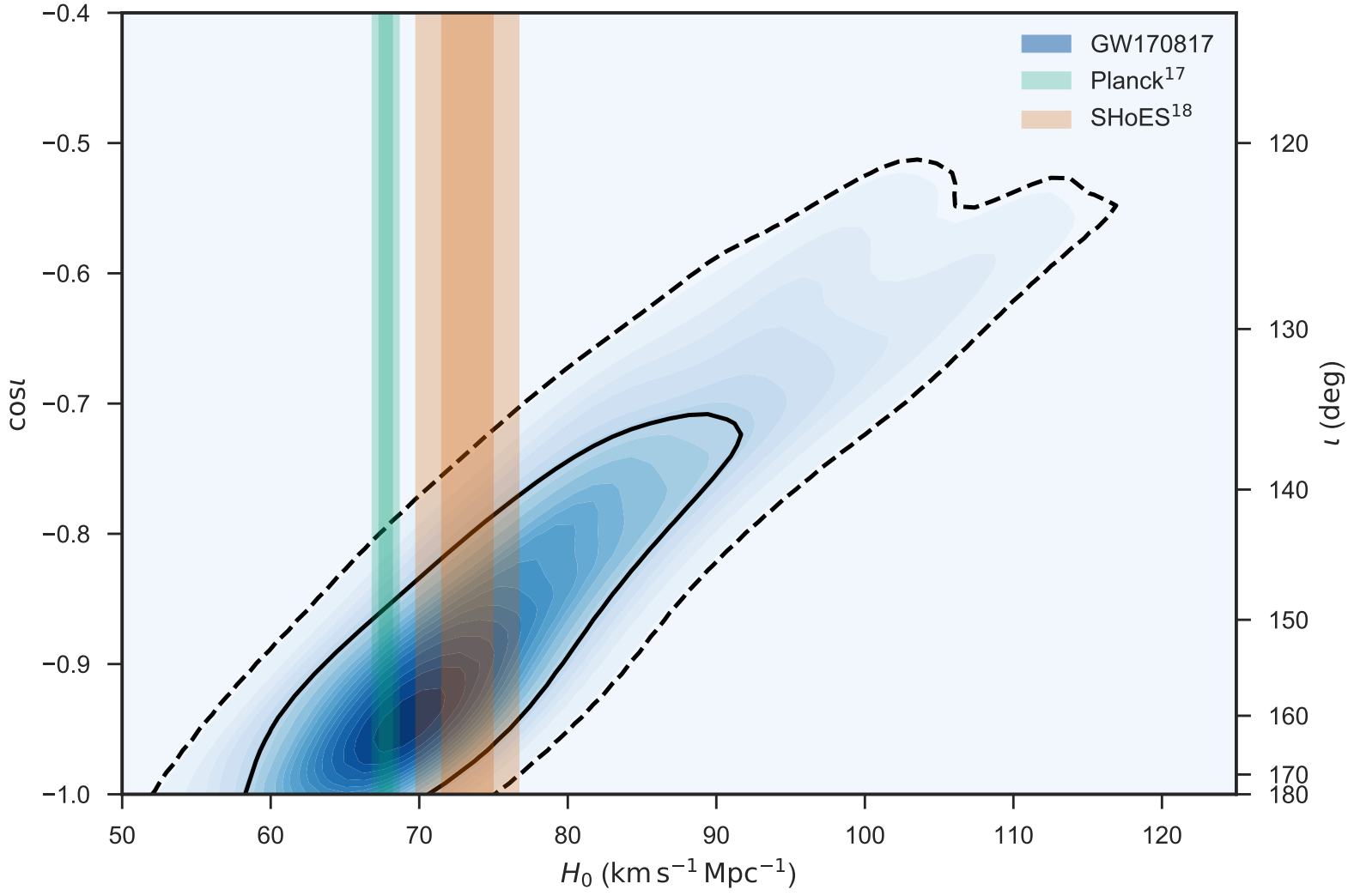
Independent measure of Hubble's constant



[Nature **551** (2017) 85]

Independent measure of Hubble's constant



[Nature **551** (2017) 85]

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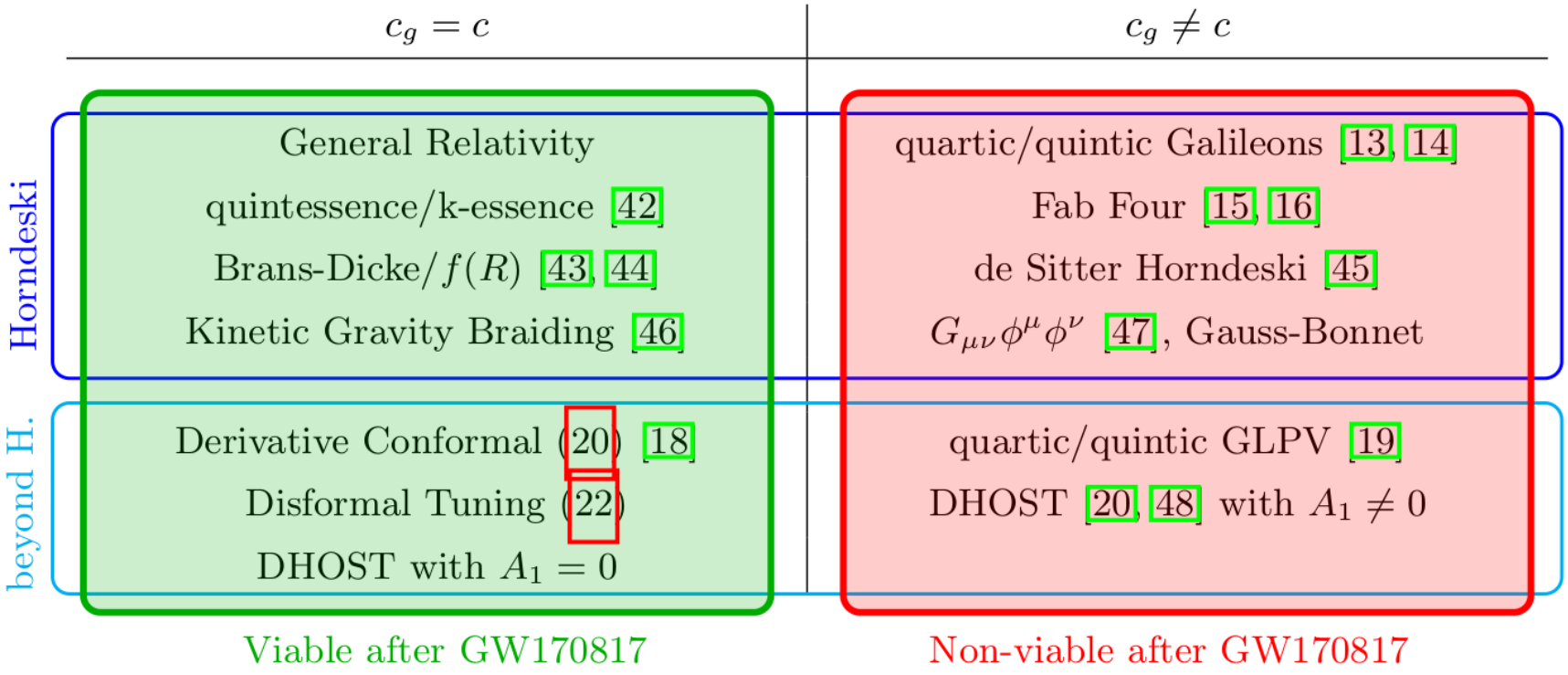
Falsifying many scalar-tensor theories

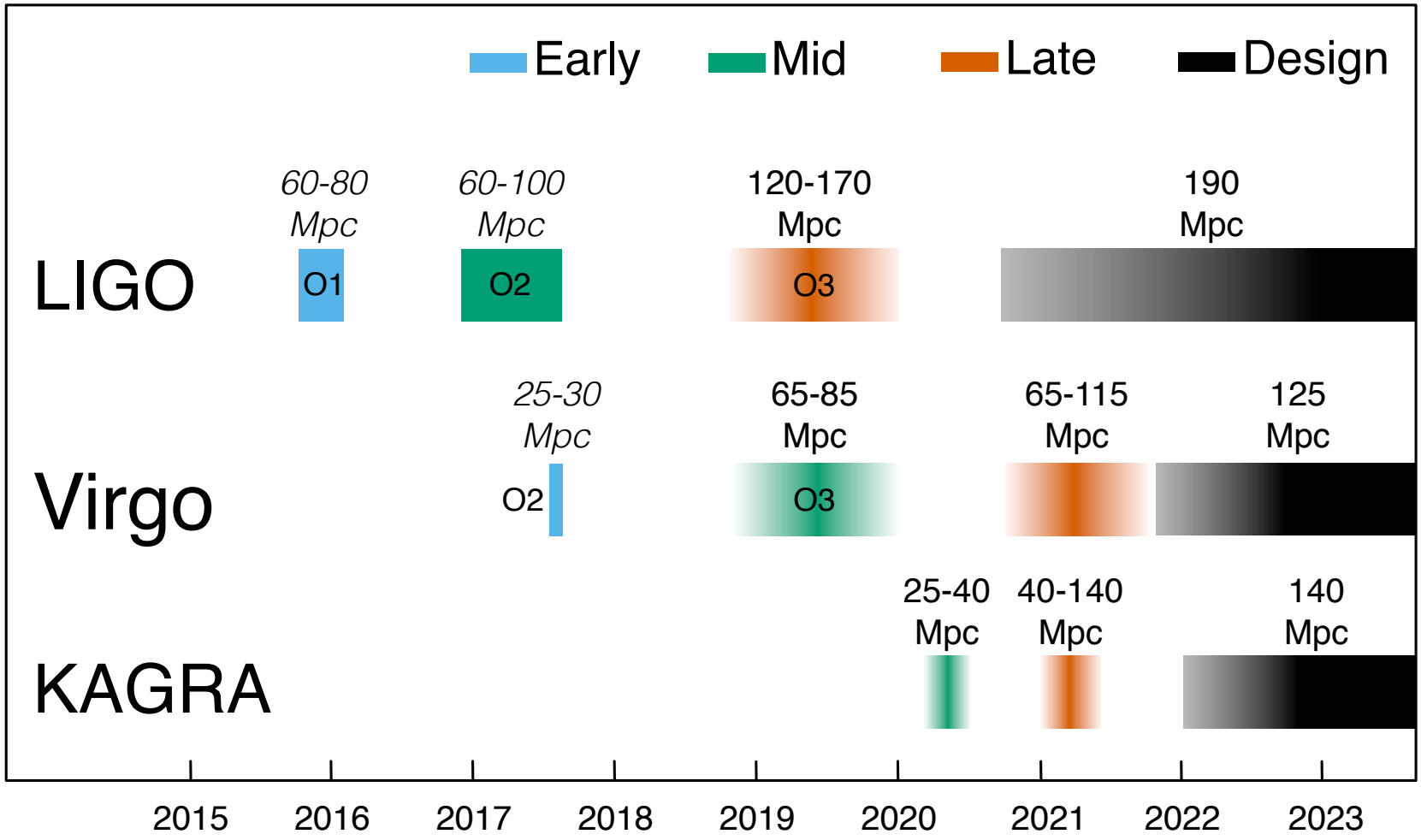


$$|c_g/c - 1| < 10^{-15}$$

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

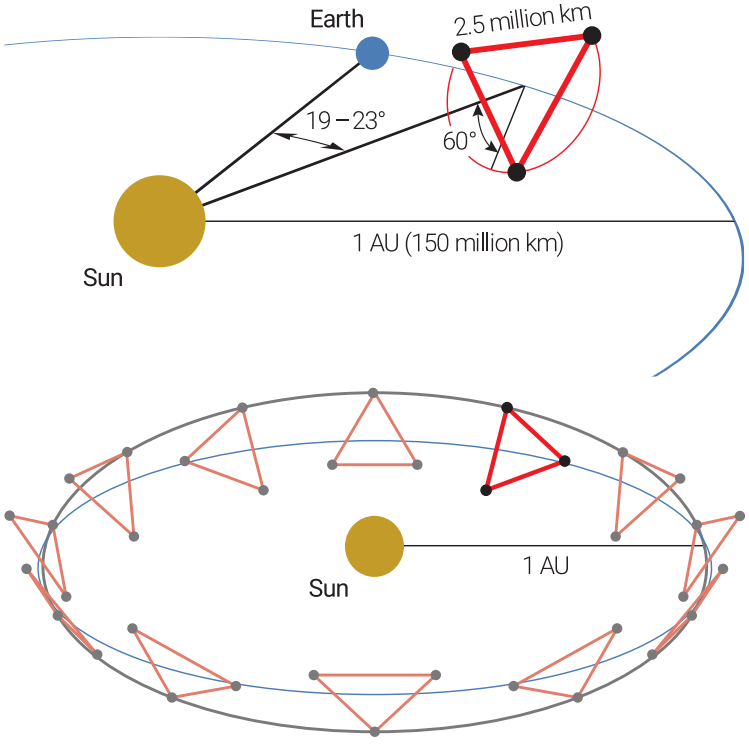
Outline

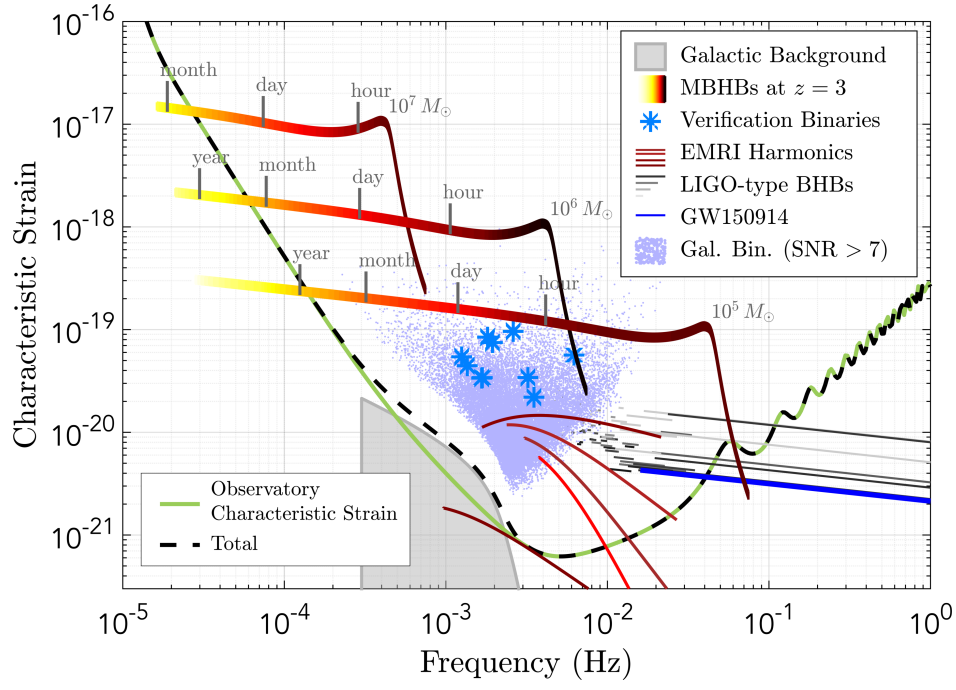
Roadmap for advanced GW detectors



[LRR **19** (2016) 1]

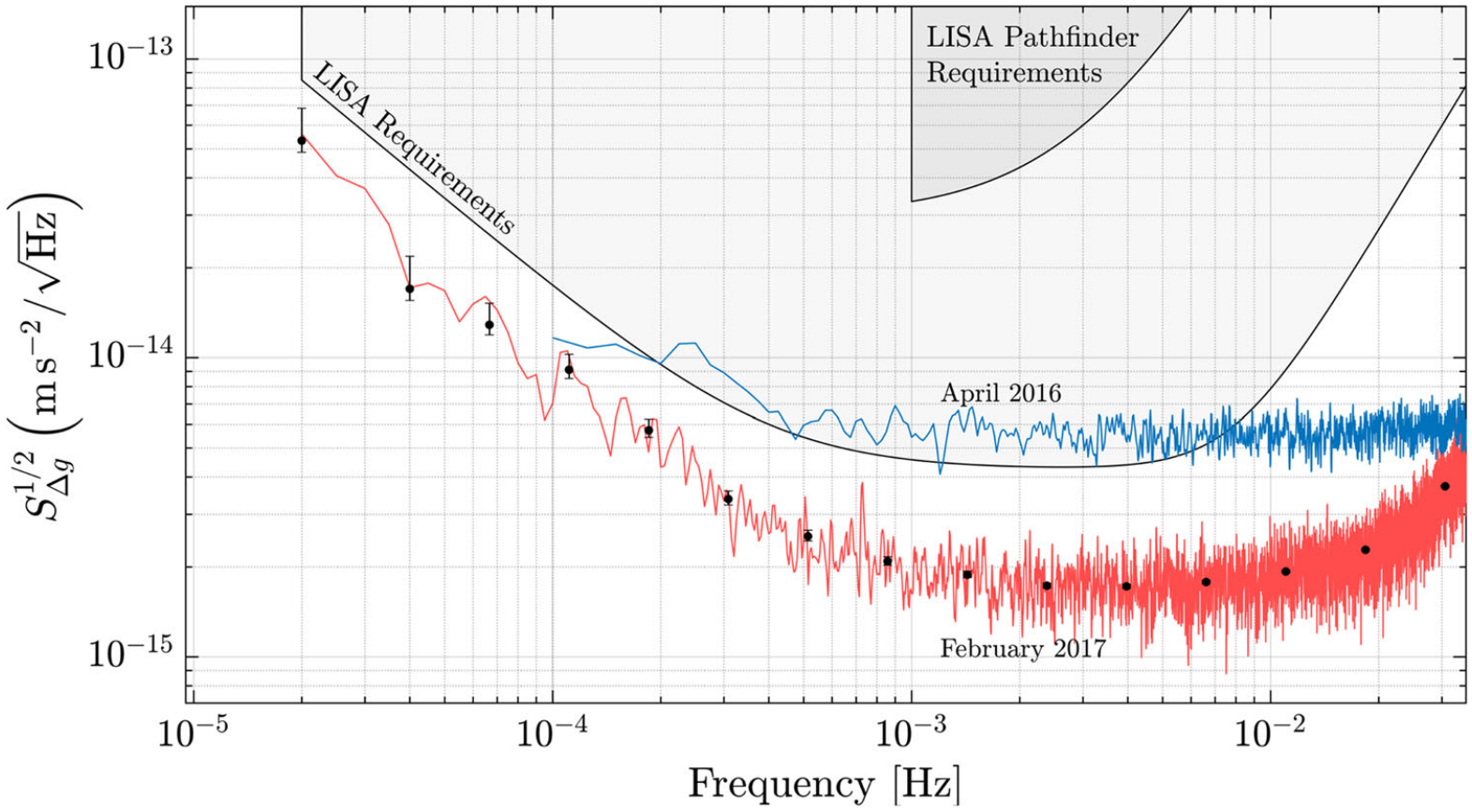
LISA: a gravitational antenna in space





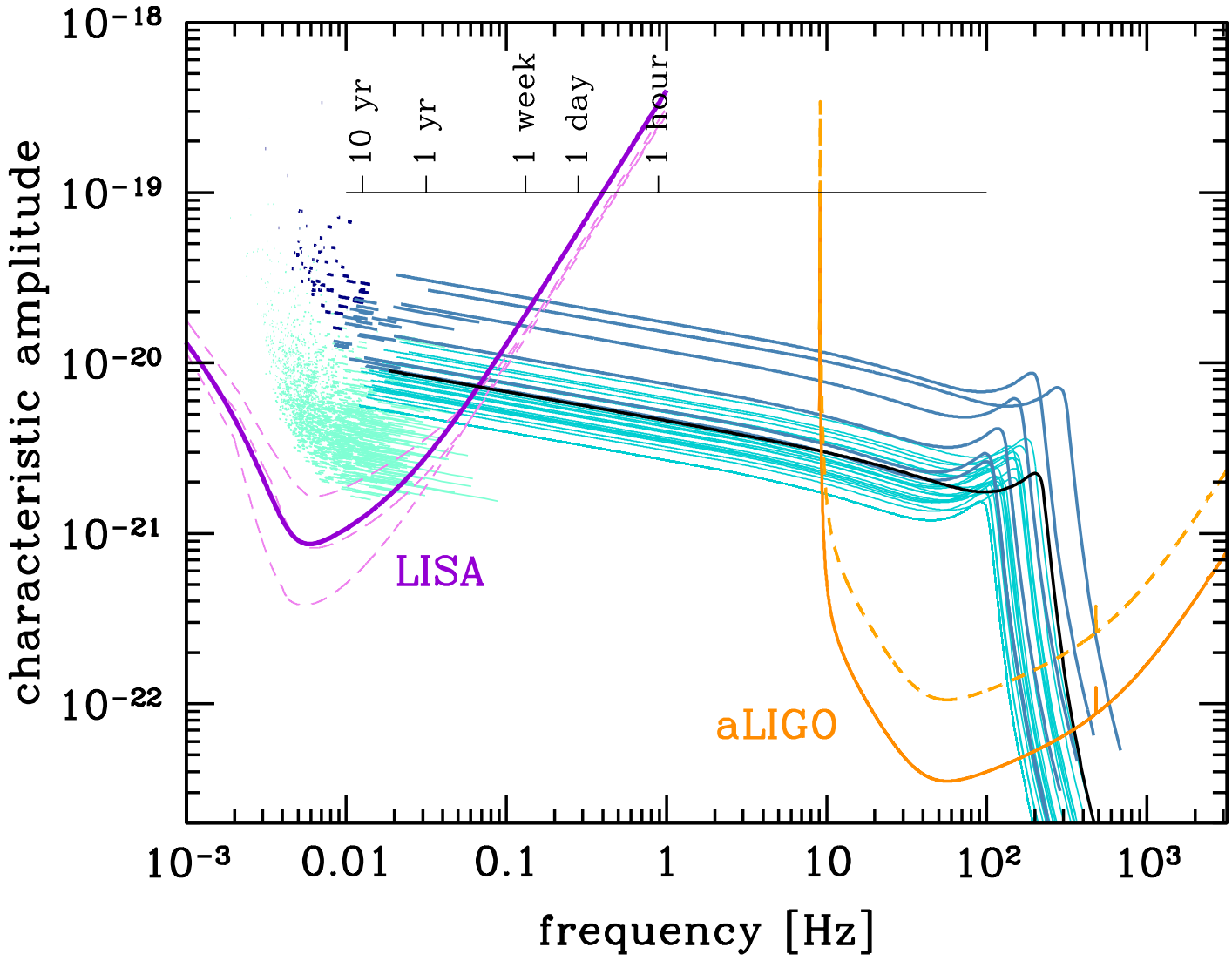
Science theme *The Gravitational Universe* selected by ESA for L3 mission with a launch planned for 2034 [elisascience.org/whitepaper]

LISA: a gravitational antenna in space



ESA's **LISA Pathfinder** mission has demonstrated the technology needed to build a space-based observatory [PRL **120** (2018) 061101]

Multi-band gravitational wave astronomy



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

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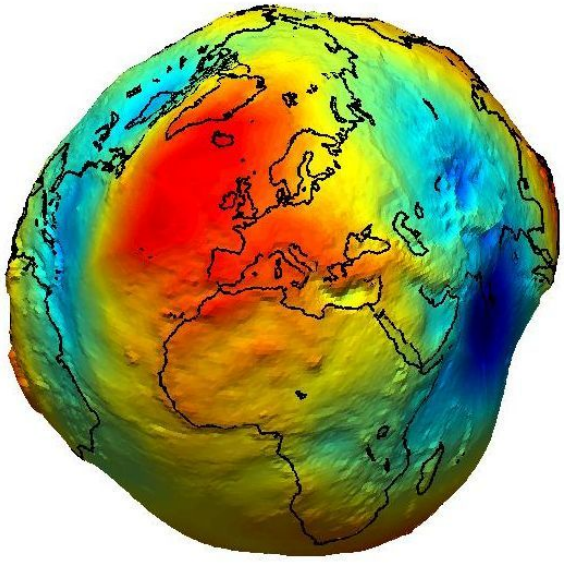
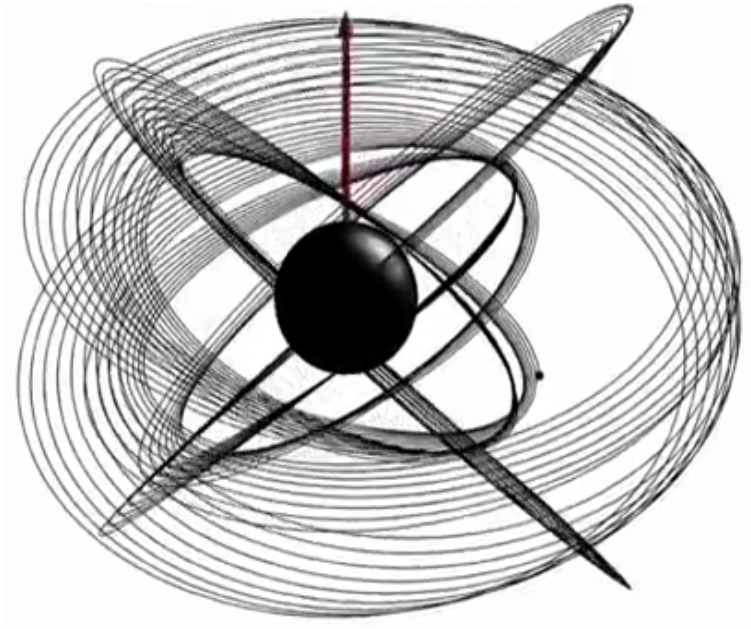
Do black holes have hair?

Geodesy



M_ℓ arbitrary

Botriomeladesy



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

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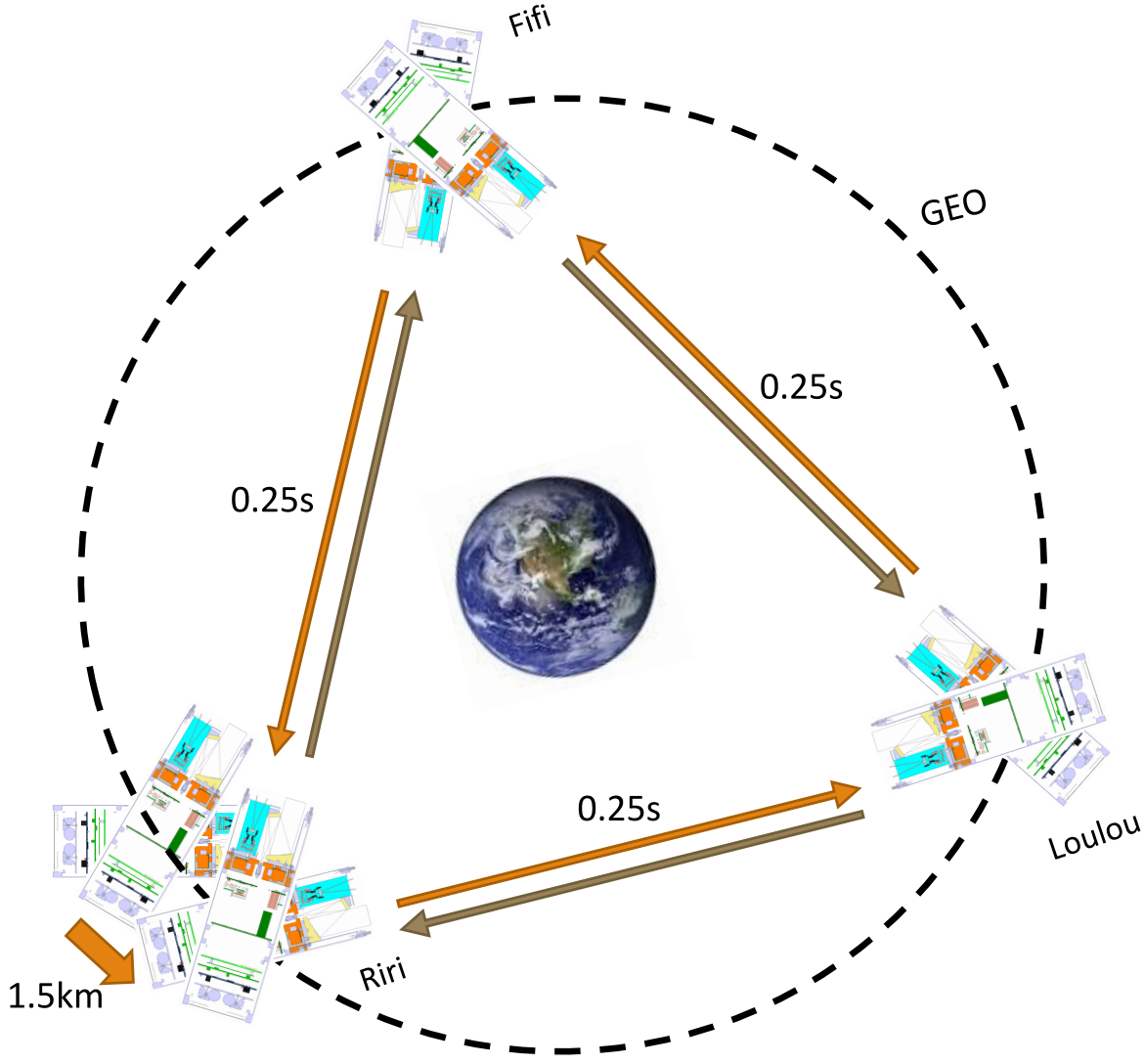
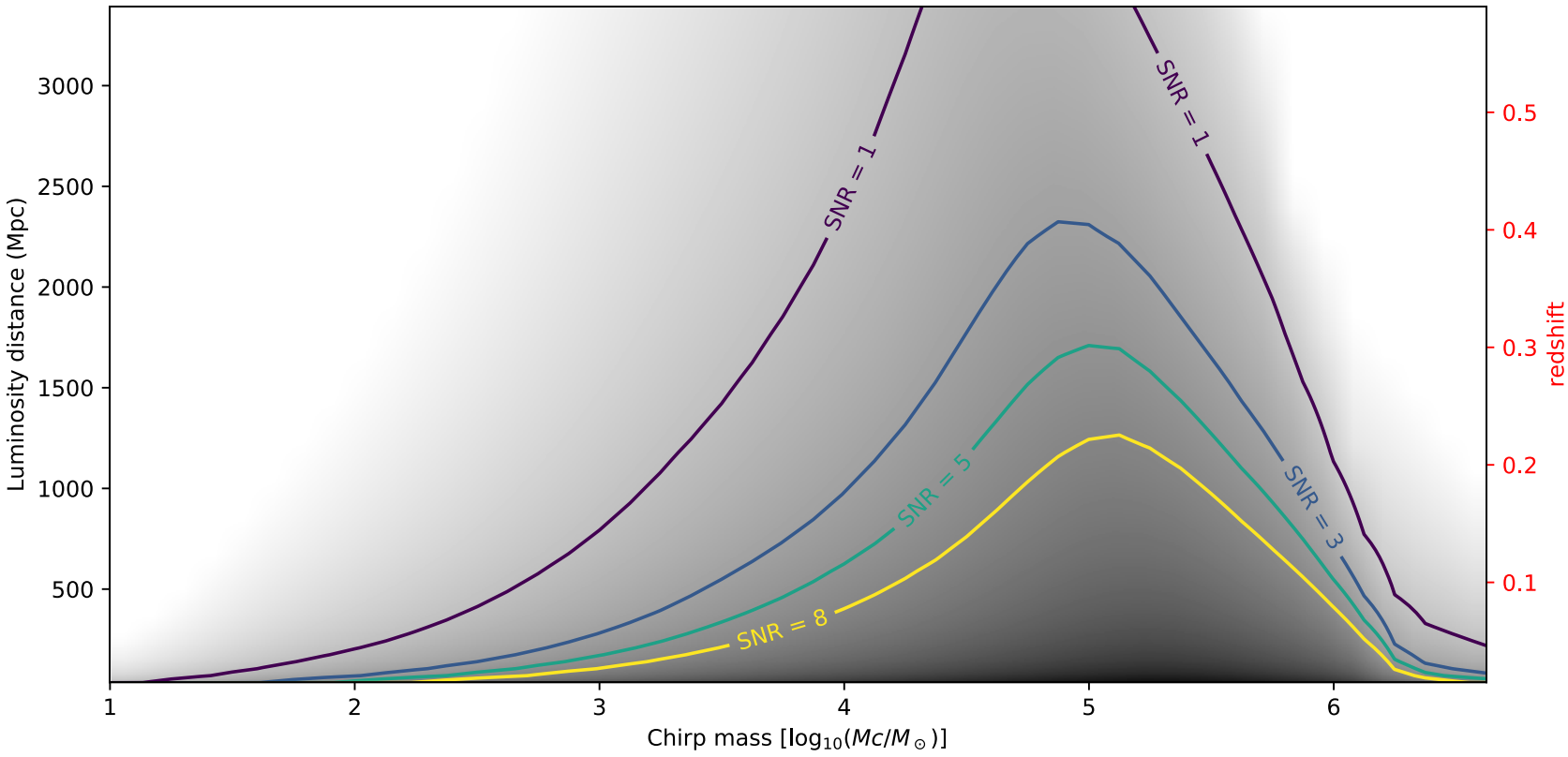
SAGE: finding IMBH in the black hole desert



[Lacour *et al.* (in preparation)]

SAGE: finding IMBH in the black hole desert



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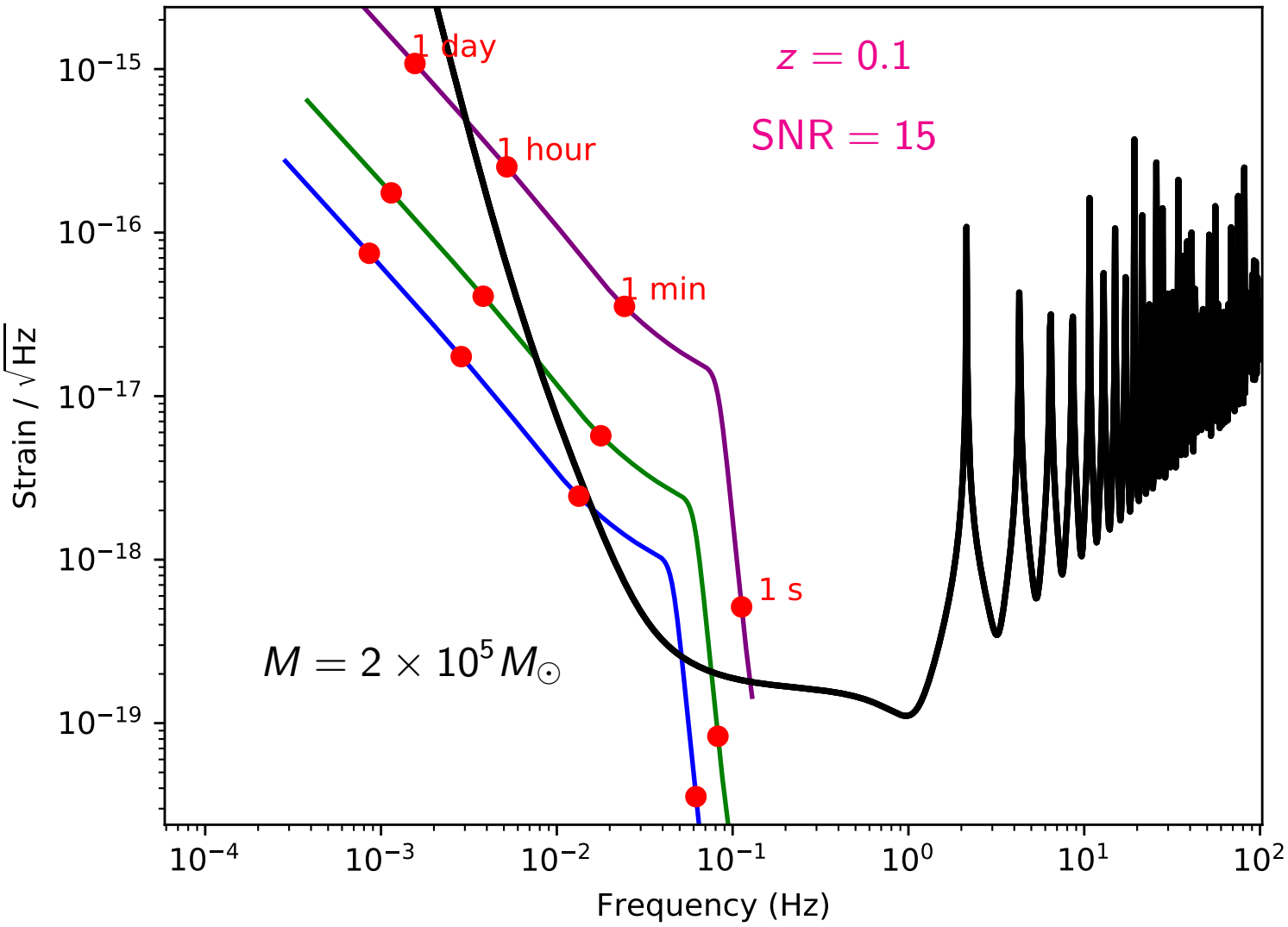

[Lacour *et al.* (in preparation)]