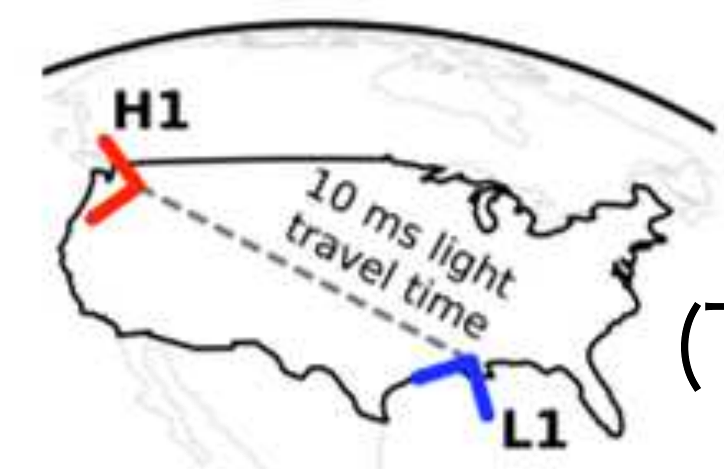
Discrepancy in tidal deformability of GW170817 between the Advanced LIGO twins

arXiv:1812.06100



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APWSW, February 12, 2019

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Abstract

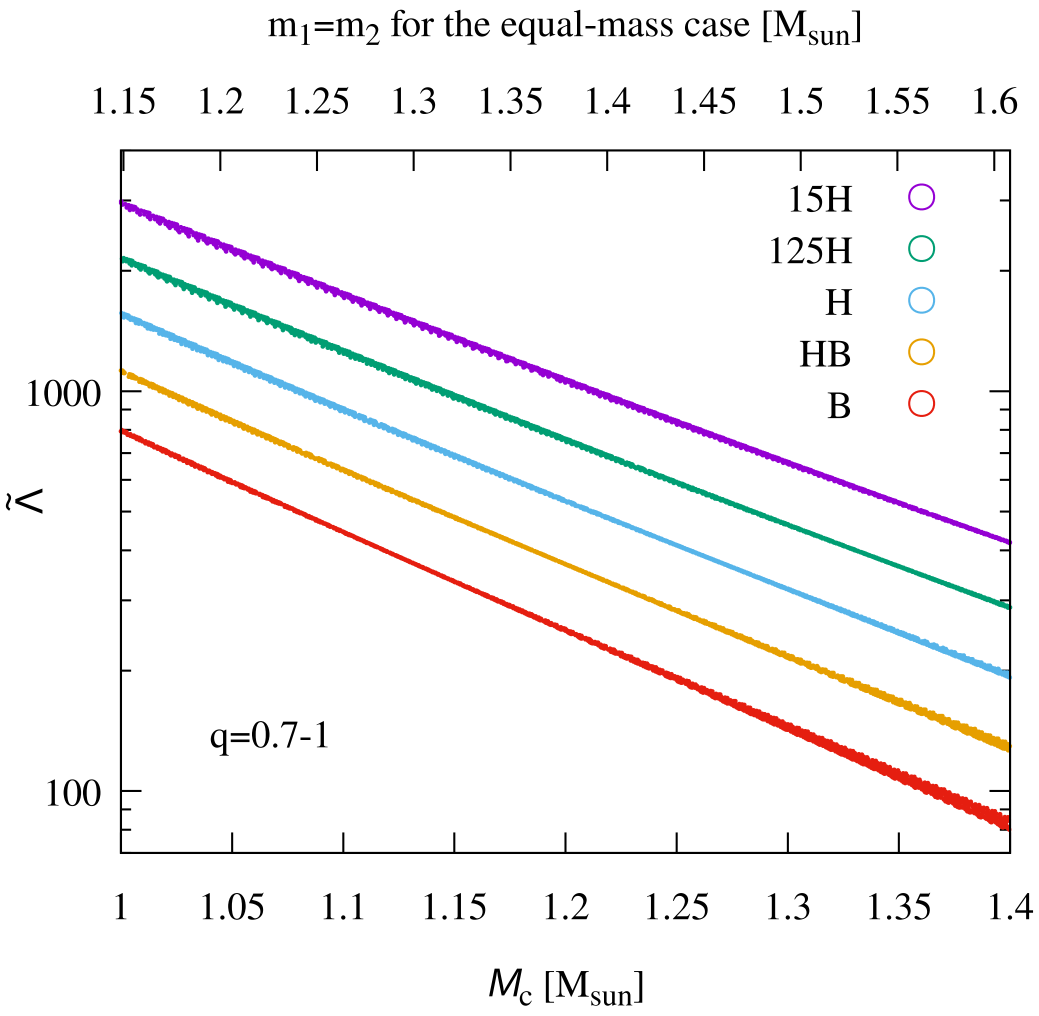
We find that

- the Hanford and Livingston detectors of Advanced LIGO derive distinct posterior probability distribution of binary tidal deformability $\tilde{\Lambda}$ of the binary-neutron-star merger GW170817.
- significantly multimodal distribution associated with a disconnected highest-posterior-density 90% credible interval from the Livingston detector.
- the distribution derived by the Livingston detector changes irregularly when we vary the maximum frequency of the data used in the analysis.

Introduction

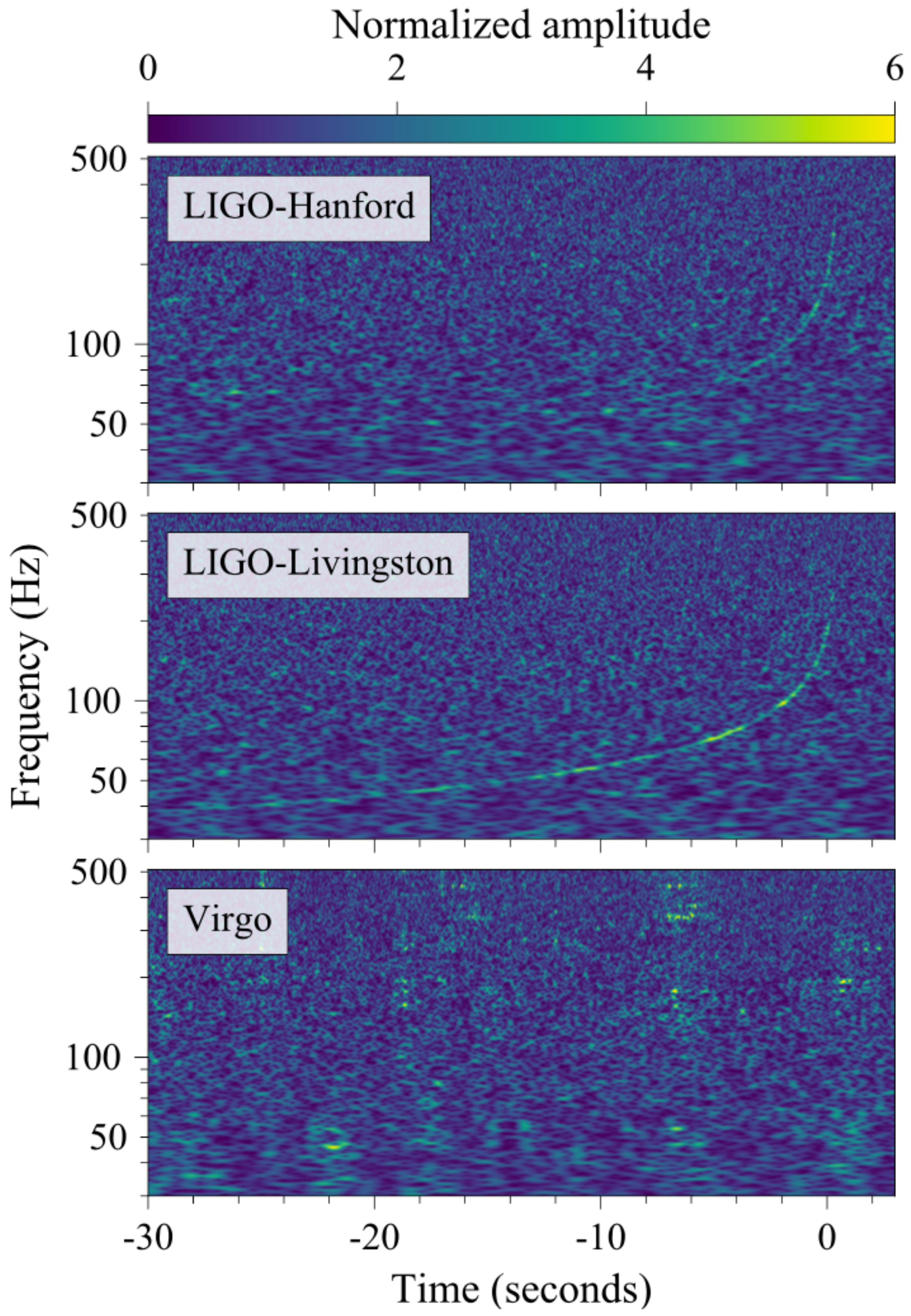
Tidal deformability of neutron stars (NSs) can be a key quantity to understand the hitherto-unknown nature of supranuclear density matter. The relation between the mass and tidal deformability is uniquely determined by the NS EOS as the mass-radius relation is.

Thus, simultaneous measurements of the mass and tidal deformability are eagerly desired, and GWs from BNS mergers give us a perfect opportunity.



Kawaguchi, et al., arXiv:1802.06518.

The direct detection of GWs from a BNS merger, GW170817

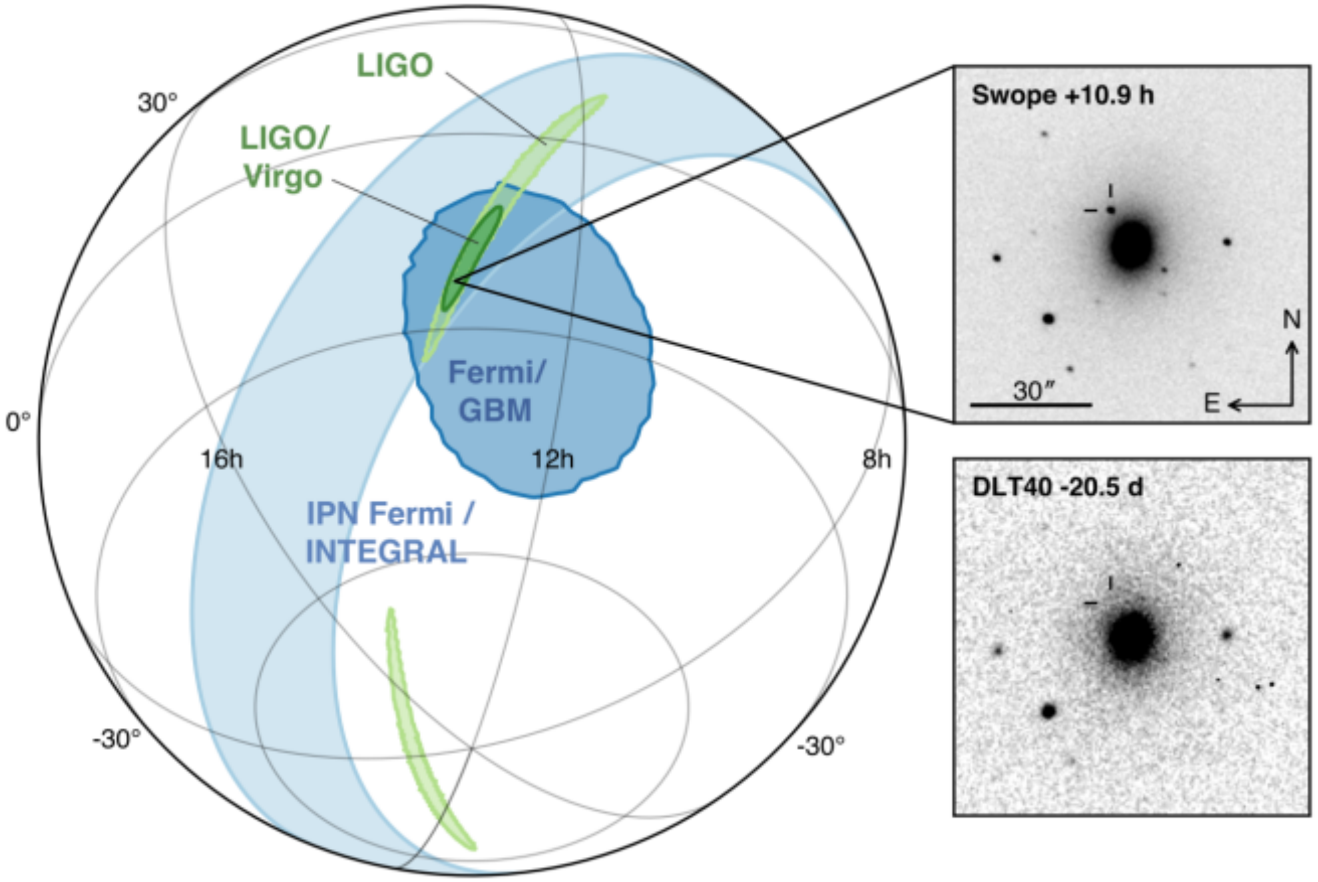


SNR **For $f_{\rm min}$=30Hz**

32.4 (Network)

18.8 (H), 26.4(L), 2.0 (V)

Sky position is determined by optical follow-up observations

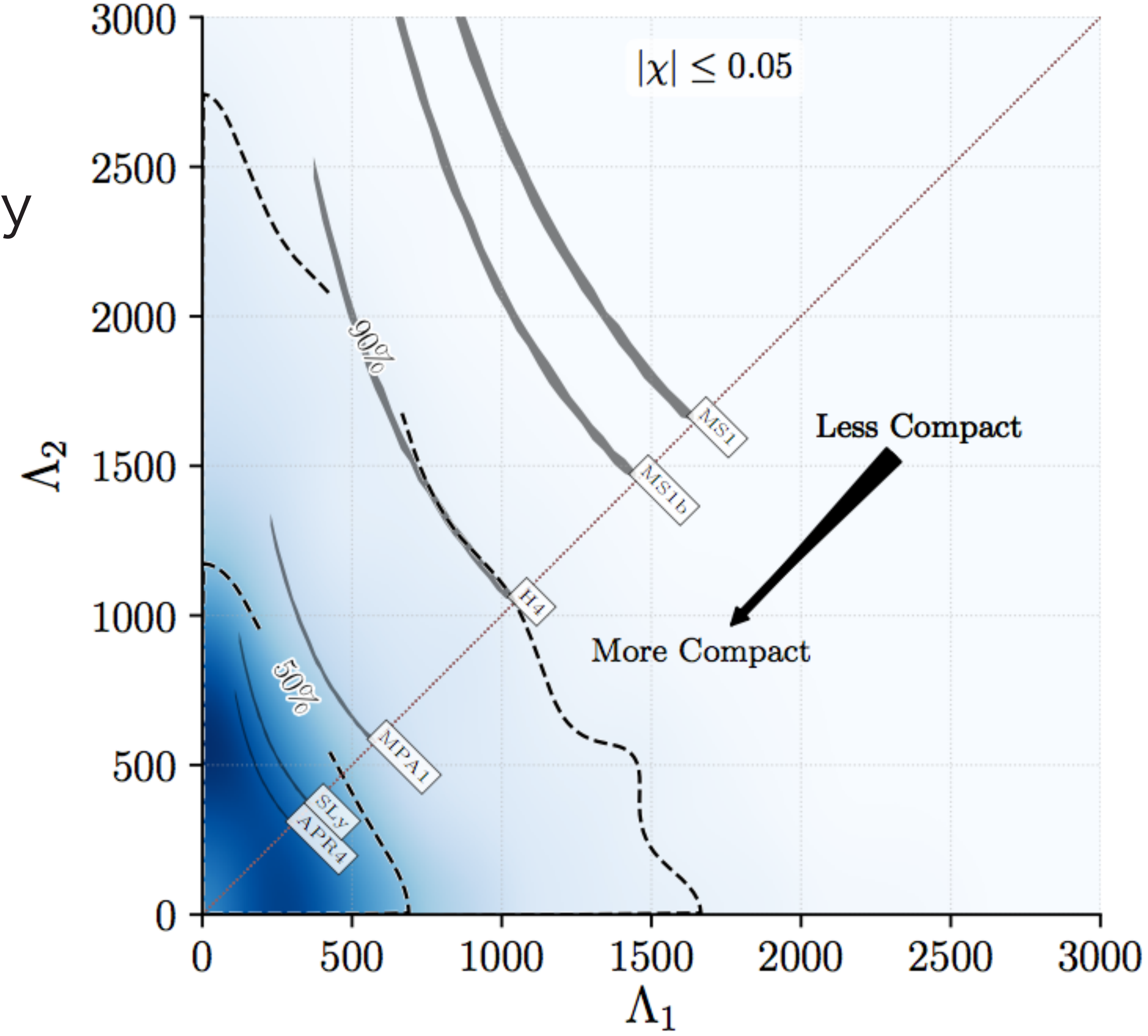


[LVC, PRL 119, 161101 (2017)]

GW170817 enabled us to measure the tidal deformability for the first time

These quantities constrain the nuclear EOS of NS matter.

LIGO-Virgo Collaboration put conservative upper limits on tidal deformability with post-Newtonian waveform.

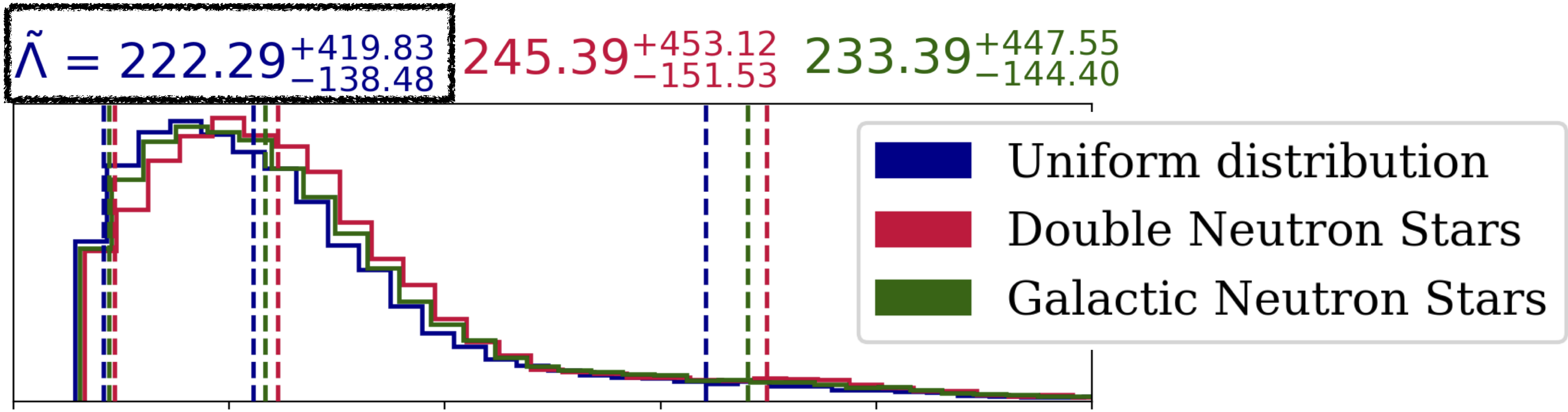


symmetric contribution of tidal deformation

$$\boxed{\tilde{\Lambda} < 900}$$

Independent analysis of GW170817

[De, et al., PRL 121, 091102 (2018)]



$\tilde{\Lambda} = 222.29^{+419.83}_{-138.48}$ $245.39^{+453.12}_{-151.53}$ $233.39^{+447.55}_{-144.40}$

With the reasonable assumption of a common, causal EOS for both NSs; this is effectively implemented by assuming that the star's dimensionless tidal deformabilities are determined by the binary's mass ratio q by $\Lambda_1/\Lambda_2 = q^6$.

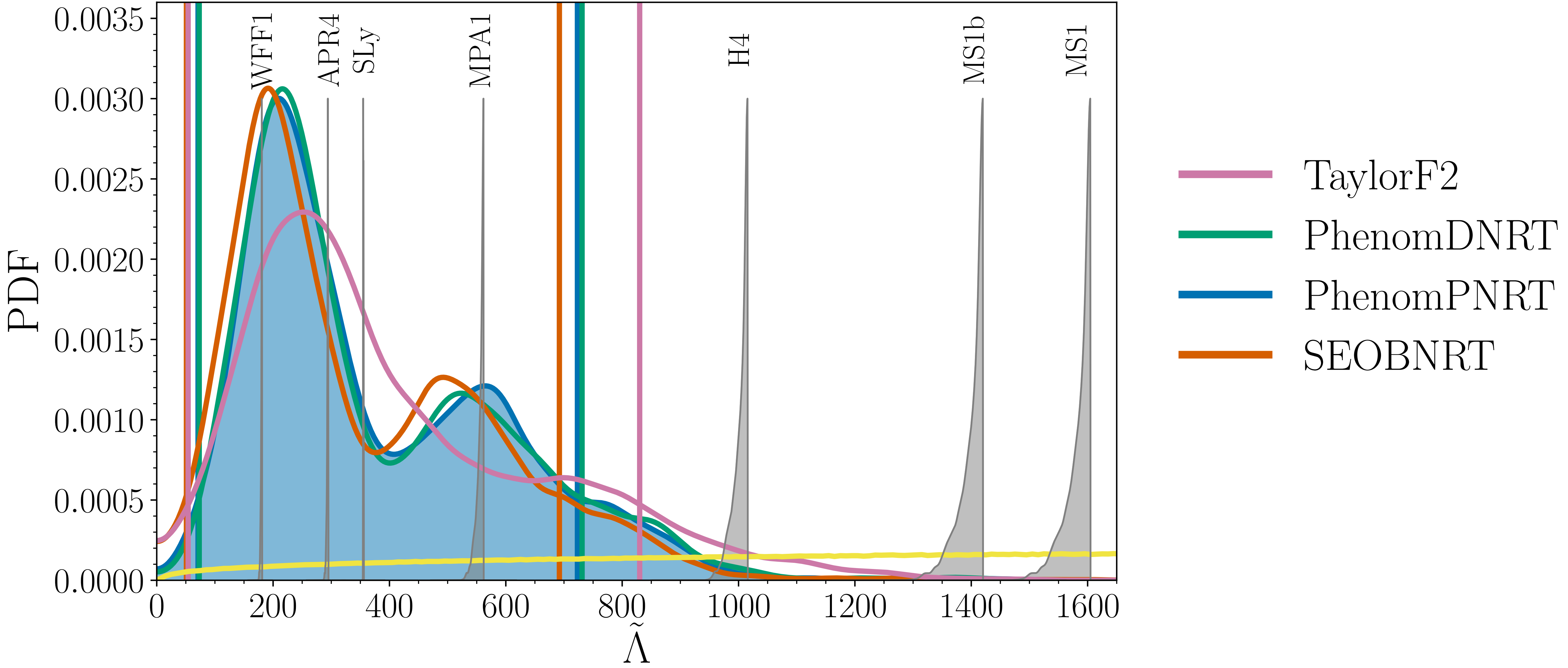
Uniform: $m_{1,2}$~U[1, 2]M_{sun}

DNS: $m_{1,2}$~N(μ=1.33, σ=0.09)M_{sun} (Gaussian prior, fit to masses of NSs observed in DNS systems)

Galactic NSs: m_1~N(μ=1.54, σ=0.23)M_{sun}, m_2~N(μ=1.49, σ=0.19)M_{sun} (fit to observed recycled and slow pulsars in the Galaxy)

Improved analysis of GW170817

[LVC, arXiv:1805.11579]



Using sophisticated waveform models, an updated highest-posterior-density (HPD) interval,

$$\boxed{\tilde{\Lambda} = 300^{+420}_{-230}}$$

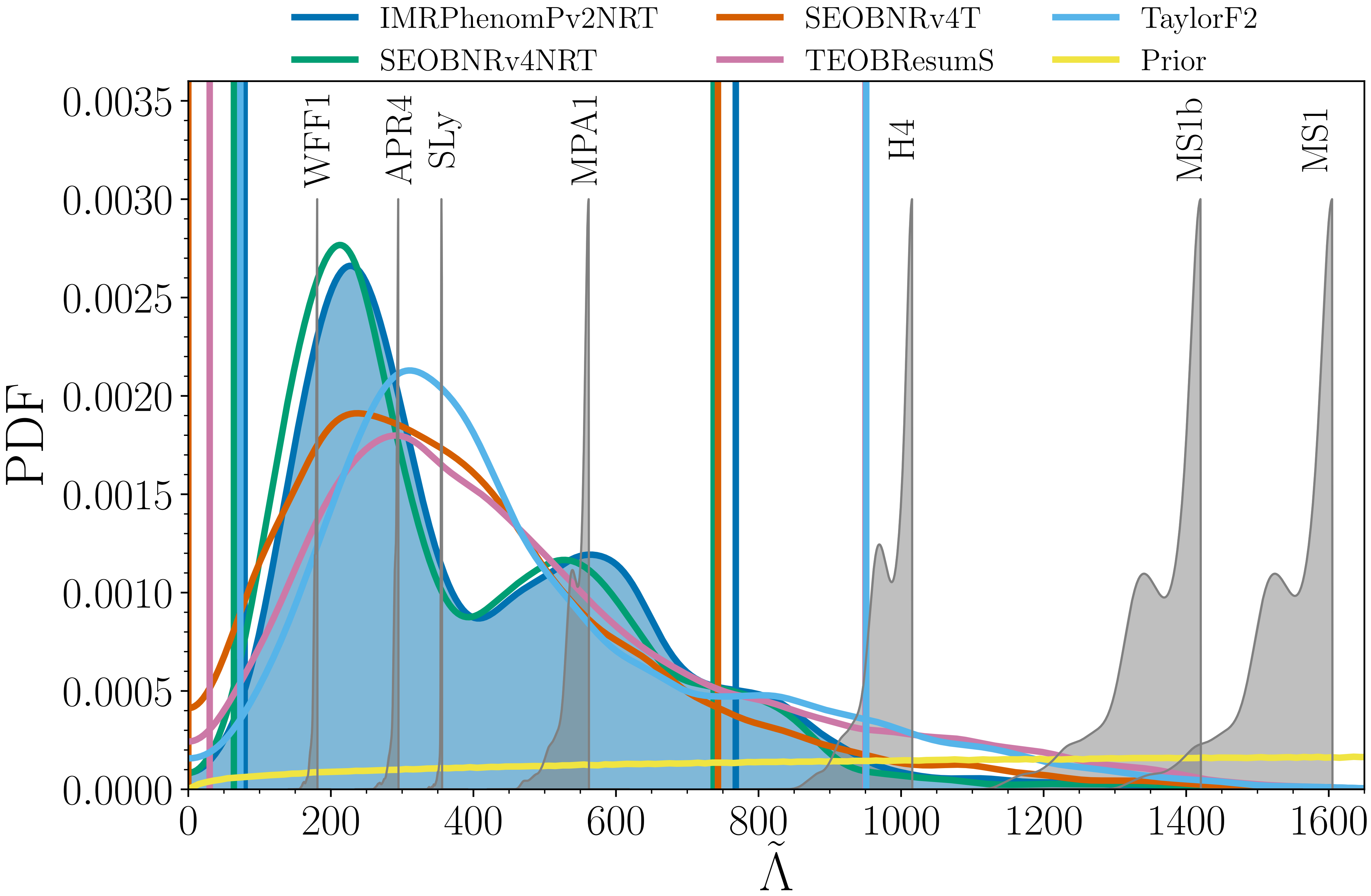
If a common EOS is assumed, this is further restricted to $\boxed{190^{+390}_{-120}}$

Recalibrated data release of GW events

GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs

The LIGO Scientific Collaboration and The Virgo Collaboration

Improved analysis of GW170817 with new waveform models.



Our independent reanalysis of GW170817

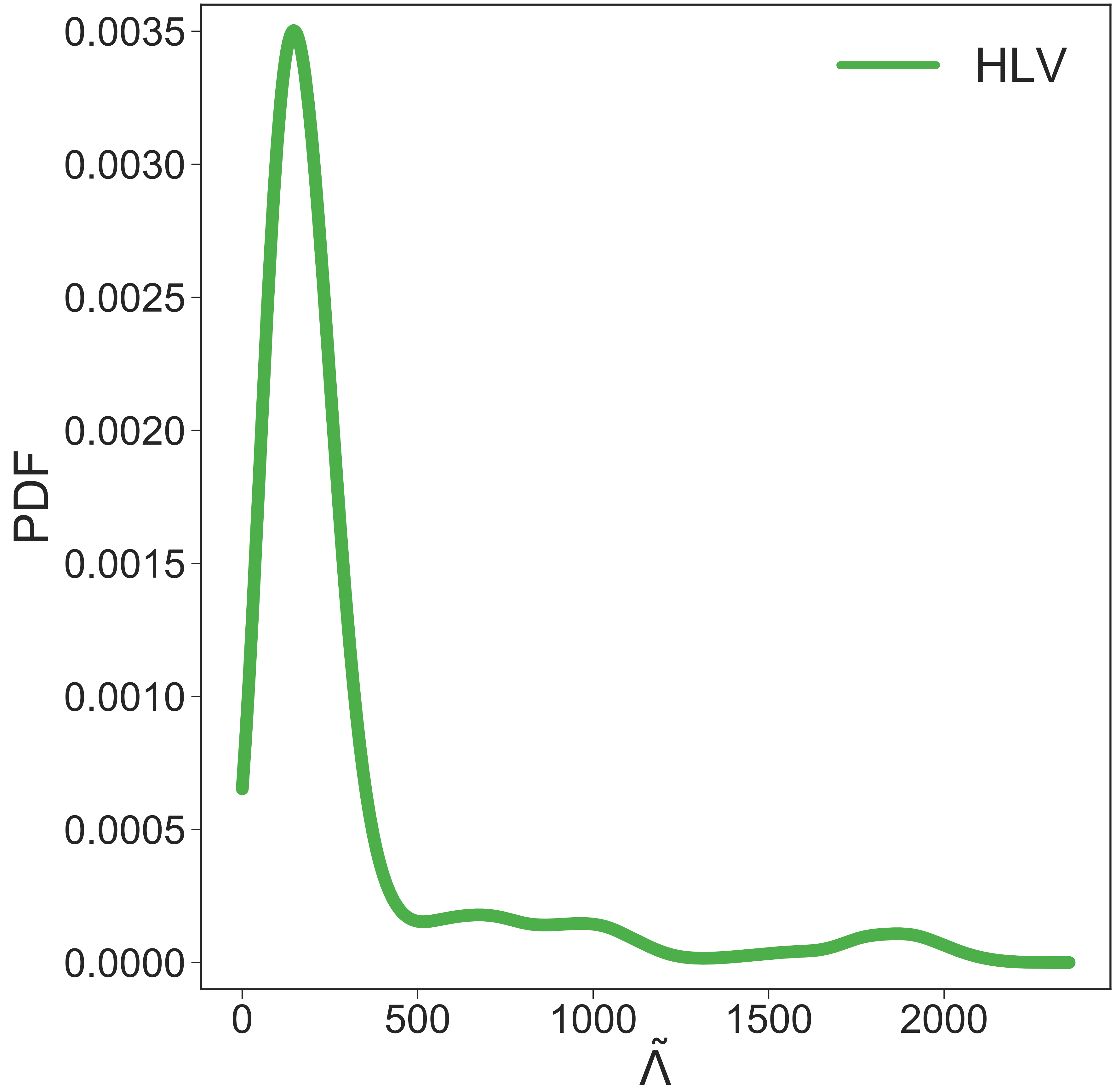
- **We analyze the Advanced LIGO twins, the Hanford and Livingston detectors, separately.**
- **We vary the upper limit f_{max} to investigate its influence on parameter estimation.** (the lower limit of the frequency to be 23Hz)

basically follow those adopted in the improved LVC analysis (arXiv:1805.11579)

- Nested sampling implemented in LALInference.
- The sky position is fixed to the location determined by optical followup observations.
- post-Newtonian waveform (TaylorF2)
- Low-spin prior ($\chi<0.05$)

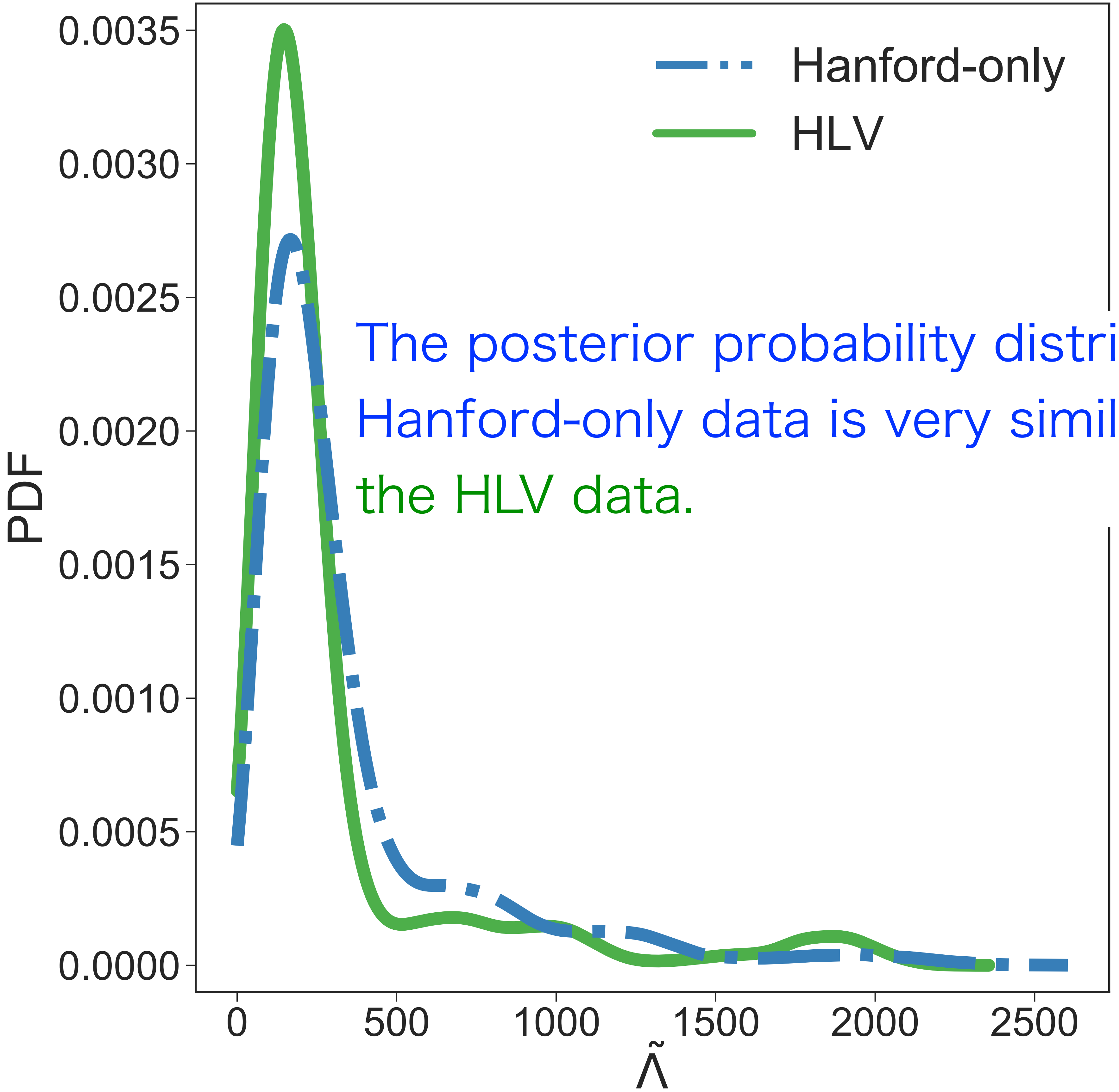
Combined analysis of the Advanced LIGO twins, the Hanford and Livingston, and Virgo

f_{max}=min[f_{ISCO}, 2048 Hz]



Separate analysis of the Advanced LIGO twins, the Hanford and Livingston detectors

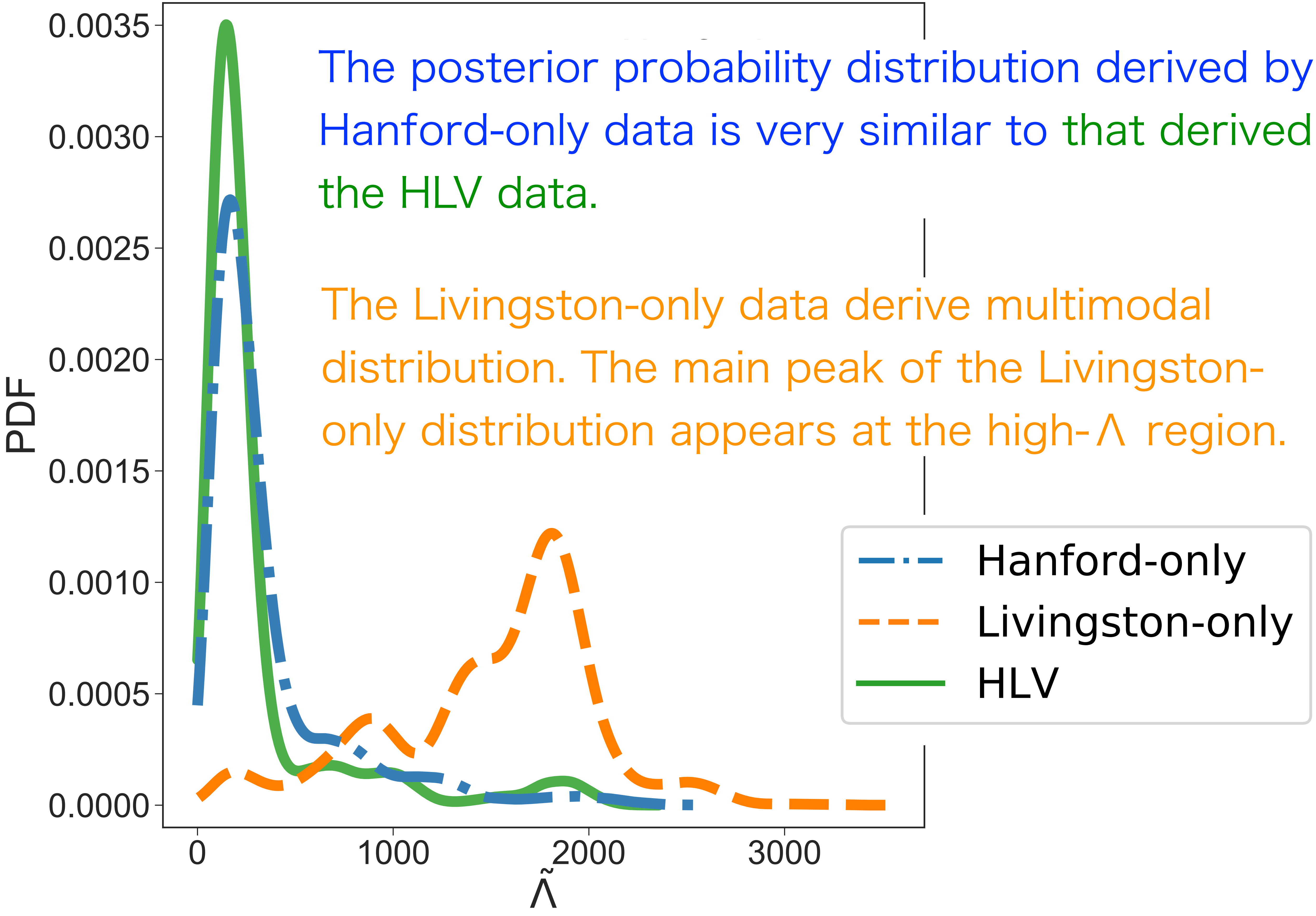
f_{max}=min[f_{ISCO}, 2048 Hz]



The posterior probability distribution derived by the Hanford-only data is very similar to that derived by the HLV data.

Separate analysis of the Advanced LIGO twins, the Hanford and Livingston detectors

f_{max}=min[f_{ISCO}, 2048 Hz]

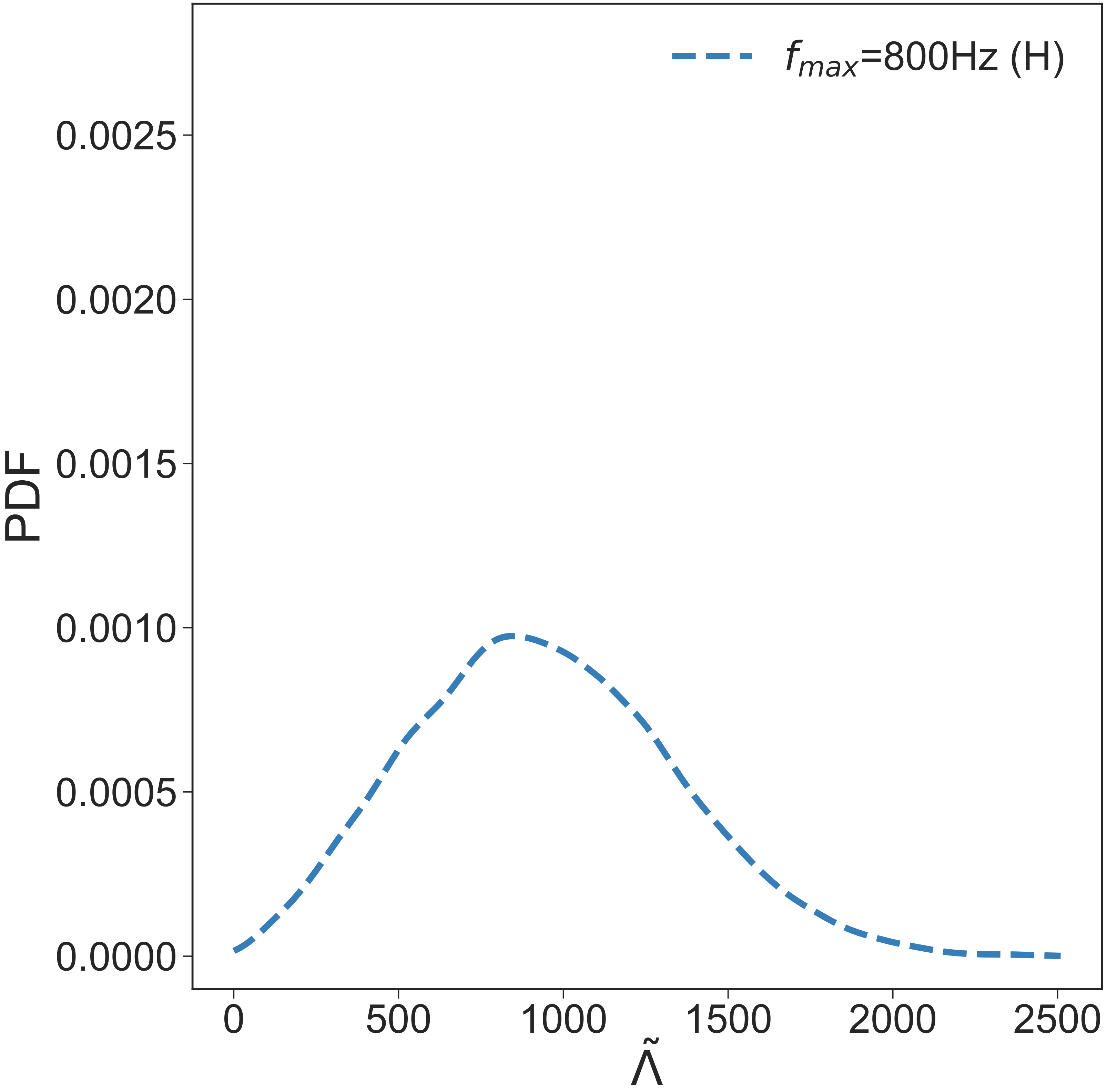


The posterior probability distribution derived by the Hanford-only data is very similar to that derived by the HLV data.

The Livingston-only data derive multimodal distribution. The main peak of the Livingston-only distribution appears at the high-Λ region.

Dependence on maximum frequency, f_{max}

The Hanford-only distribution



Dependence on maximum frequency, f_{max}

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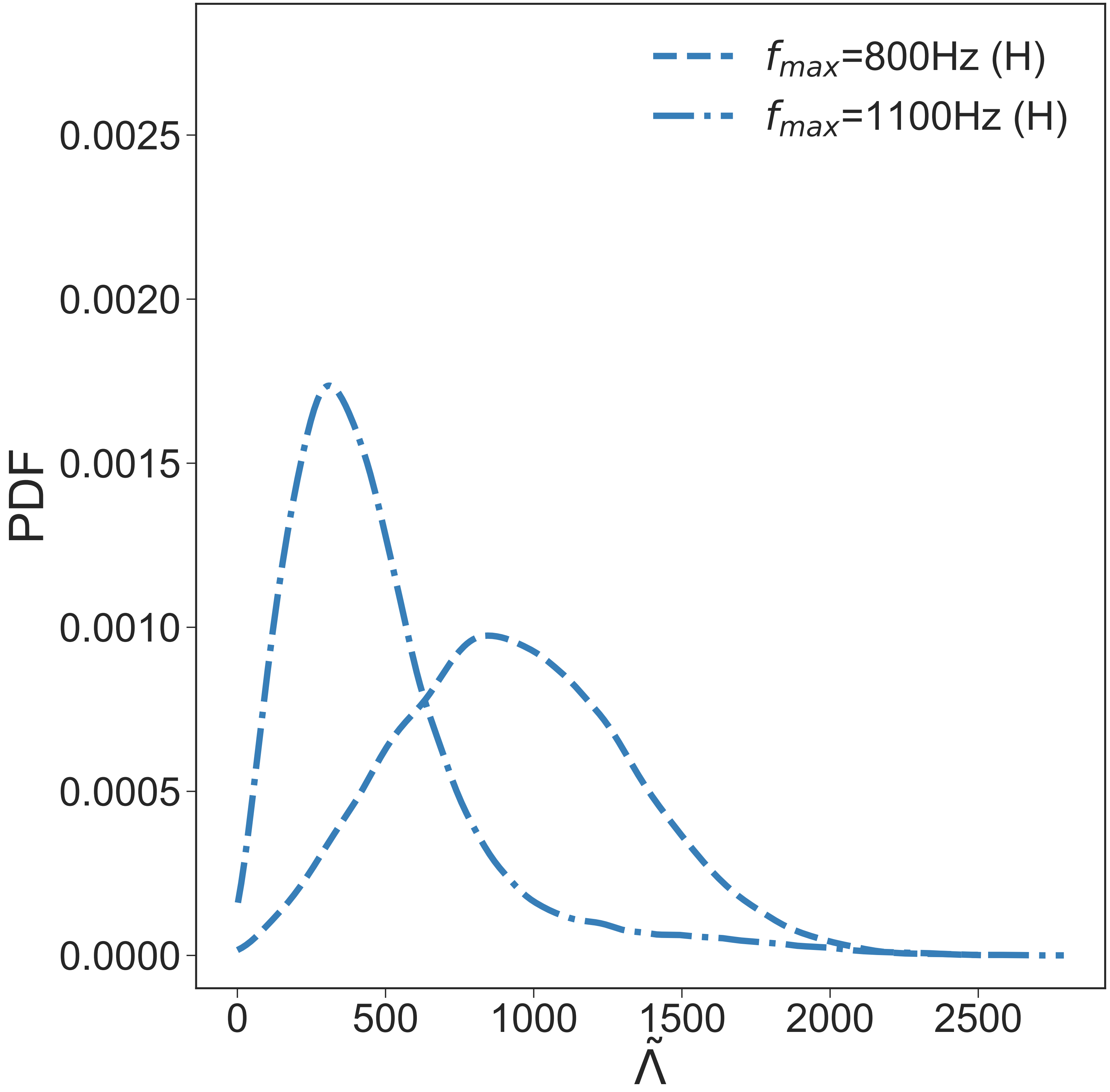
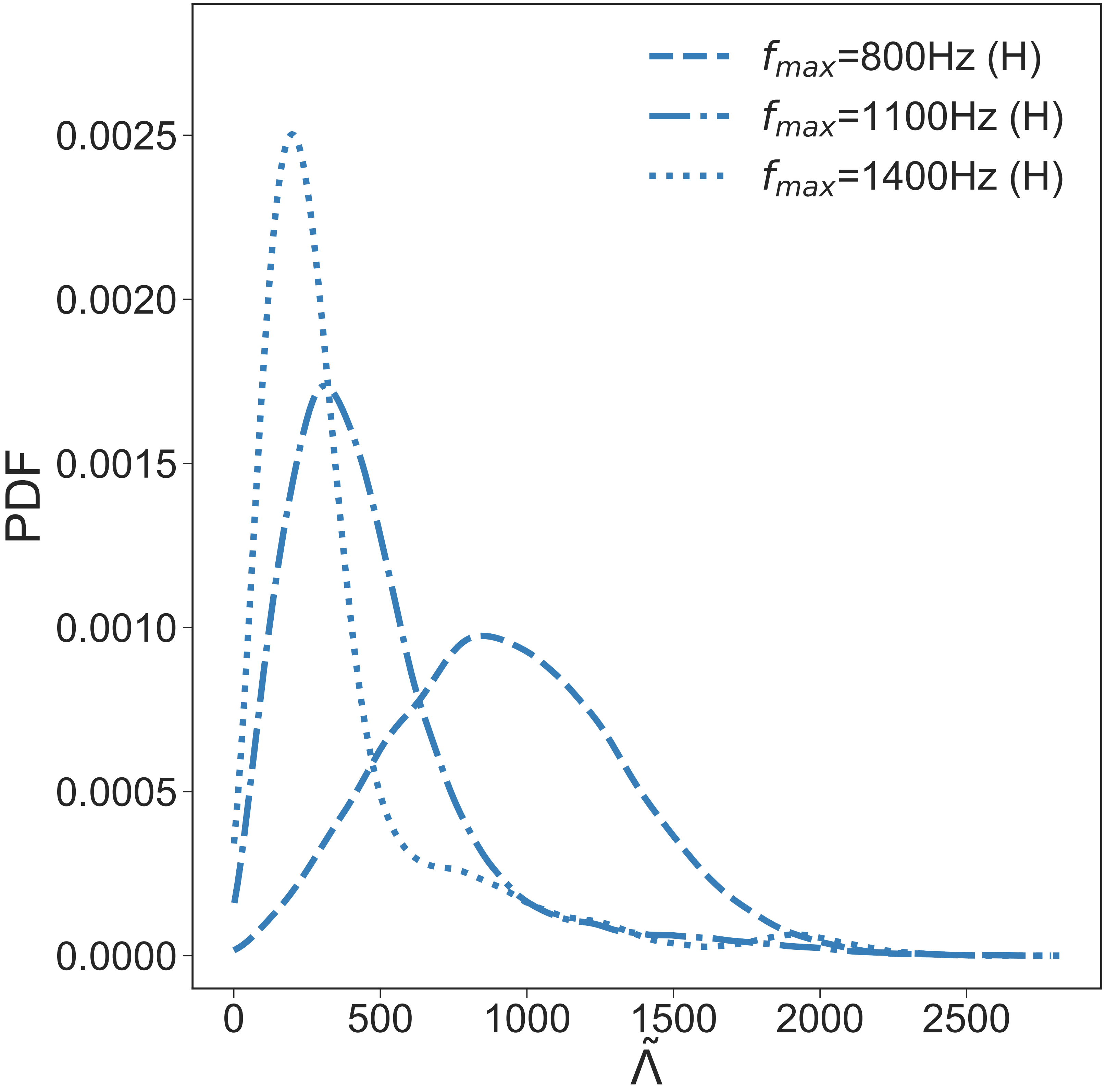


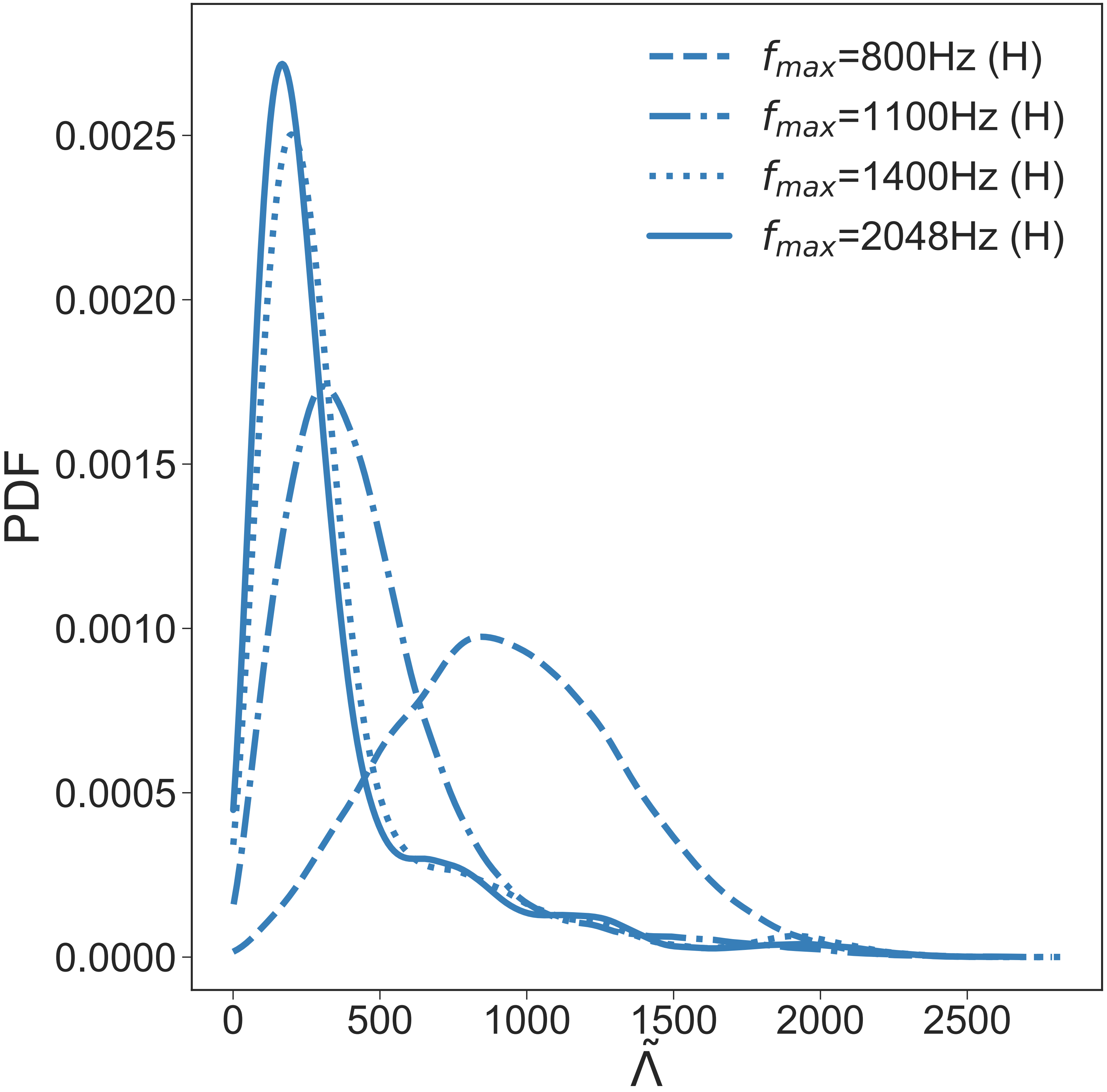
Dependence on maximum frequency, f_{max}

The Hanford-only distribution



Dependence on maximum frequency, f_{max}

The Hanford-only distribution shrinks monotonically and appears to become narrowly peaked as f_{max} increases.



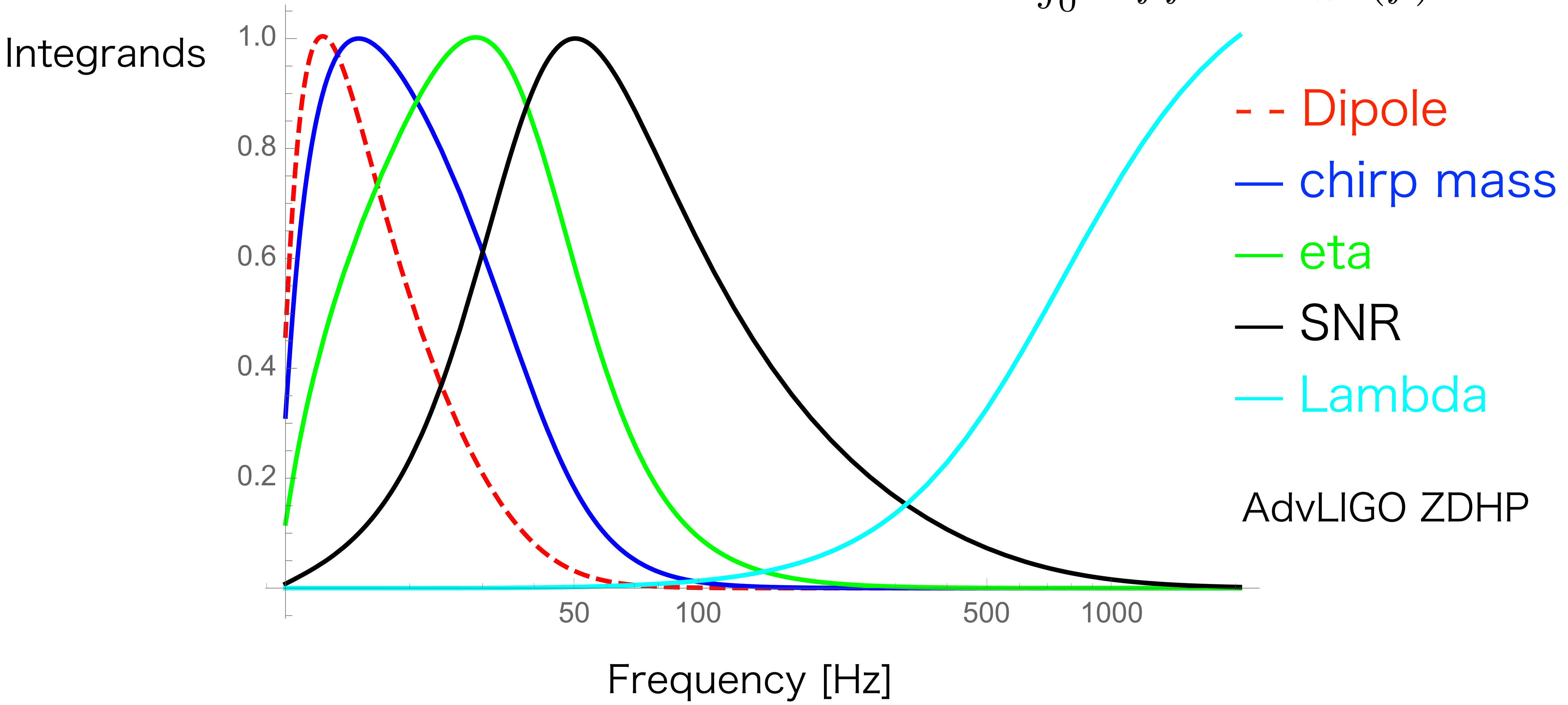
This is reasonably expected, because the tidal deformability is primarily determined by the GW data at high frequency.

Measurability

Information about parameters is contained in different frequency ranges.

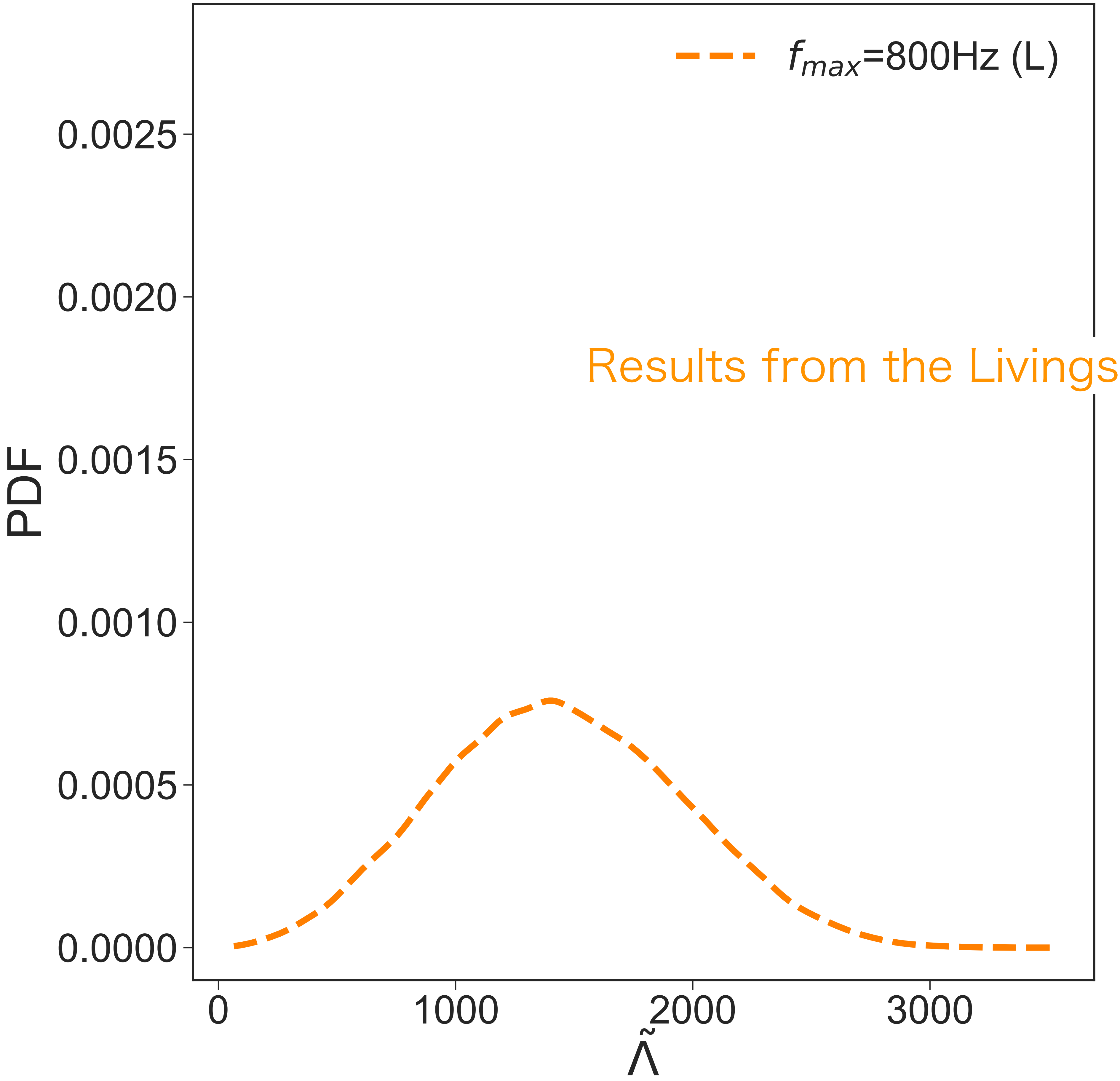
The terms in the Fisher matrix that determine the measurability are essentially proportional to integrals of

$$I_x = \int d\ln f\, f\gamma(f)v(f)^x \text{ , where } \gamma(f)df := \frac{df\, f^{-7/3}S_n^{-1}(f)}{\int_0^{f_c} df\, f^{-7/3}S_n^{-1}(f)} .$$



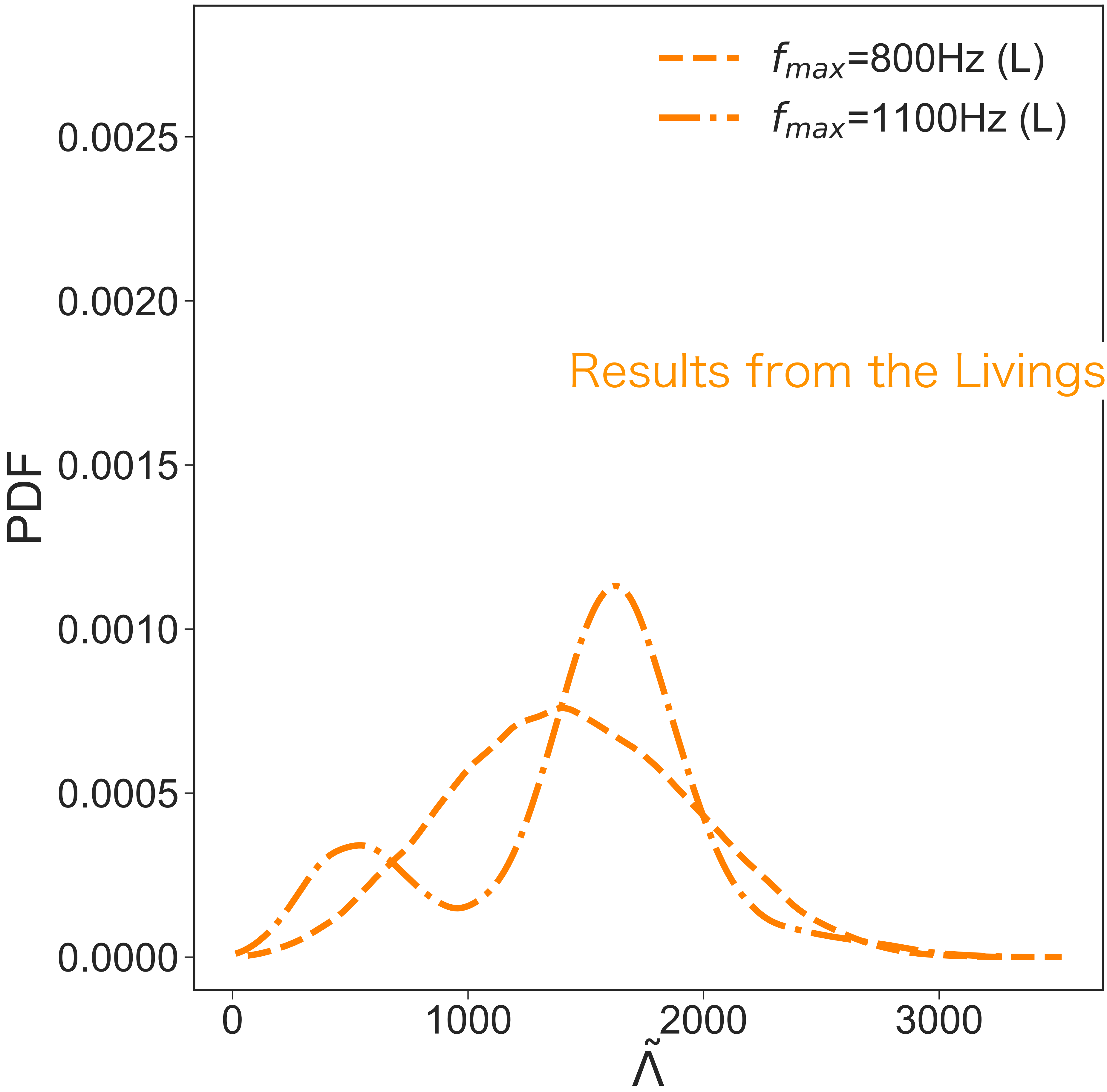
c.f., [Damour, Nagar, Villain, et al., PRD 85, 123007 (2012)]

Dependence on maximum frequency, f_{max}



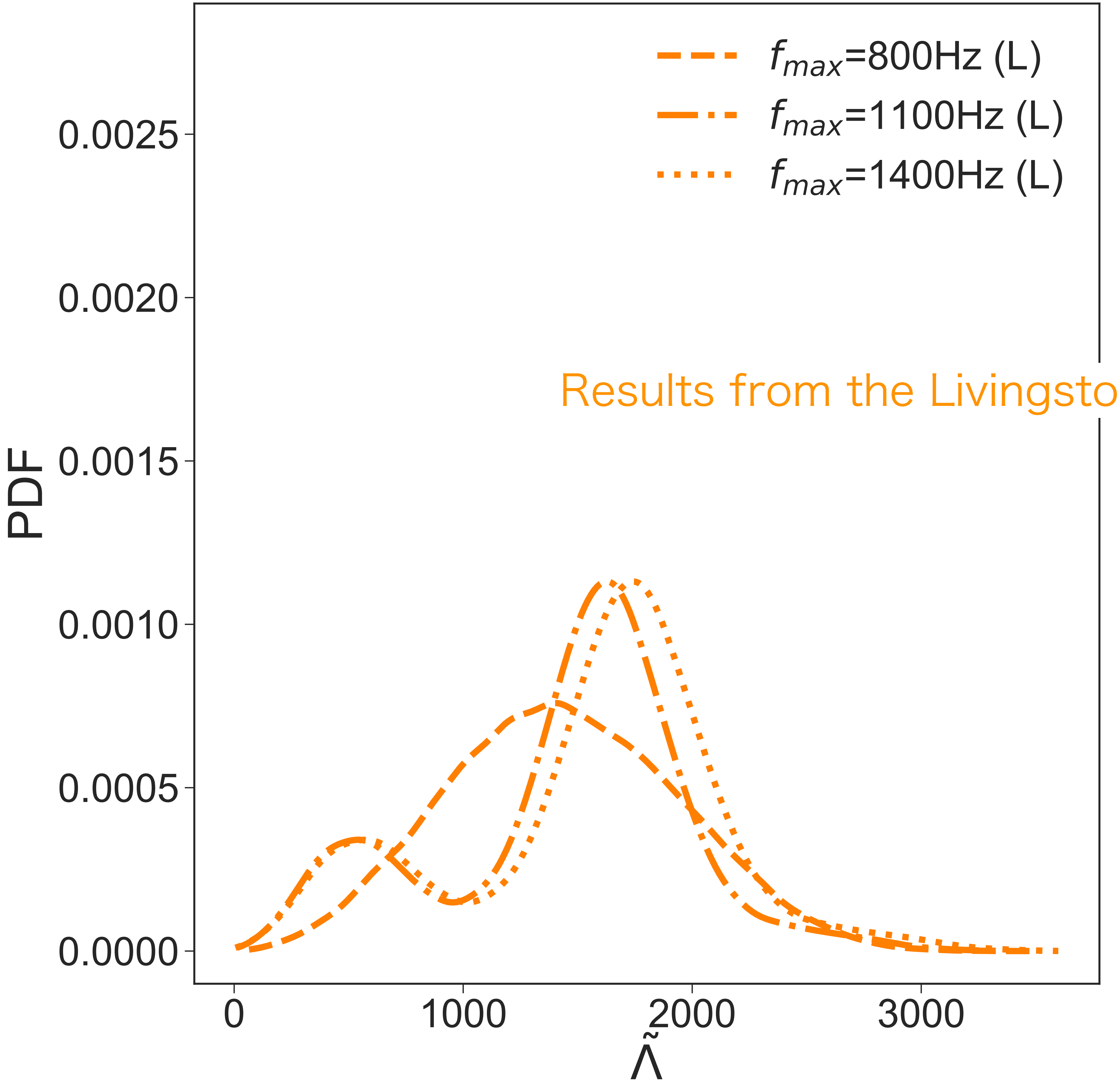
Results from the Livingston-only data

Dependence on maximum frequency, f_{max}



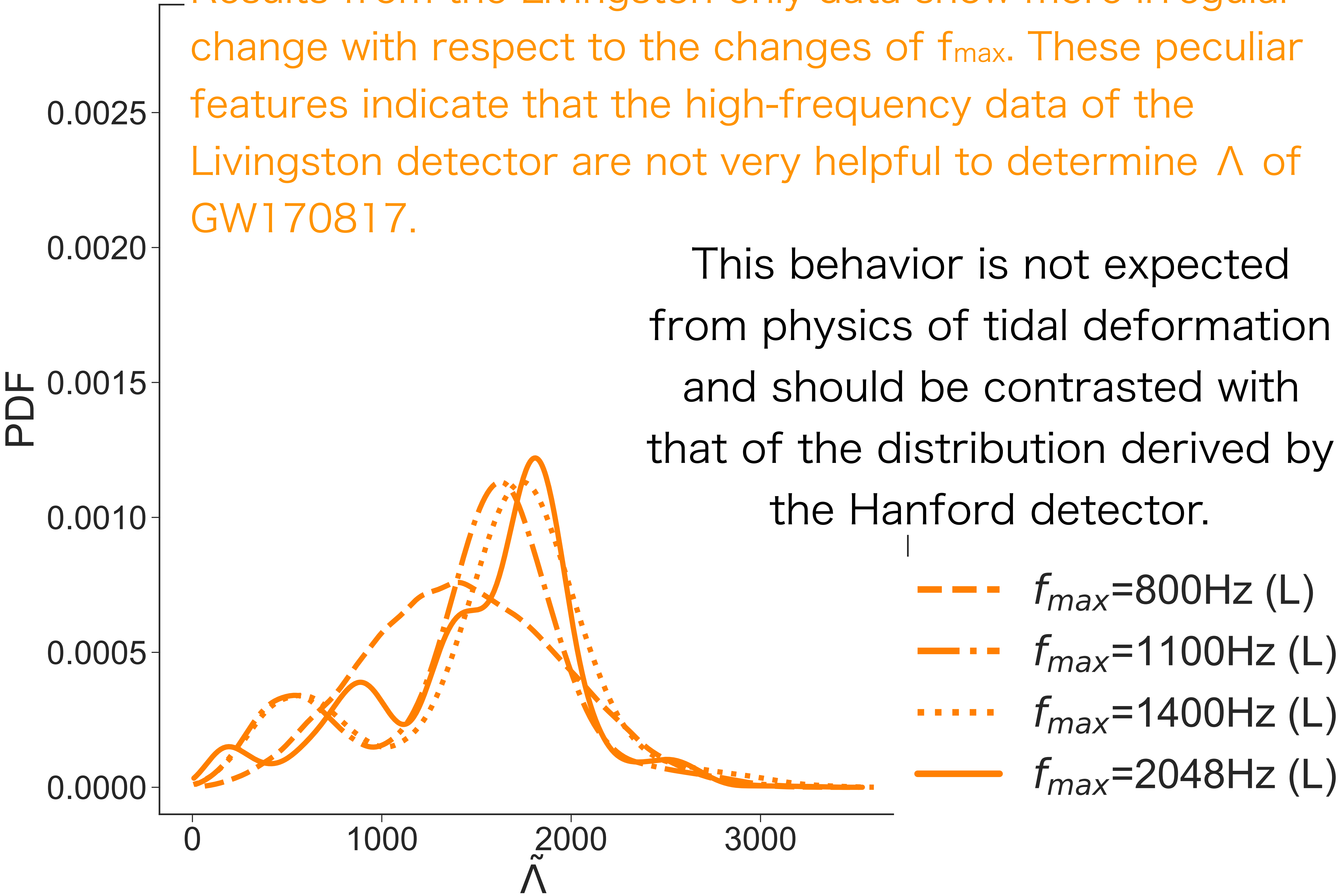
Results from the Livingston-only data

Dependence on maximum frequency, f_{max}



Results from the Livingston-only data

Dependence on maximum frequency, f_{max}

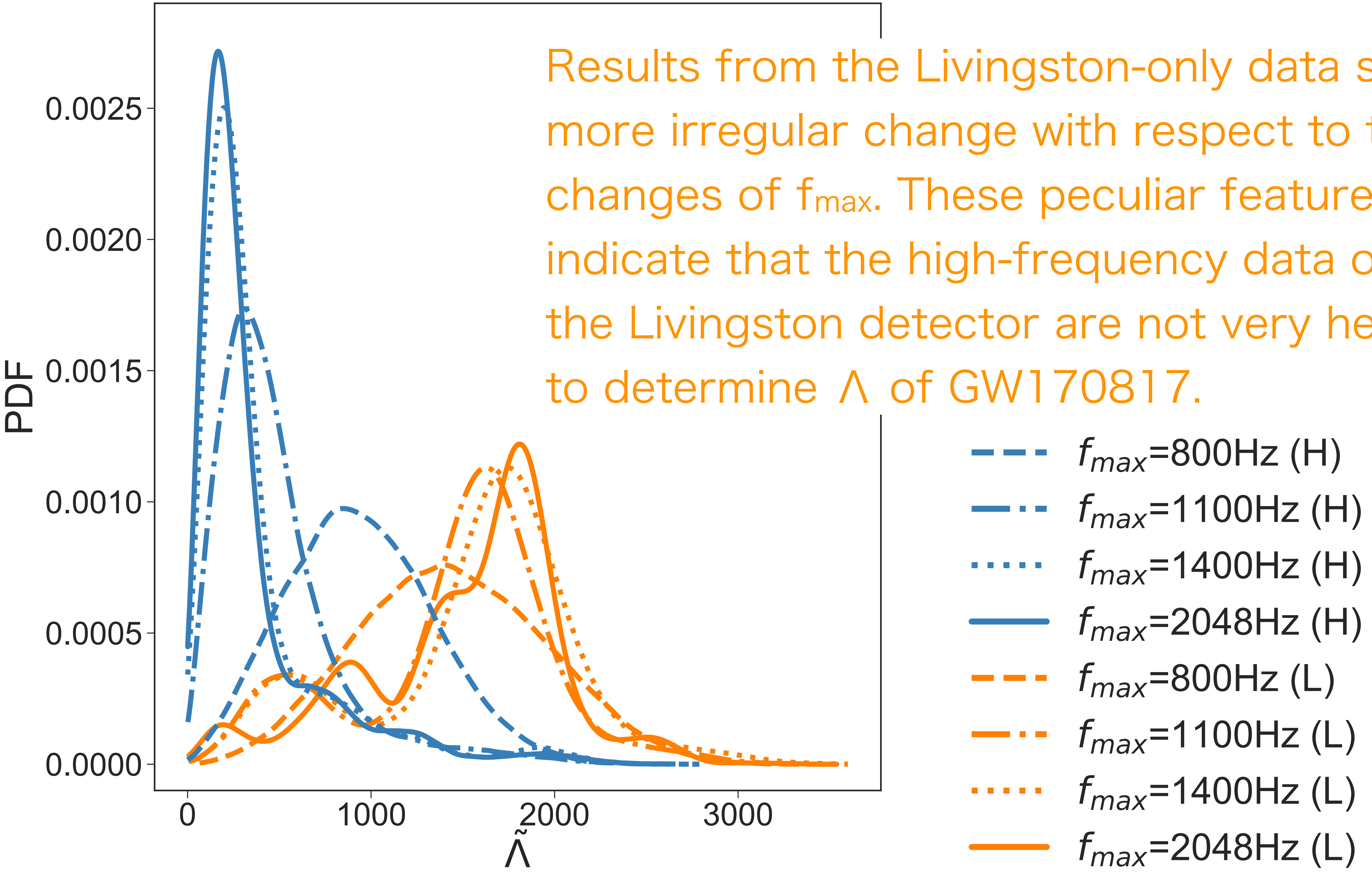


Results from the Livingston-only data show more irregular change with respect to the changes of f_{max}. These peculiar features indicate that the high-frequency data of the Livingston detector are not very helpful to determine Λ of GW170817.

This behavior is not expected from physics of tidal deformation and should be contrasted with that of the distribution derived by the Hanford detector.

Dependence on maximum frequency, f_{max}

The Hanford-only distribution shrinks monotonically and appears to become narrowly peaked as f_{max} increases.



Results from the Livingston-only data show more irregular change with respect to the changes of f_{max}. These peculiar features indicate that the high-frequency data of the Livingston detector are not very helpful to determine Λ of GW170817.

Summary

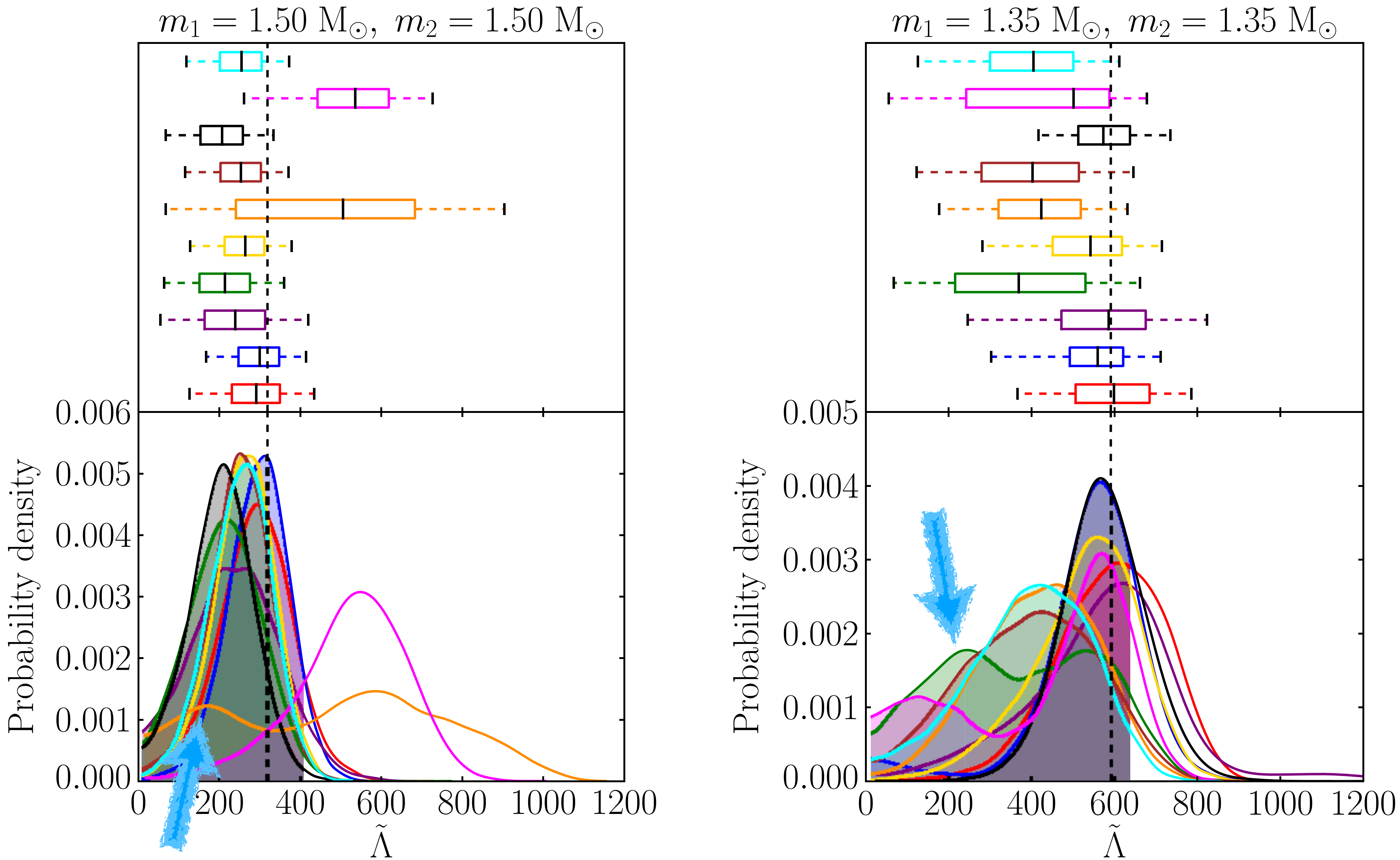
- We show that the Advanced LIGO twins derive distinct posterior probability distribution of Λ.
- Specifically, the distribution derived by the Livingston detector exhibits significant multimodal structures favoring larger values of Λ than those derived by combing the twins.
- The distribution of the Livingston detector does not behave smoothly with respect to the variation of the f_{max}.
- The discrepancy and irregular behavior suggest that an in-depth study of noise properties might improve our understanding of GW170817 and future events.

Discussion

- Our analysis suggests that the noise in the high-frequency region of the Livingston data somehow corrupted information about tidal deformability of GW170817.
- Although the multimodal structure can appear simply because of particular noise realization, it is a bit tricky that the posterior density distribution does not become narrow as f_{max} increases.

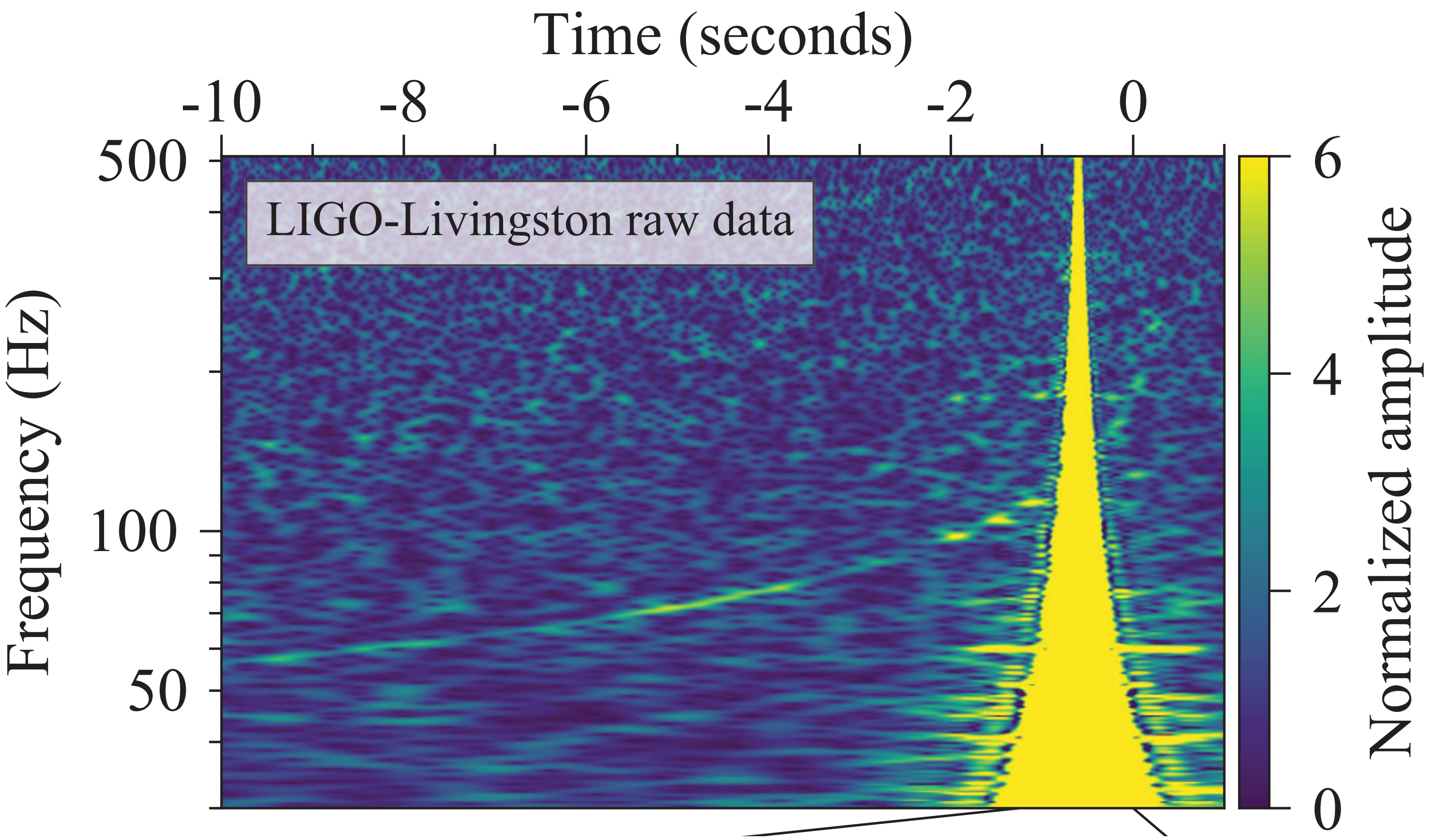
It may result from a specific noise realization, as similar results have been seen with injected waveforms with simulated Gaussian noise.

[Wade, et al., PRD 89, 103012 (2014)]



They inject the same BNS signal into ten different noise realizations.

Removing the glitch (instrumental noise transient) surrounding GW170817



A short instrumental noise transient appeared in Livingston 1.1s before the coalescence time.

Applied a modeling of the glitch and removing it.

We suspect that a residual of the glitch in the Livingston data at about a half second before merger or removing high-frequency part of signal causes multimodal structure of Λ.

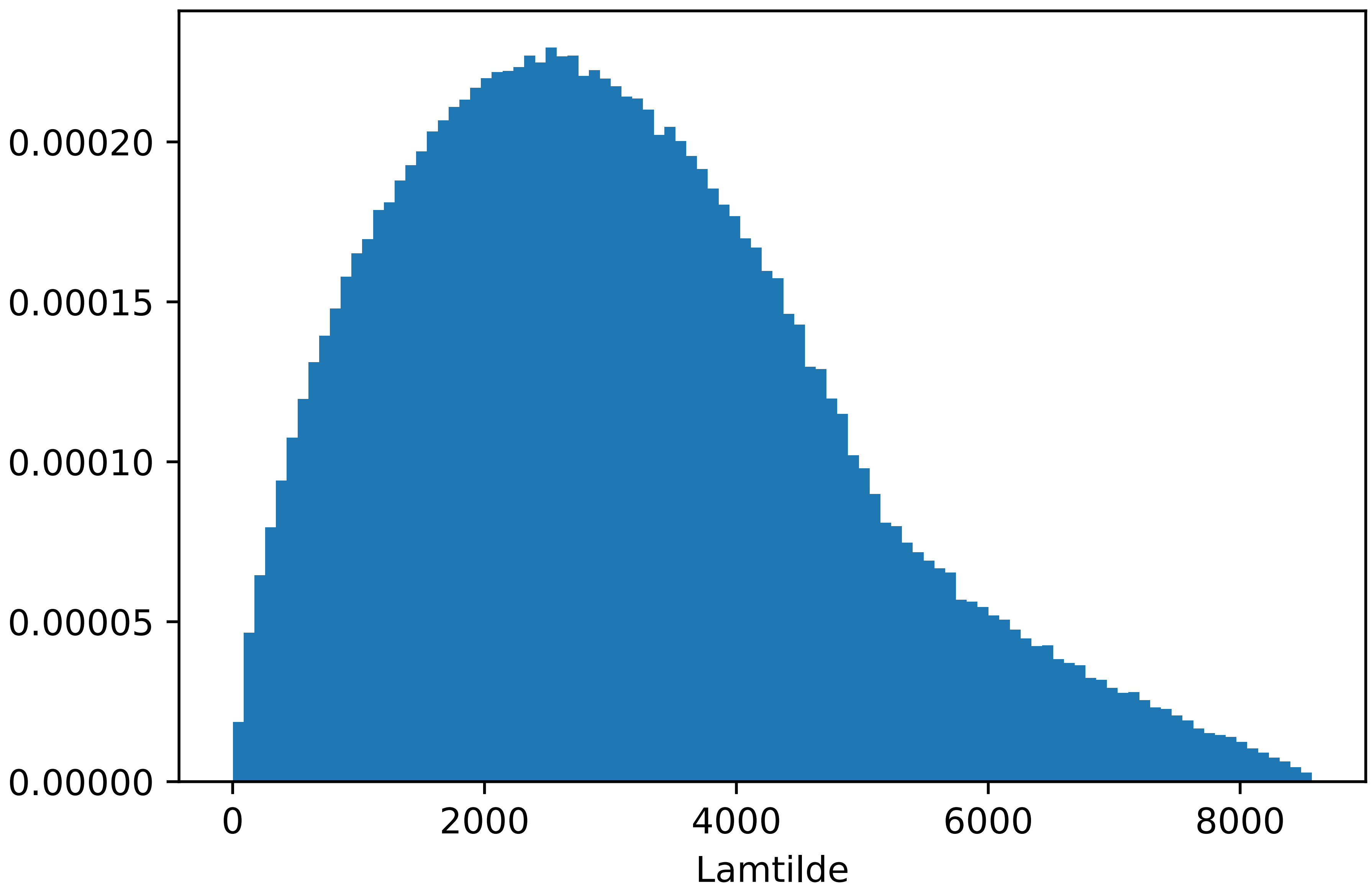
・It should be emphasized that the 90% credible intervals are consistent between the twins.

・What we may safely conclude is that the posterior probability distribution is exceptionally distinct for binary tidal deformability and that the Livingston data are not very useful for constraining its value in the case of GW170817.

・Secure parameter estimation will be helped by unambiguous detection by other instruments such as Advanced Virgo or KAGRA. However, if the irregular multimodal behavior and associated loss of information is typical for detections with a moderate signal-to-noise ratio, accurate determination of tidal deformability will remain challenging unless its origin is identified.

Thank you!

Prior PDF of tilde{Lambda} for flat prior on Lambda₁ and Lambda₂



symmetric contribution of tidal deformation

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