

Multi-messenger Extended Emission from the Compact Remnant of GW170817

Maurice H.P.M. van Putten

Physics and Astronomy, Sejong University
Seoul, South Korea

VIA Lecture, APC In2p3 (France)

April 12 2019



OUTLINE

GW170817 with Extended Emission ('GW170817EE')

Model-independent detection by butterfly filtering

Calorimetry on EE by signal injection

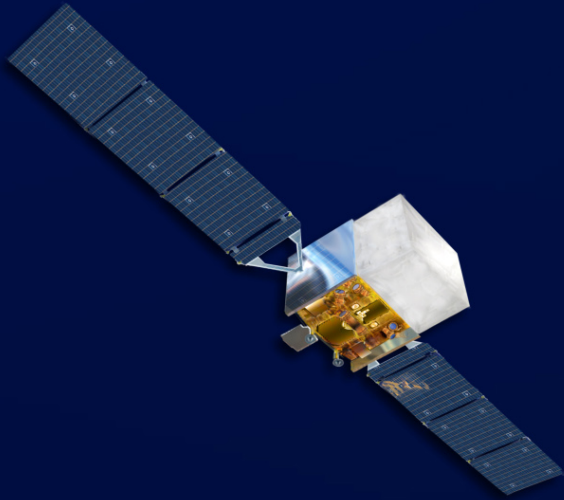
EE from black hole spin-down

Multi-messenger EE

Conclusion and outlook

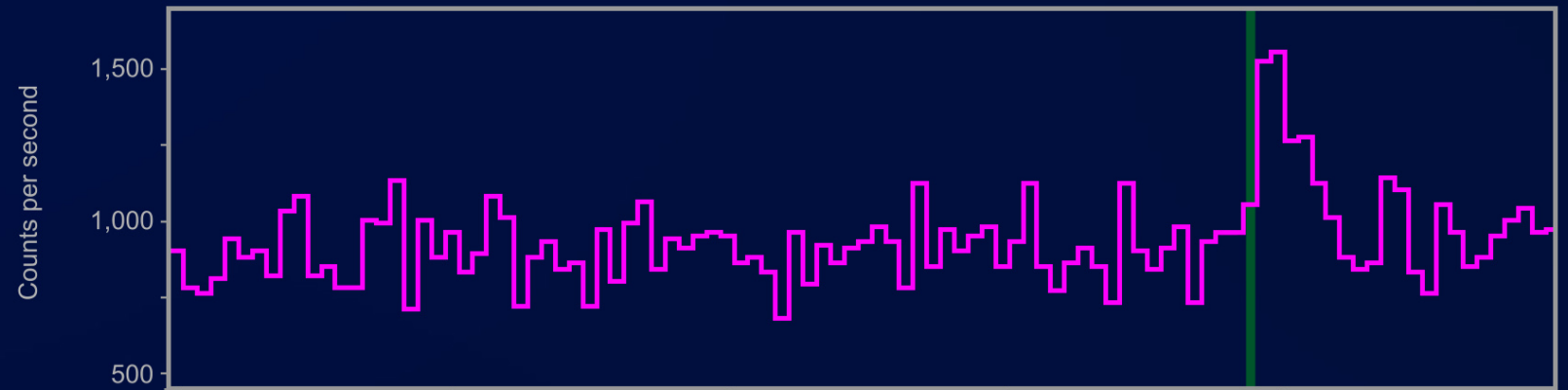
A multi-messenger window to the Universe

Fermi



Gamma rays, 50 to 300 keV

GRB 170817A

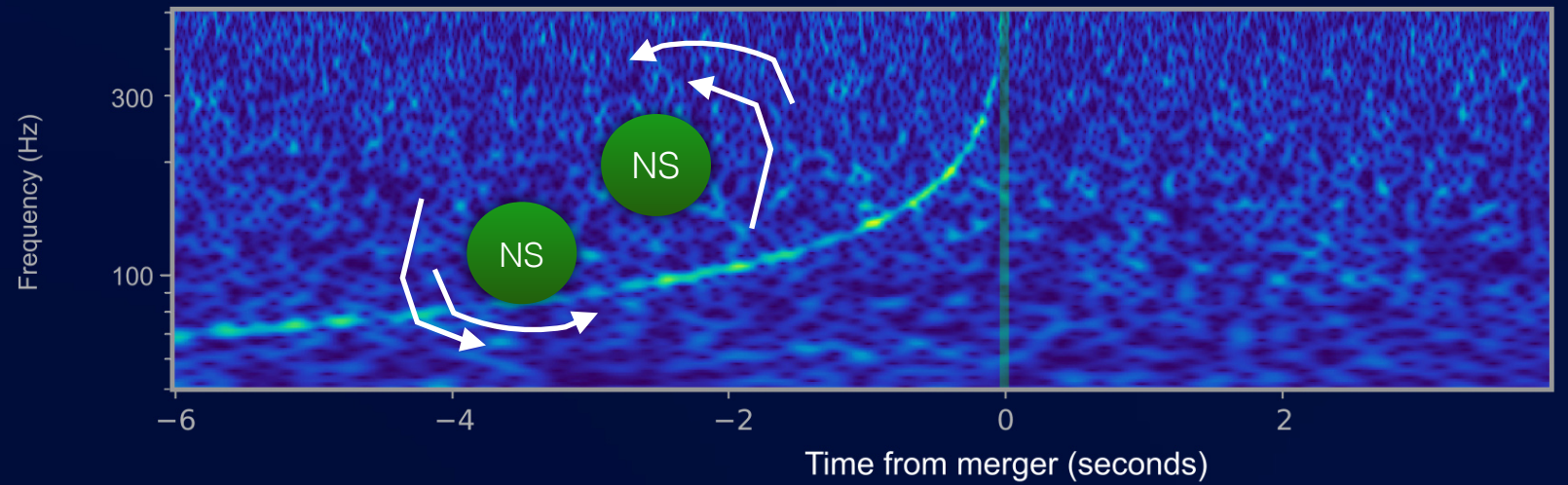


LIGO



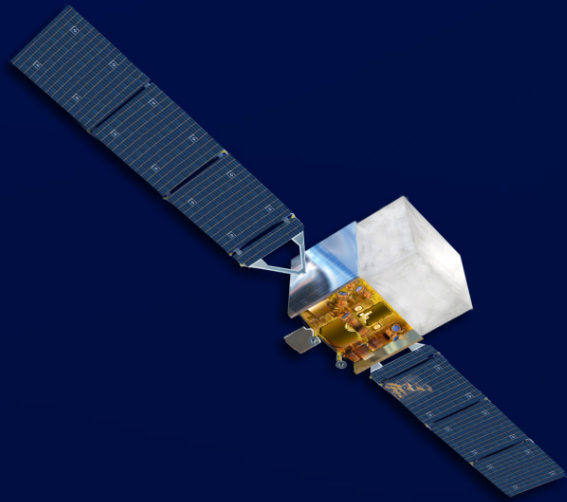
Gravitational-wave strain

GW 170817



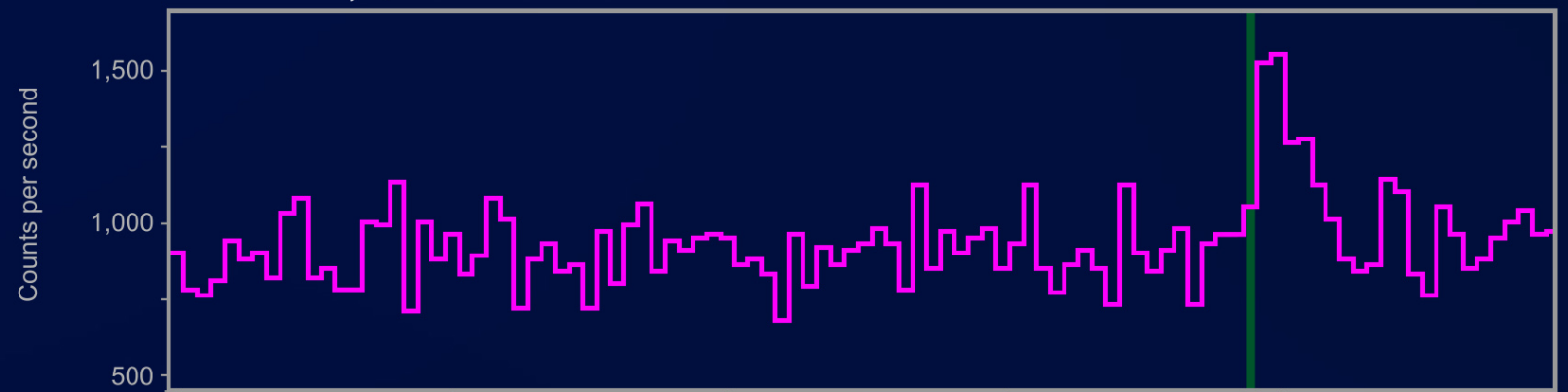
GW170817: *what happened?*

Fermi



Gamma rays, 50 to 300 keV

GRB 170817A

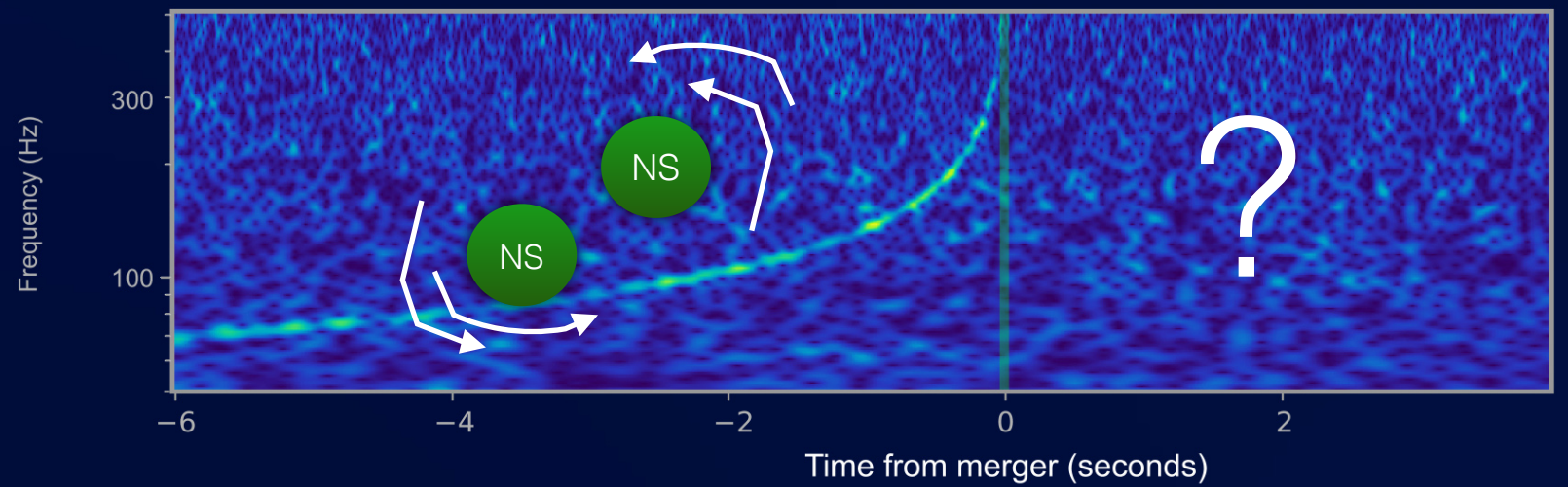


LIGO



Gravitational-wave strain

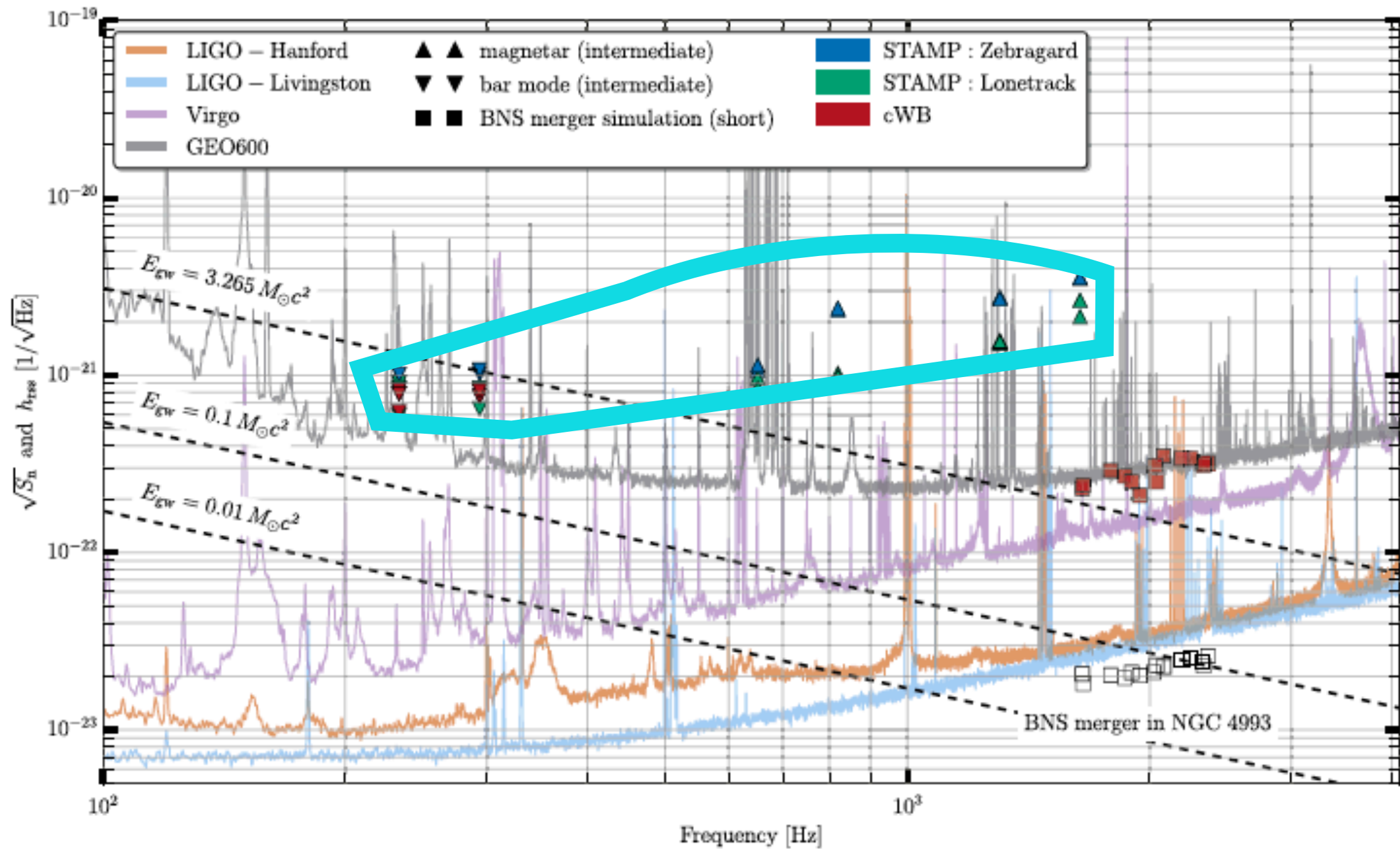
GW 170817



LIGO post-merger search (2017)

THE ASTROPHYSICAL JOURNAL LETTERS, 851:L16 (13pp), 2017 December 10

Abbott et al.

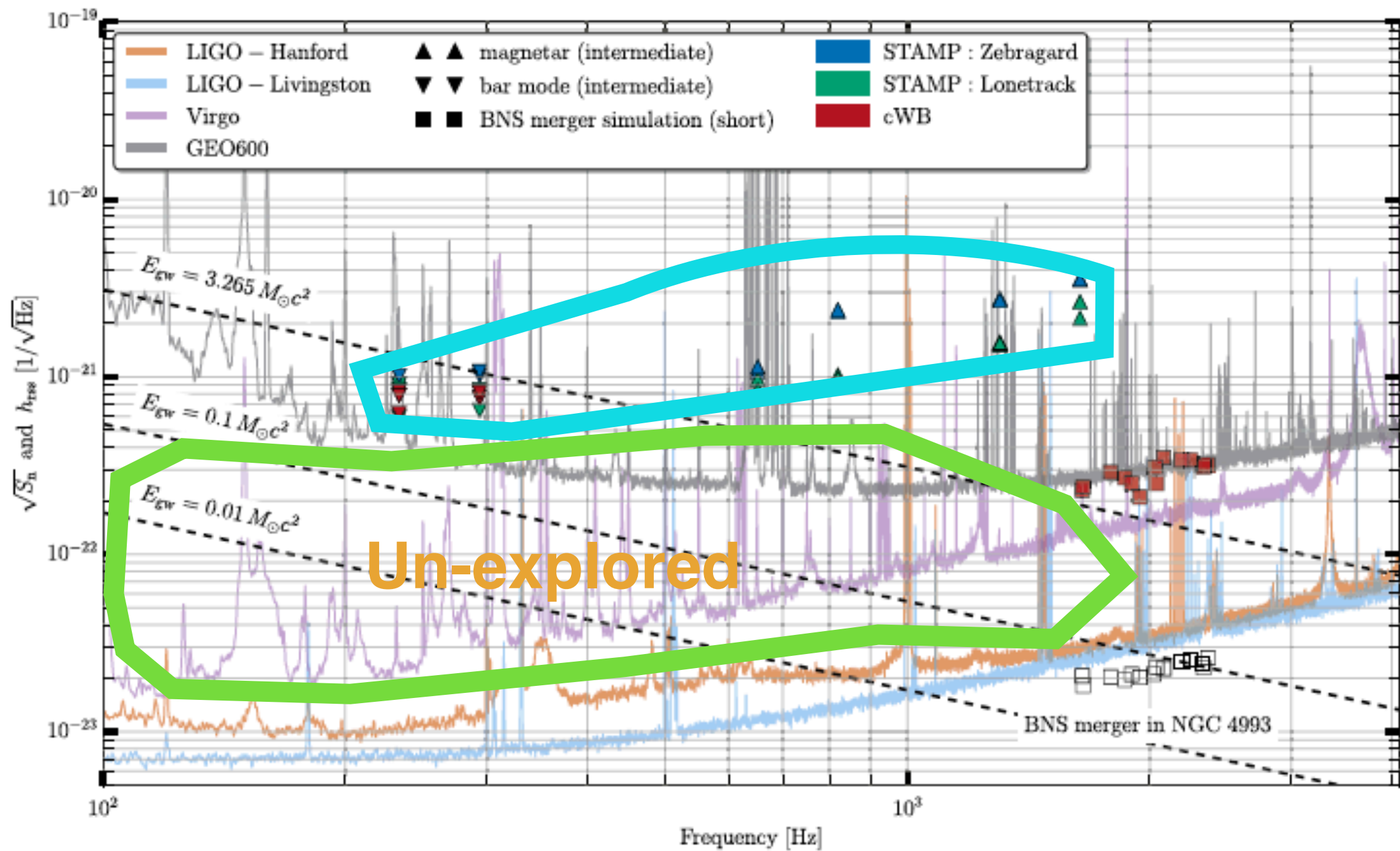


$$h_{50\%} \sim 10^{-22} - 10^{-21}$$

LIGO post-merger search (2017)

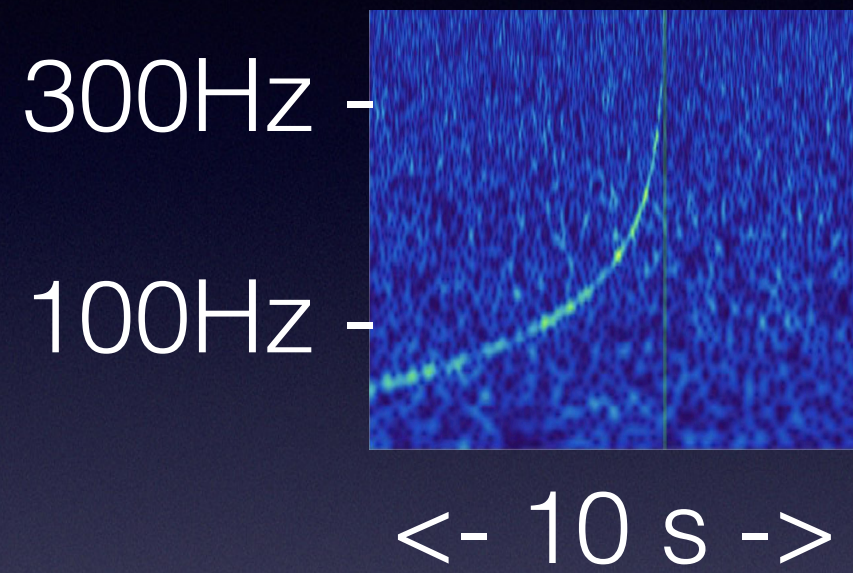
THE ASTROPHYSICAL JOURNAL LETTERS, 851:L16 (13pp), 2017 December 10

Abbott et al.

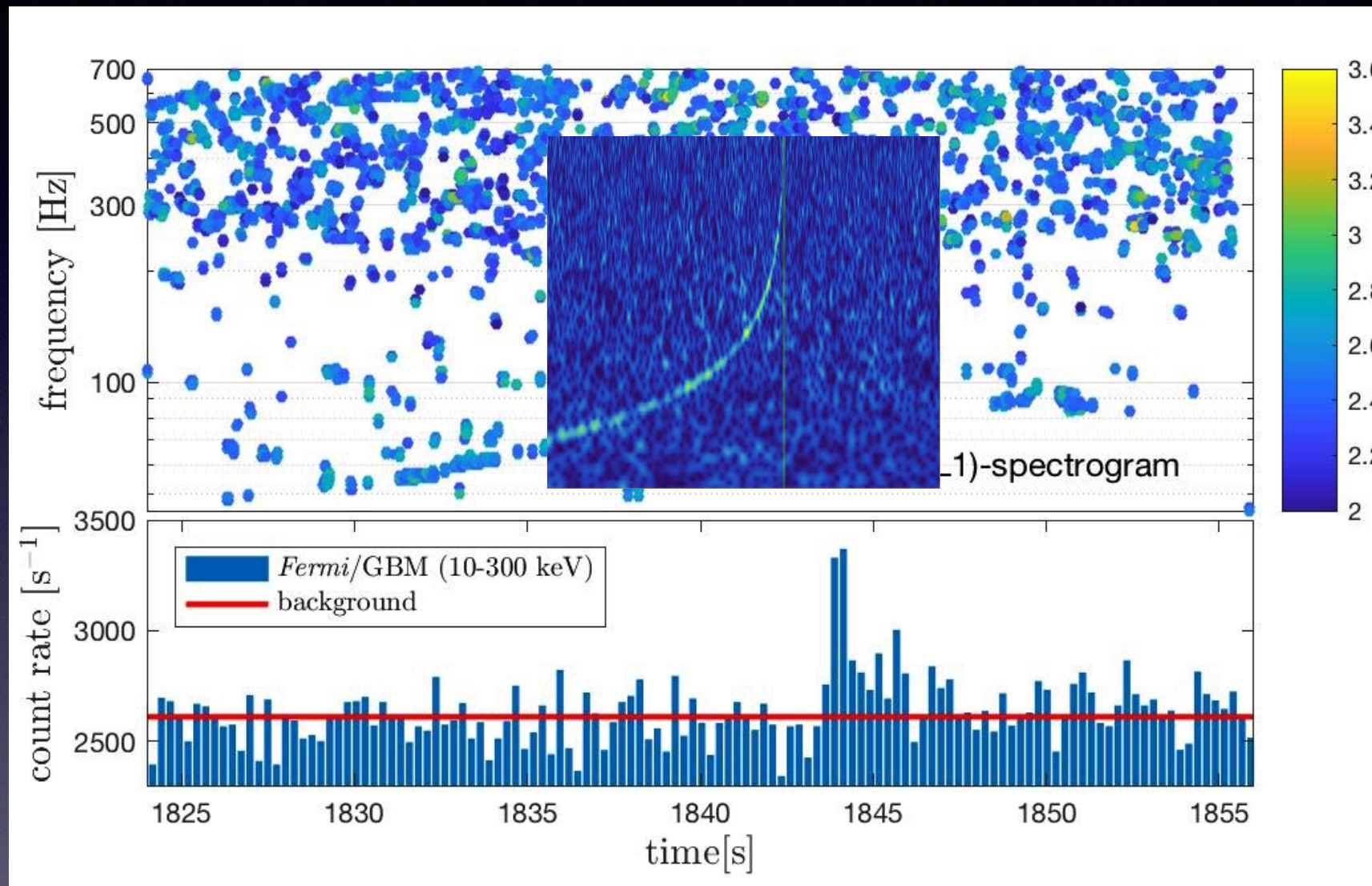


$$h_{50\%} \sim 10^{-23} - 10^{-22}$$

GW170817:



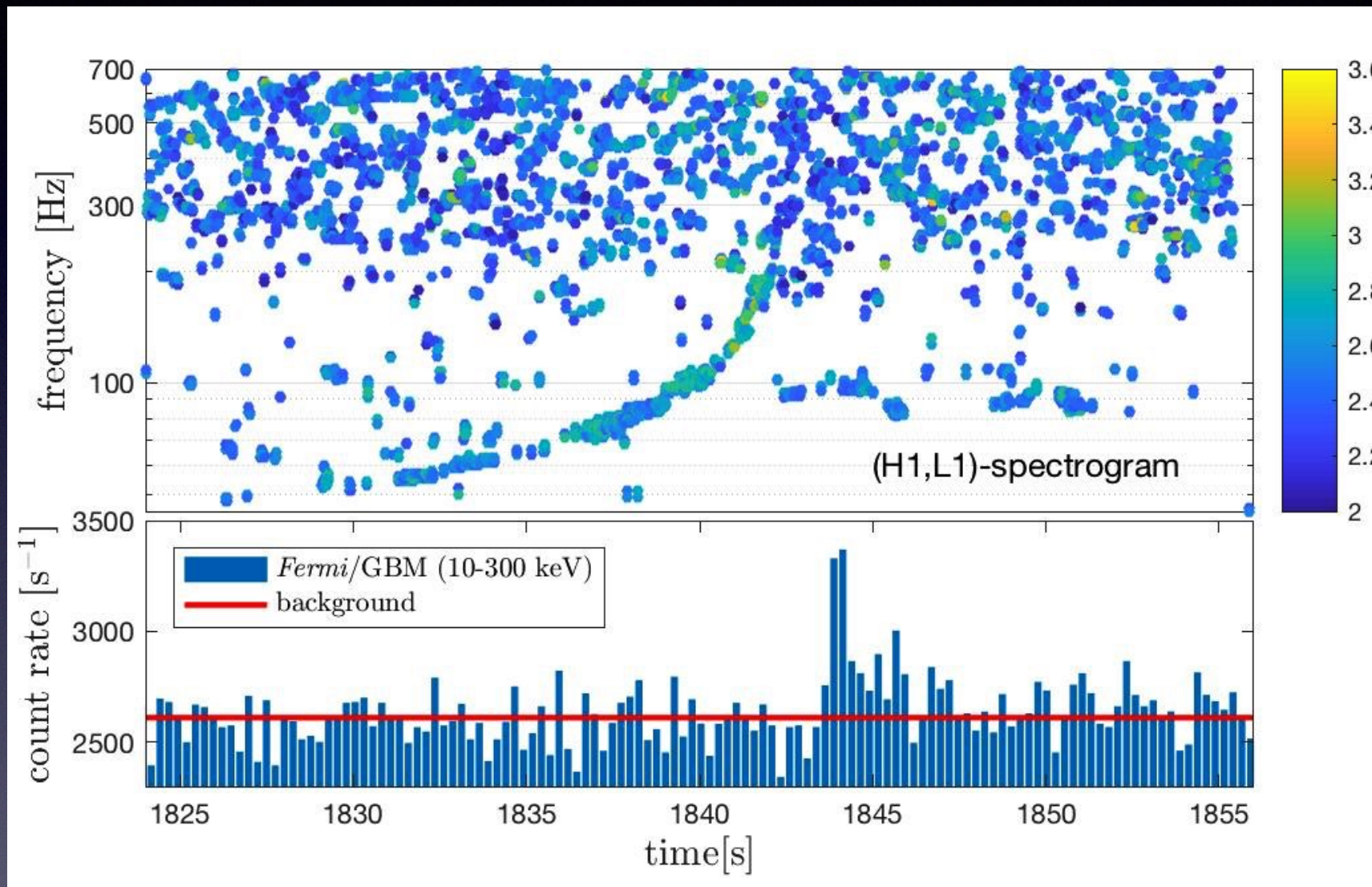
GW170817: *Extended Emission*



van Putten & Della Valle, 2018, MNRAS Letters, 482, L46

JGW-G1808513-v1 <https://gwdoc.icrr.u-tokyo.ac.jp/>

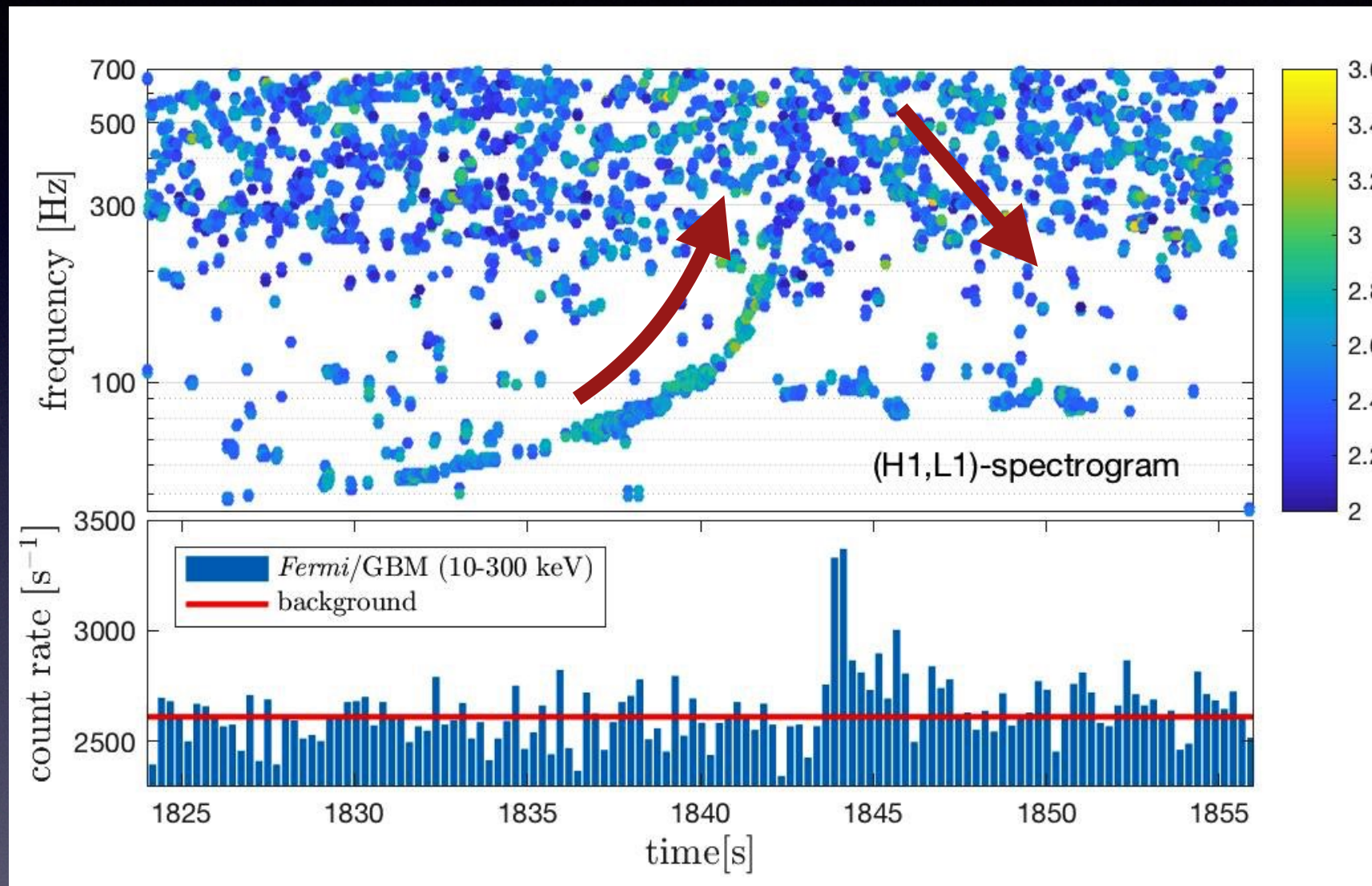
GW170817: *Extended Emission*



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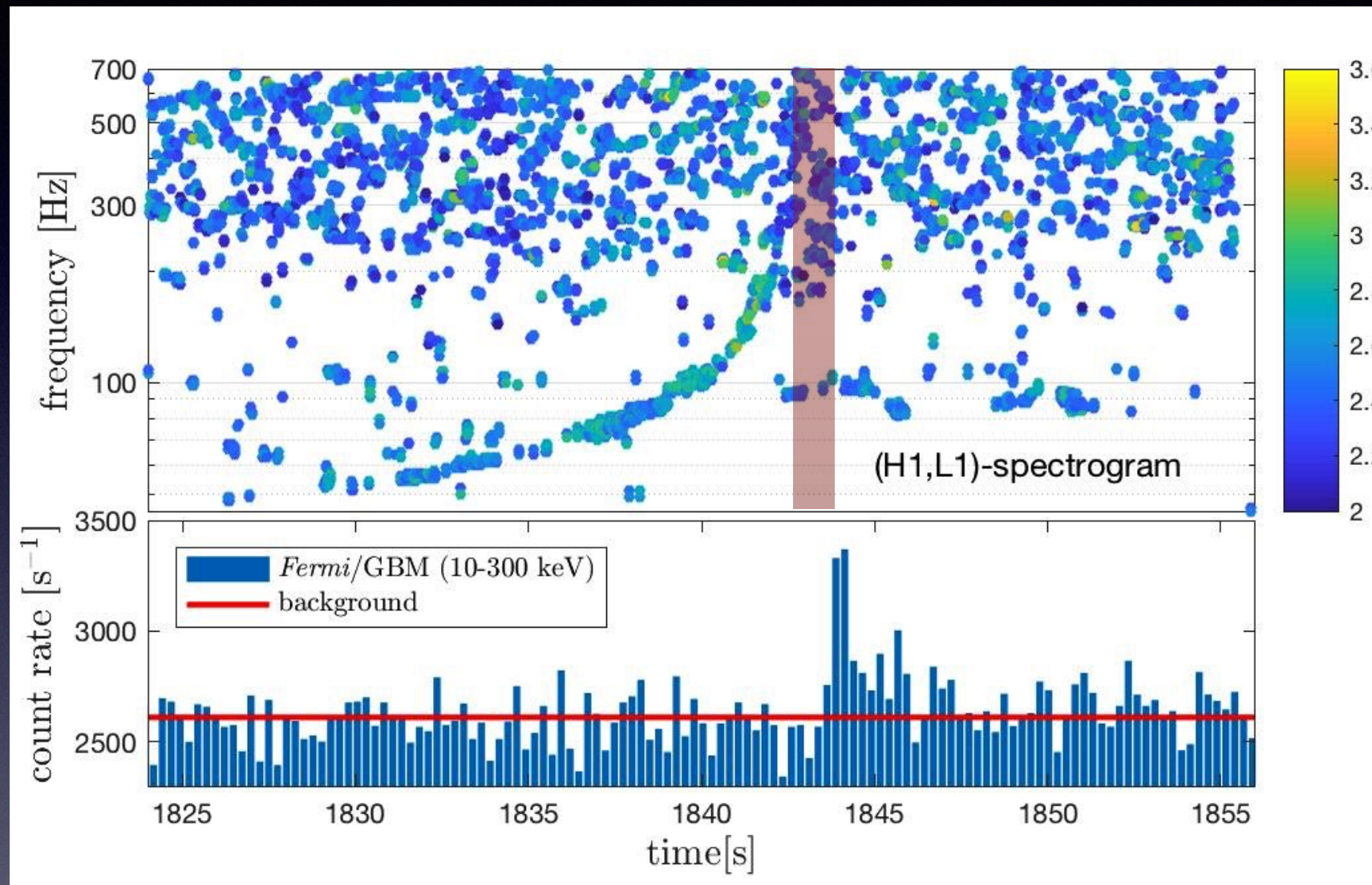
GW170817: *Extended Emission*



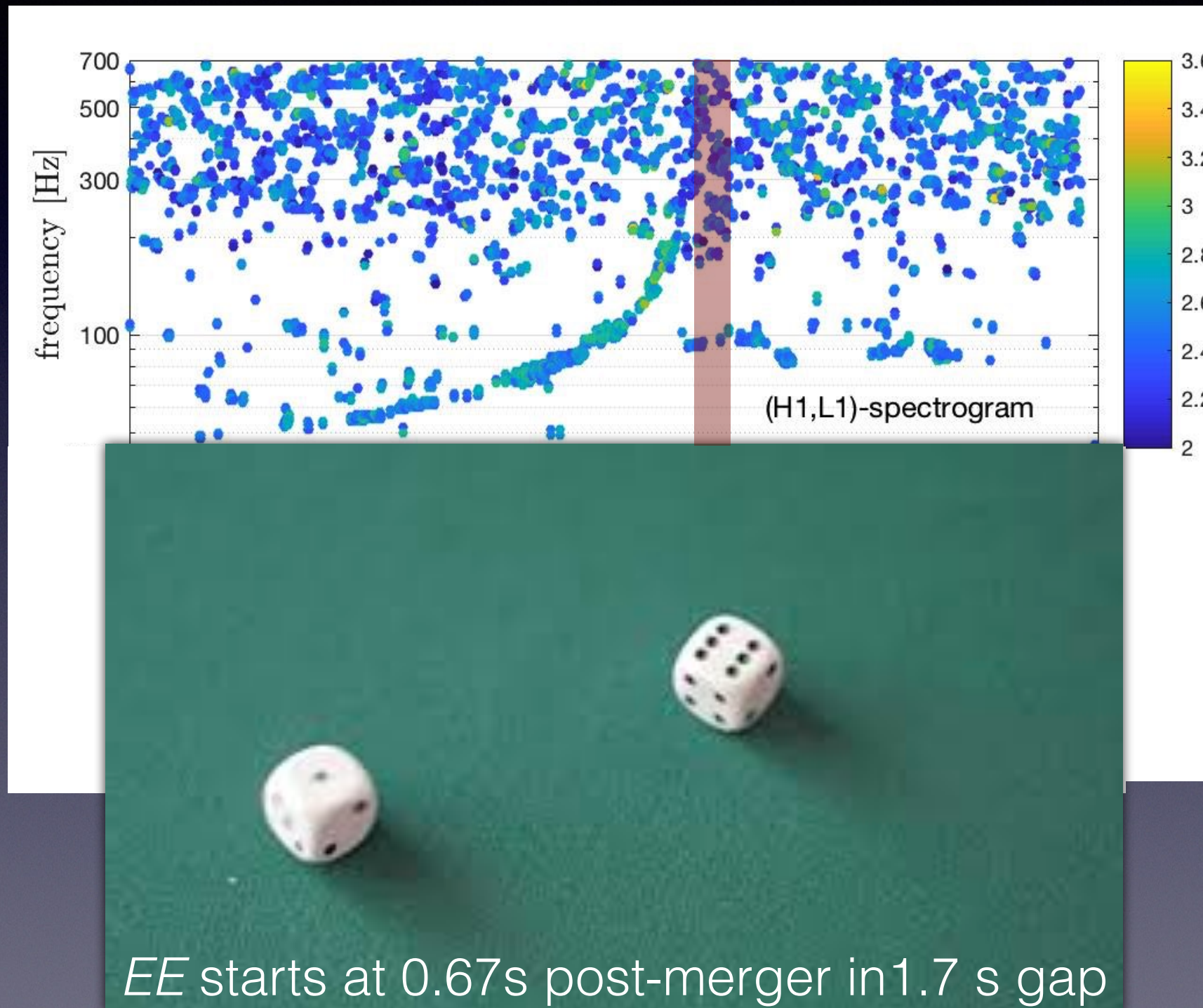
van Putten & Della Valle, 2018, MNRAS Letters, 482, L46

JGW-G1808513-v1 <https://gwdoc.icrr.u-tokyo.ac.jp/>

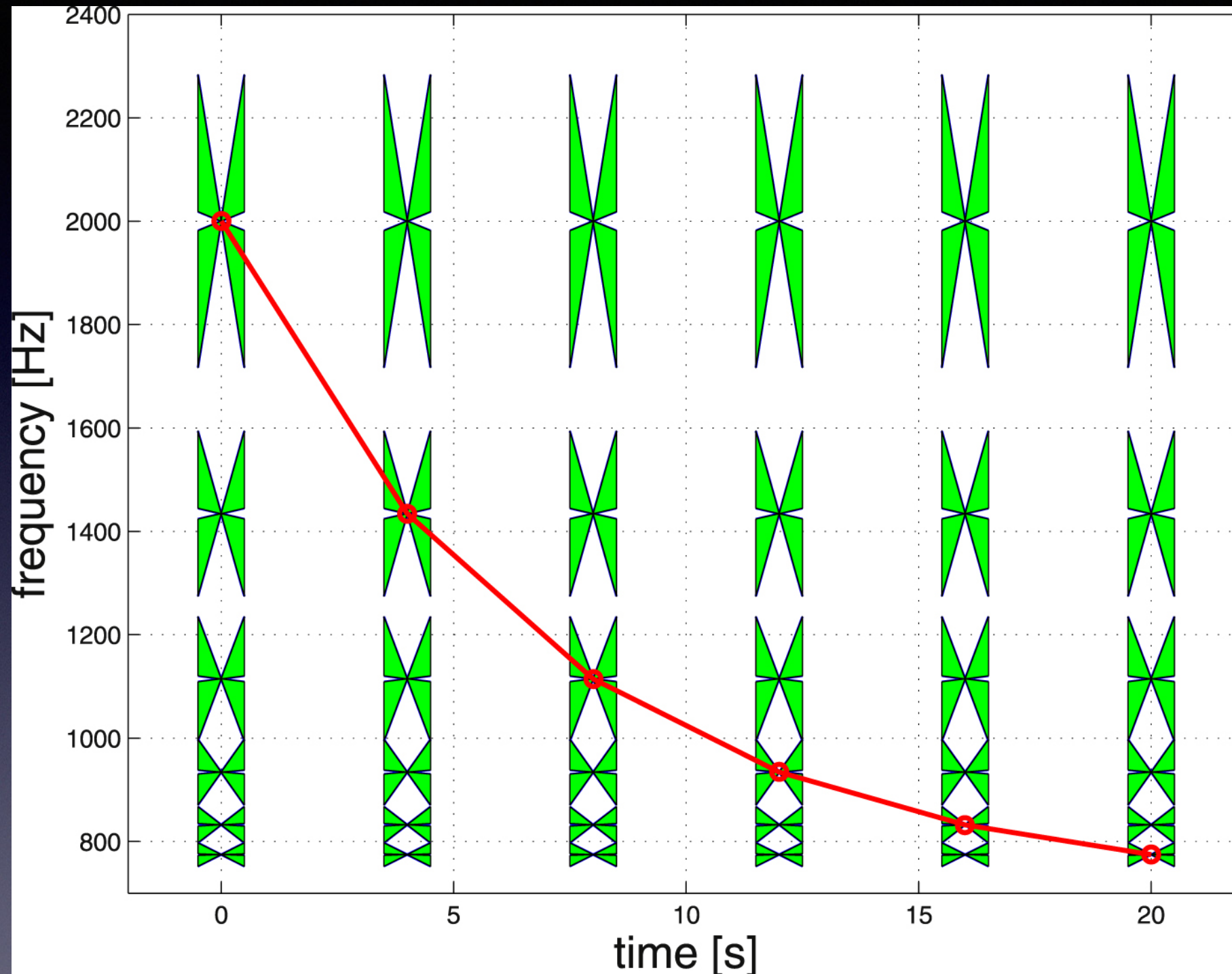
Observational significance by timing and amplitude (statistically independent attributes)



Observational significance 4.2σ (1:40.000) by timing and amplitude (statistically independent attributes)

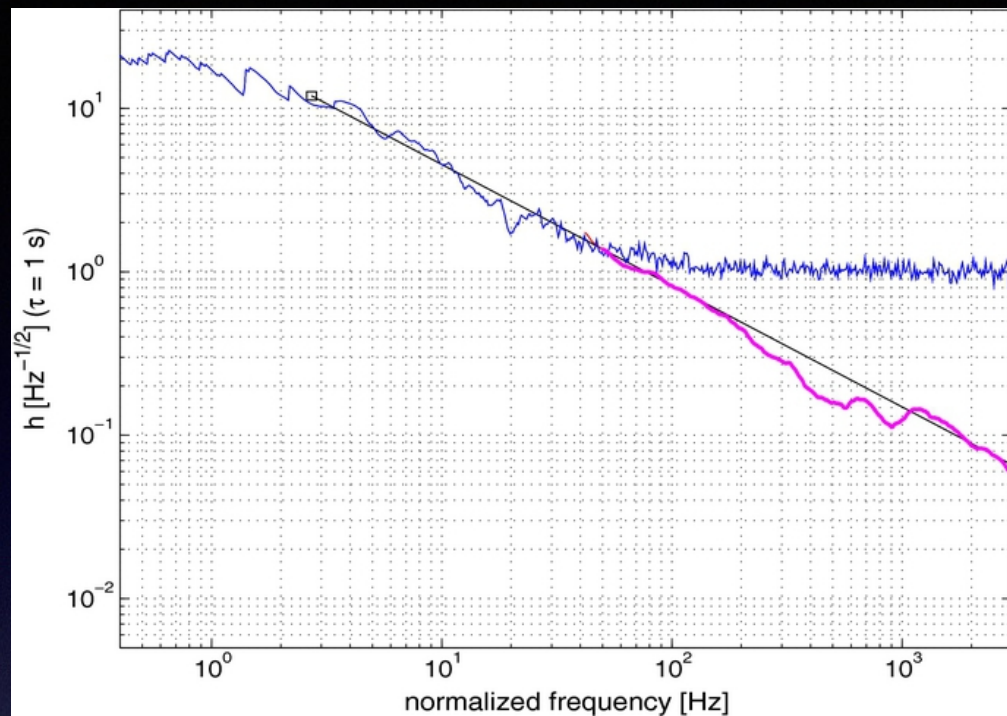


Butterfly filtering by time-symmetric chirp-like templates



Intermediate time-scale of phase coherence $0 < \tau < 1$ s in un-modeled searches

Applications

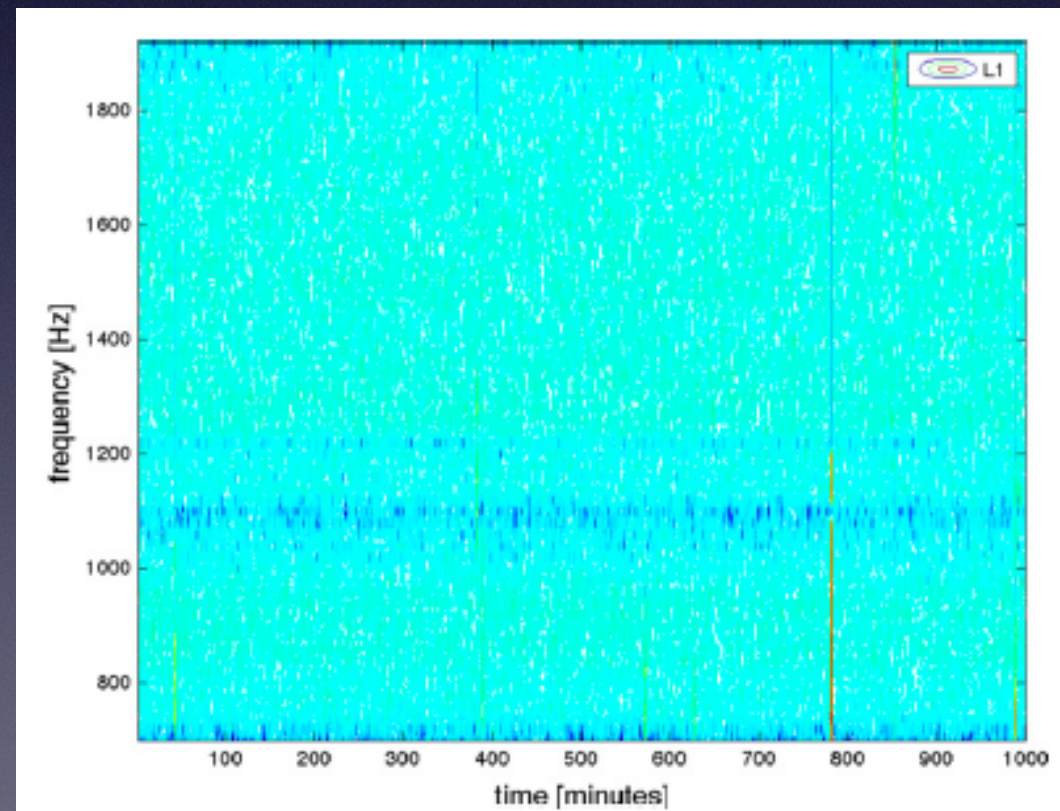
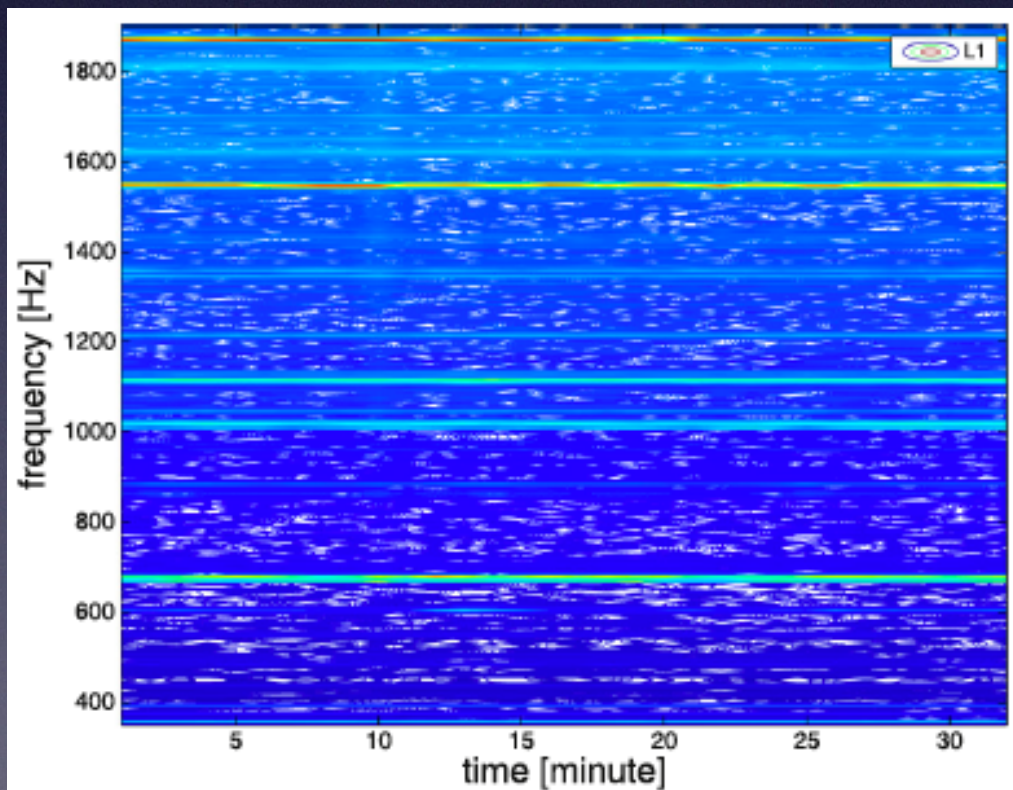


Kolmogorov spectrum BeppoSAX light curves of long GRBs

van Putten, Guidorzi & Frontera, 2014, ApJ, 786, 146

8.64 million templates ($\tau=1$ s)

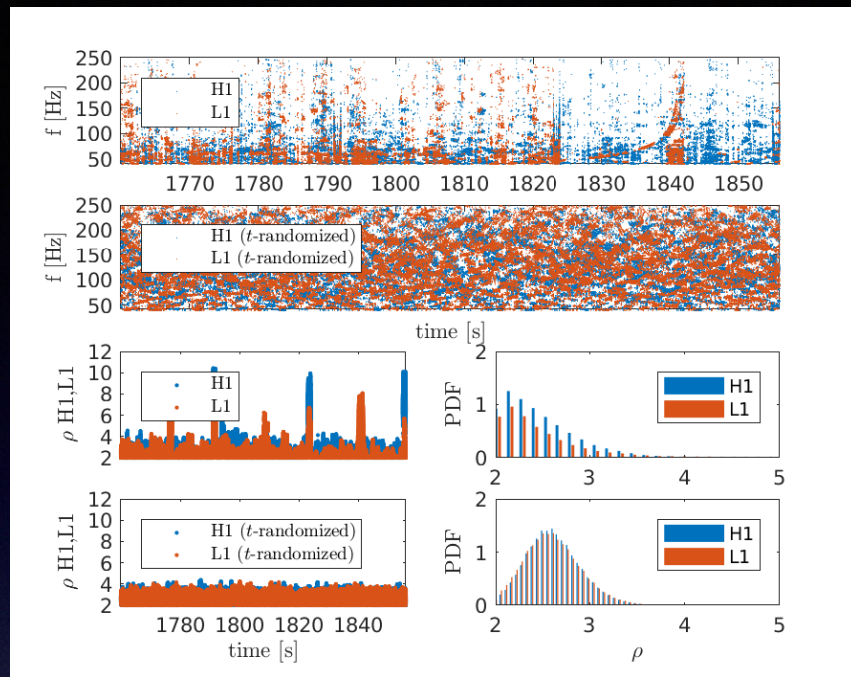
16k templates ($\tau=1$ s)



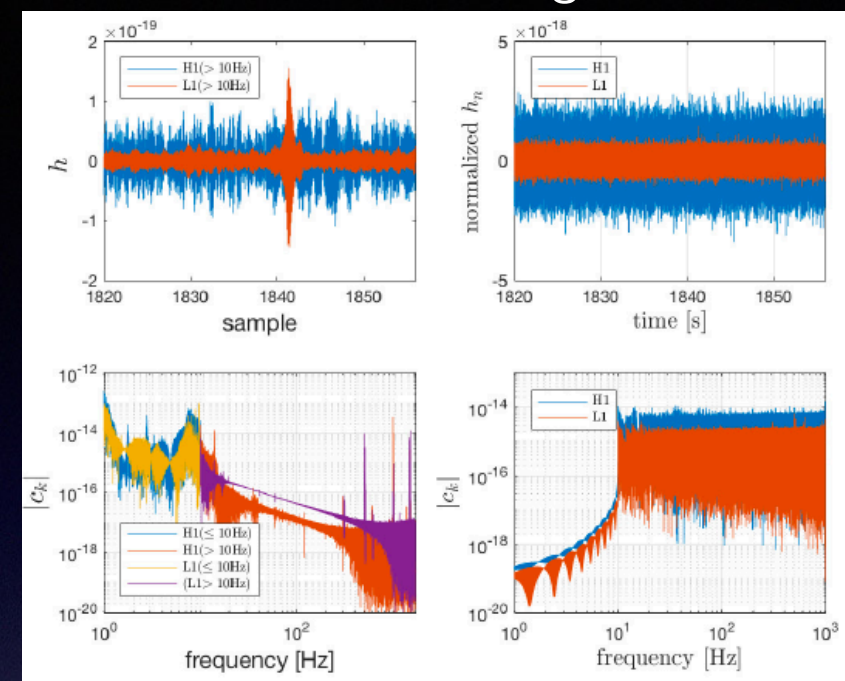
Line-suppression in LIGO S6 (van Putten, 2016, ApJ, 819, 169)

Whitening LIGO O2

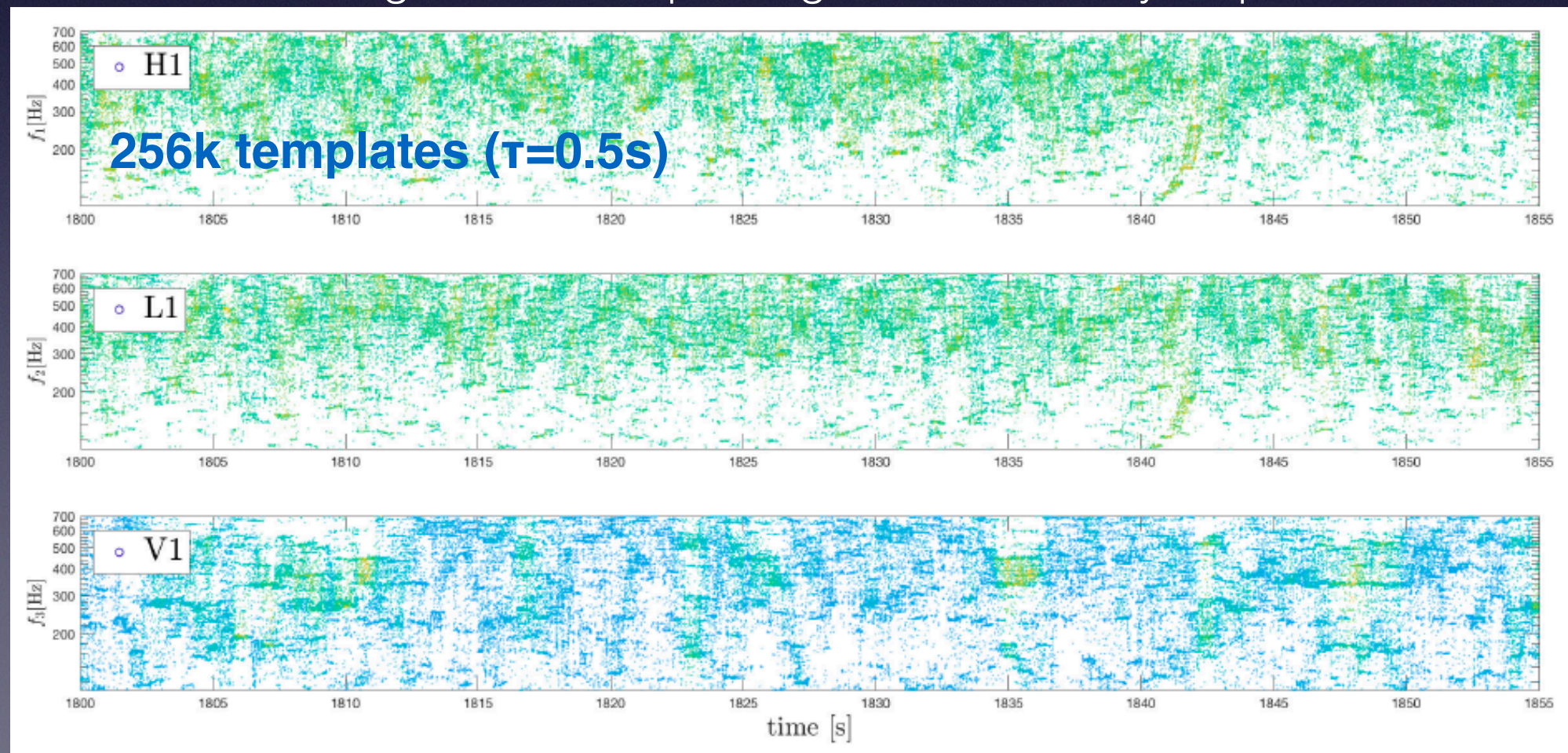
Un-whitened



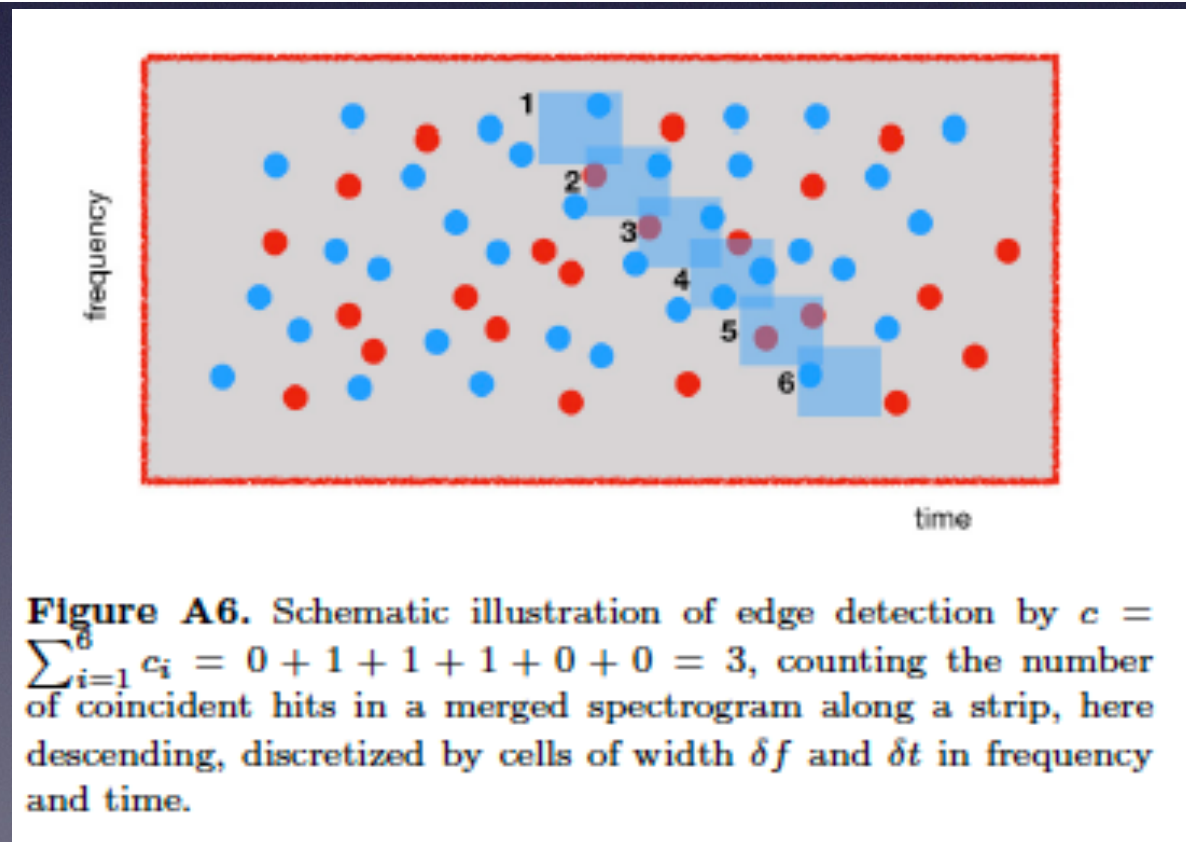
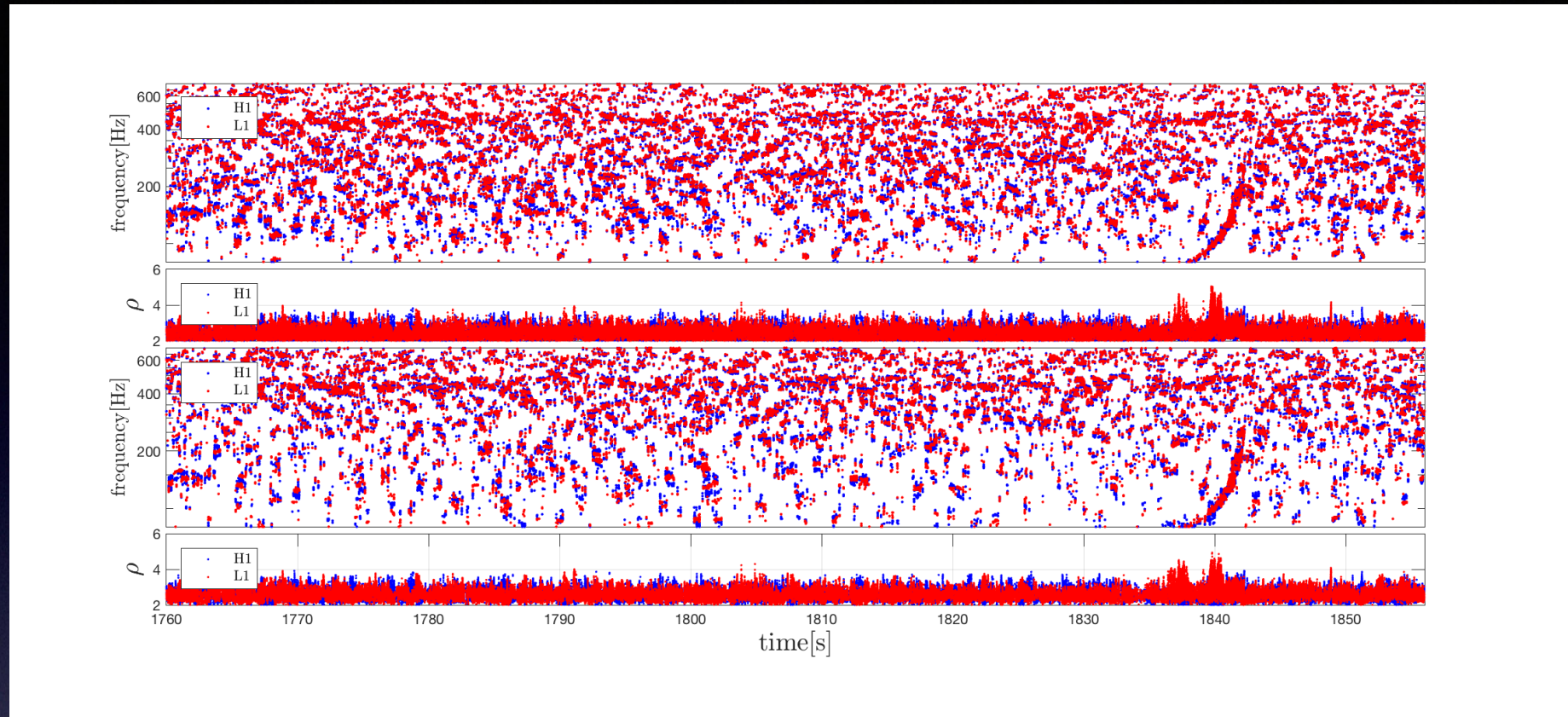
Whitening



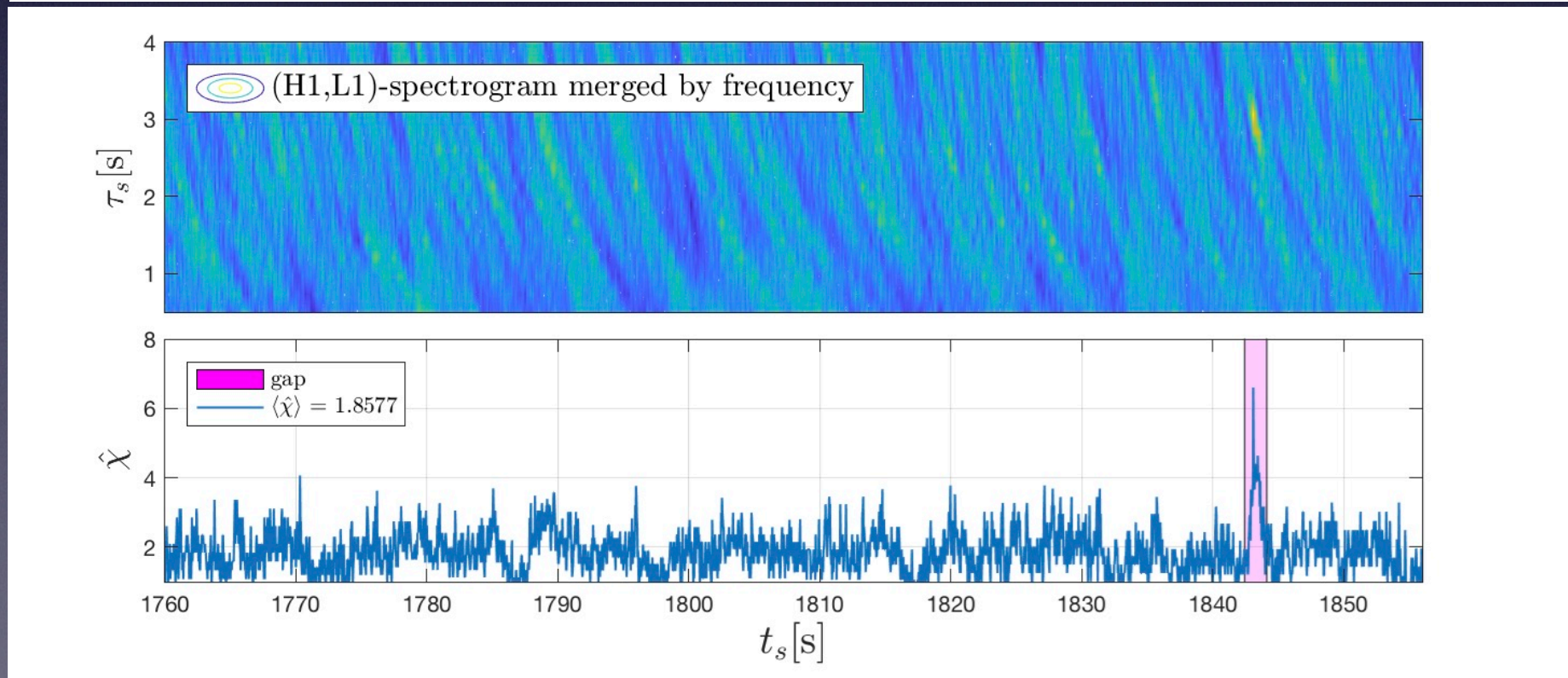
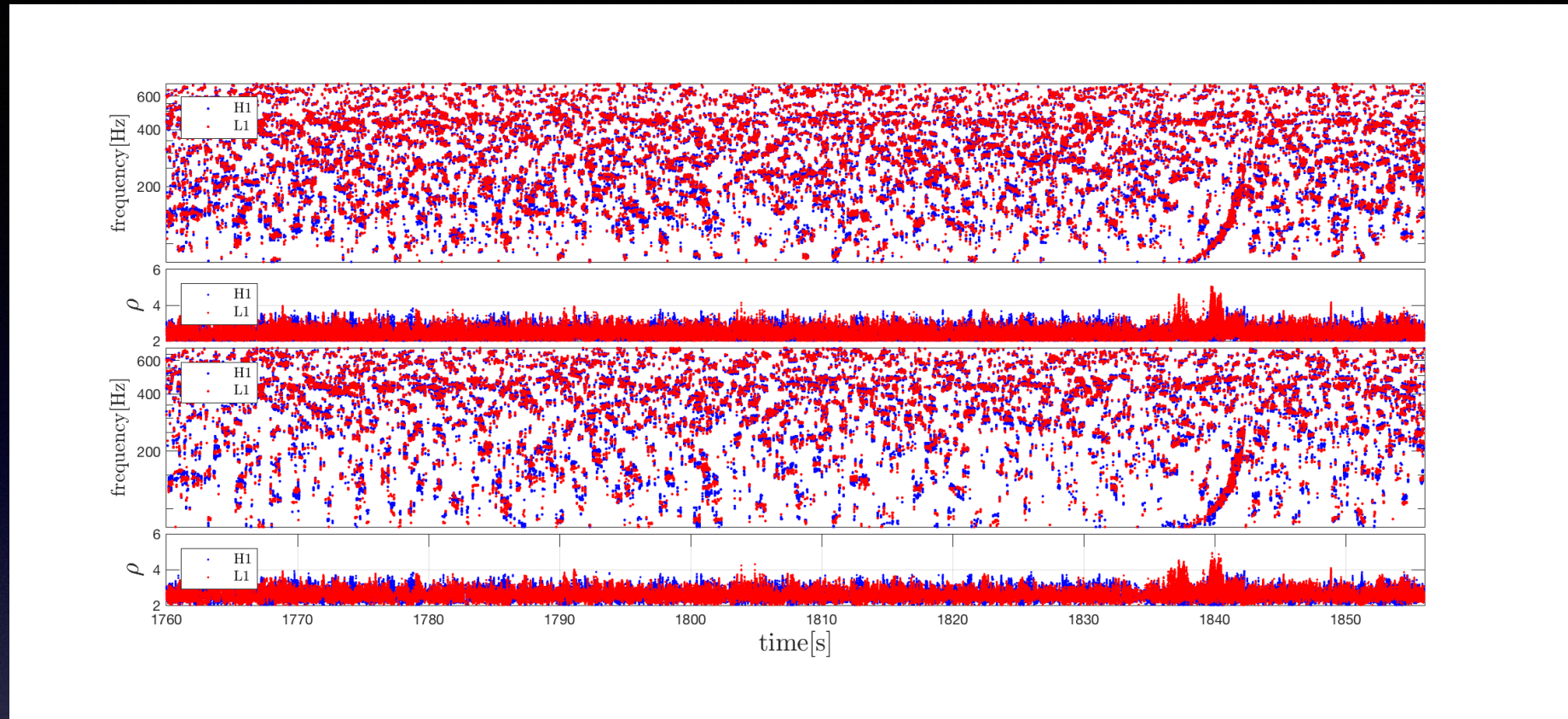
Single detector spectrograms of butterfly output



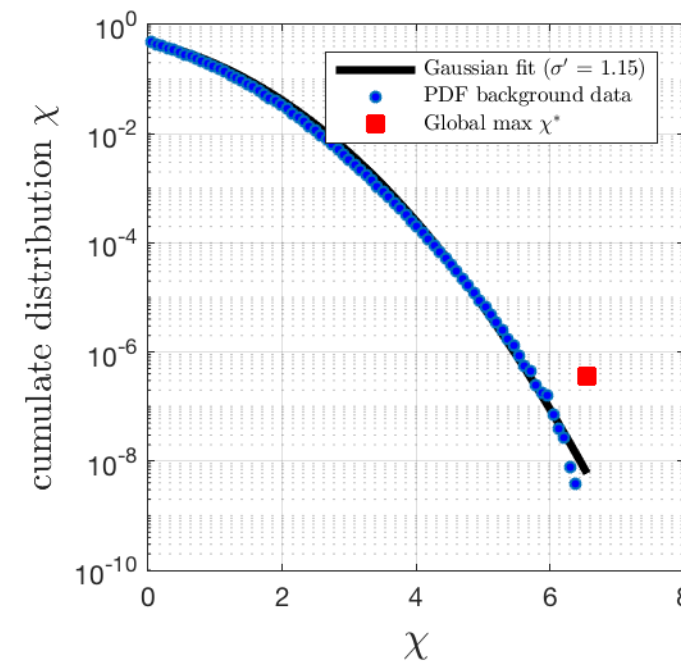
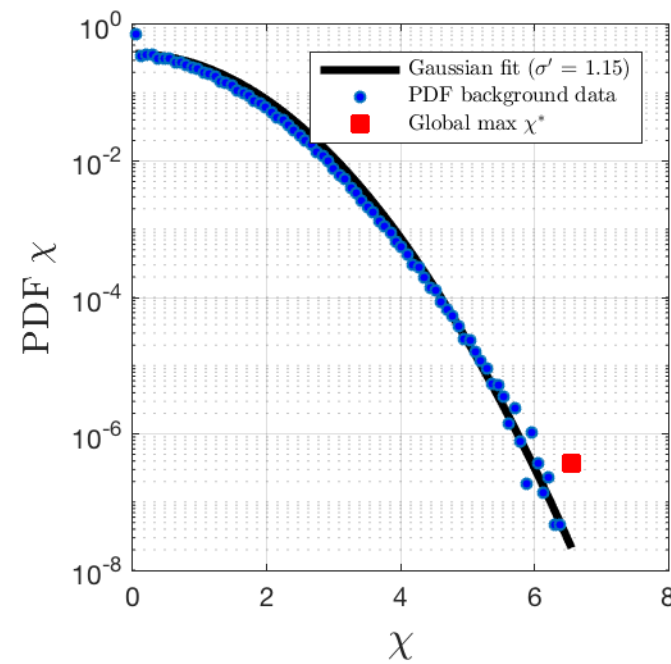
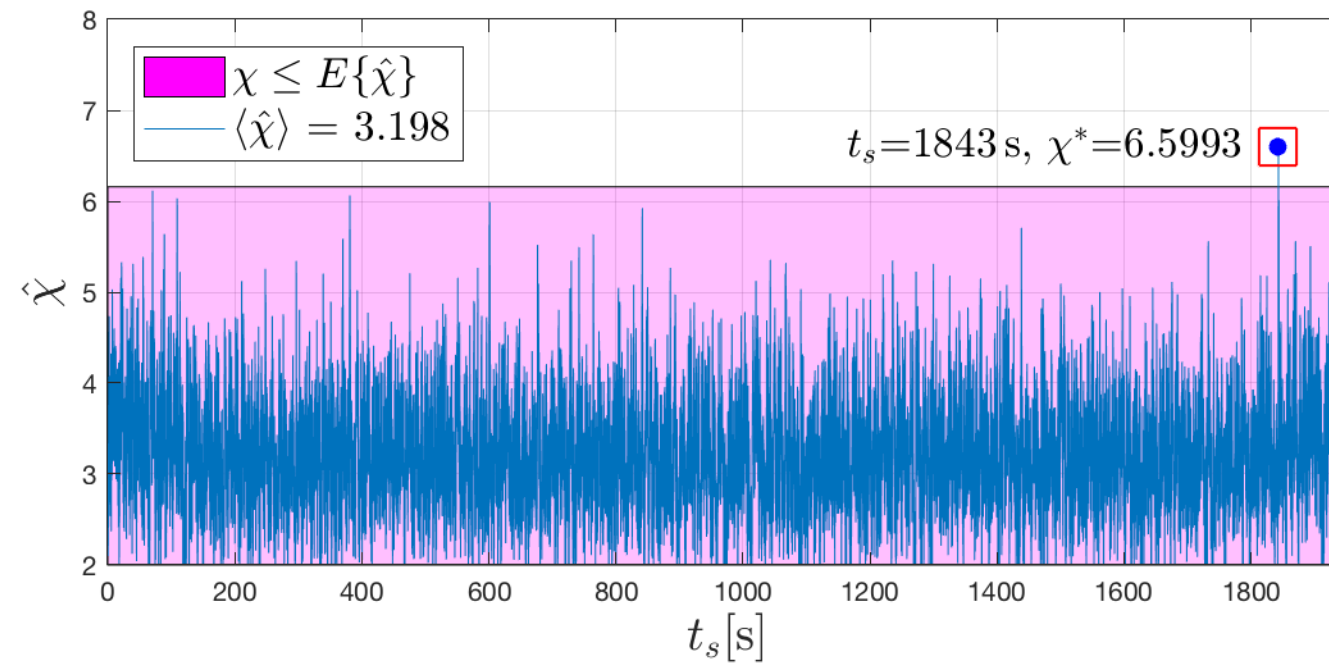
Edge detection by χ -image analysis on H1&L1



χ -image analysis: peak

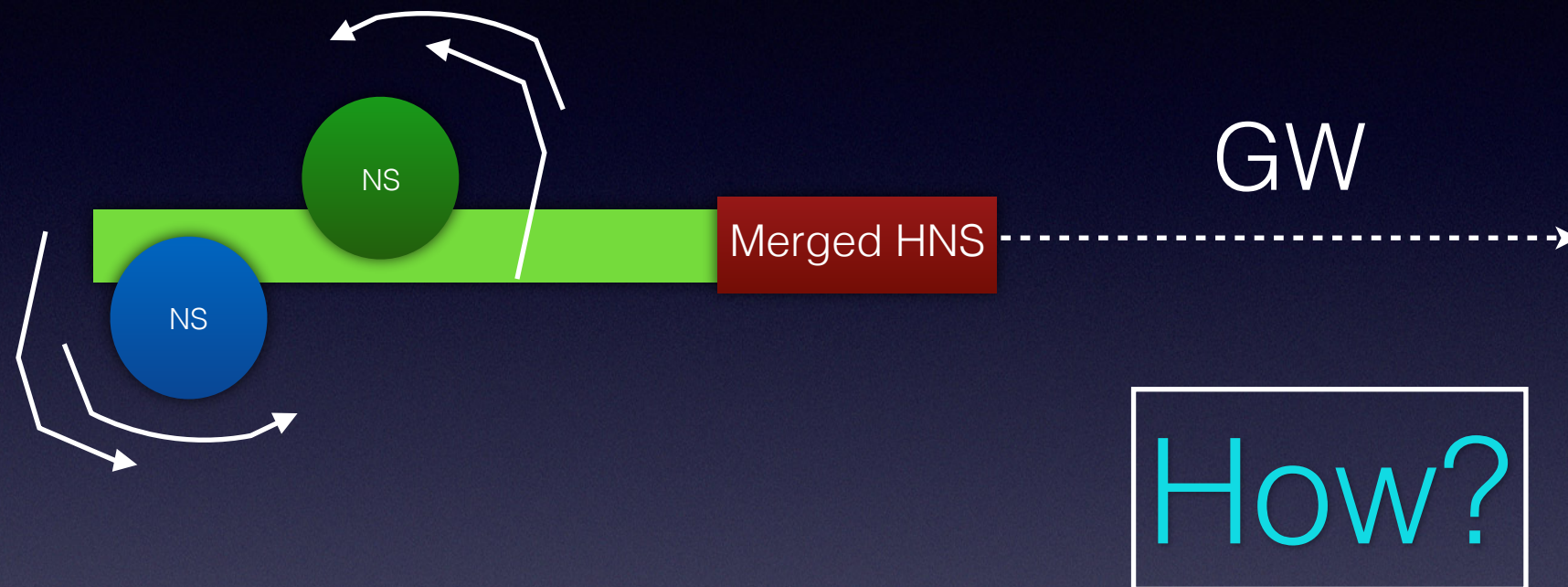


χ -Image analysis: peak and background statistics



256 million scan parameters

EE - a descending chirp - radiates J HNS out to infinity.



YAHOO!
NEWS

<https://news.yahoo.com/epic-crash-neutron-stars-creates-174436470.html>

Epic Crash of Neutron Stars Creates 'Hypermassive Magnetar'

Mike Wall, Nov. 16 2018

Calorimetry on Extended Emission

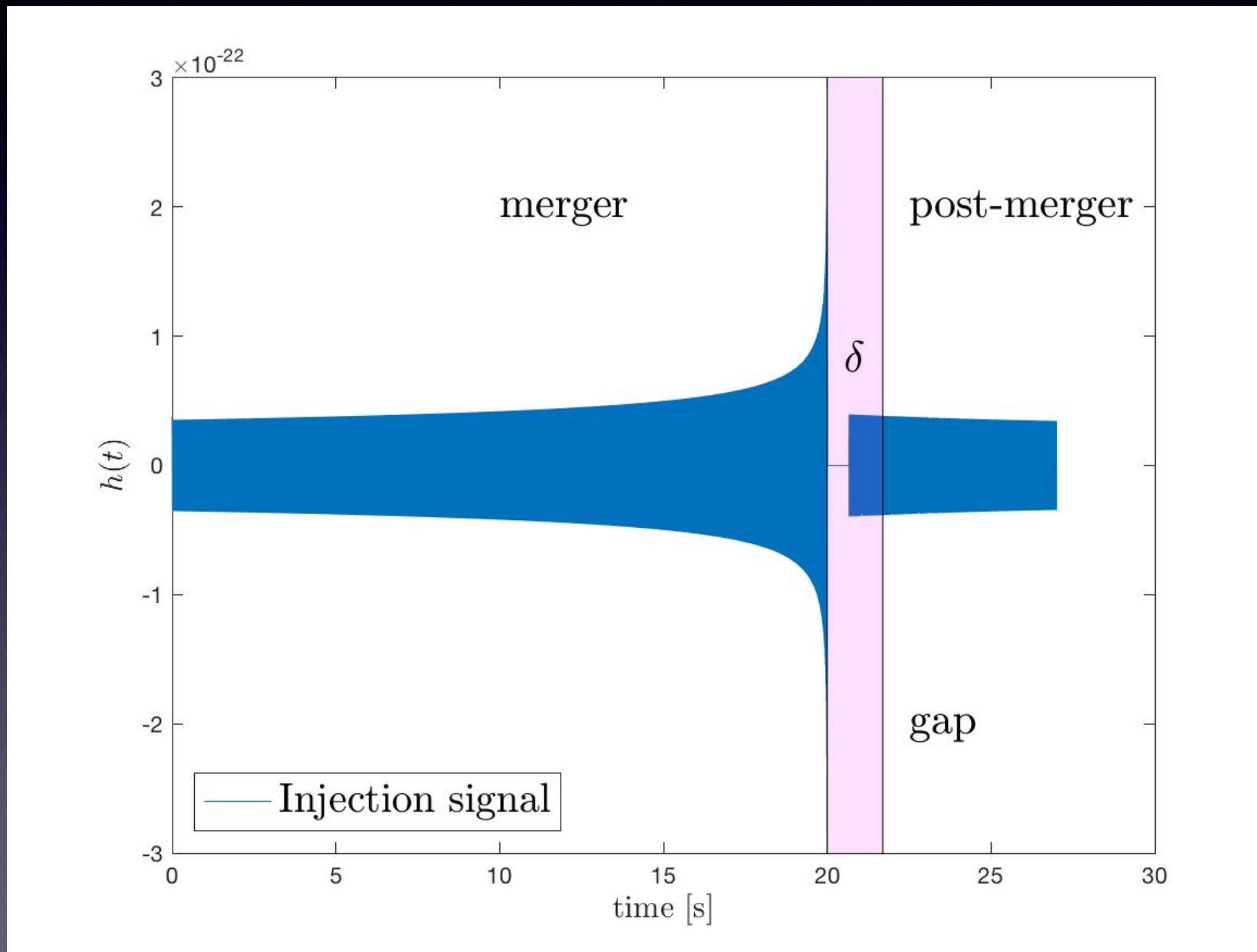
$$\mathcal{E} = \int_0^T L_{GW}(t) dt, \quad L_{GW} = \left(\frac{h}{C_h} f_{GW} \right)^2$$

Observed-to-true strain C_h

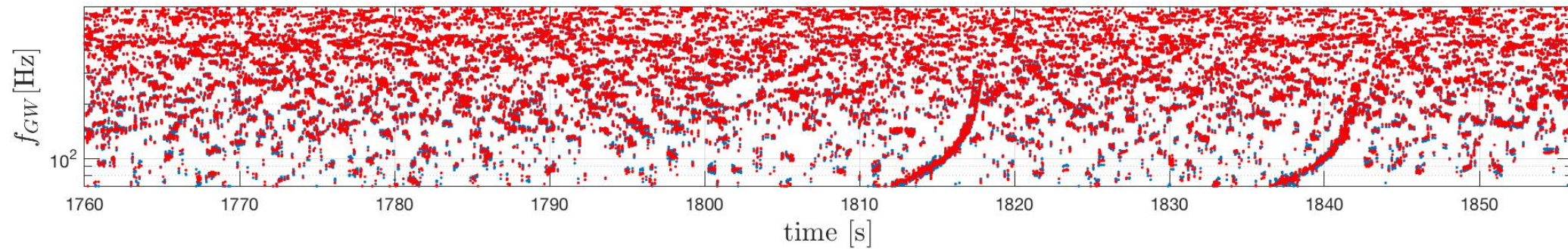
van Putten & Levinson, 2002, Science, 295, 1874; ibid. 2003 ApJ 584 937
van Putten Della Valle & Levinson, 2019, under review

GW170817

$$\mathcal{E} \simeq ? \% M_{\odot} c^2$$



(H1,L1)-spectrogram merged by frequency coincidences



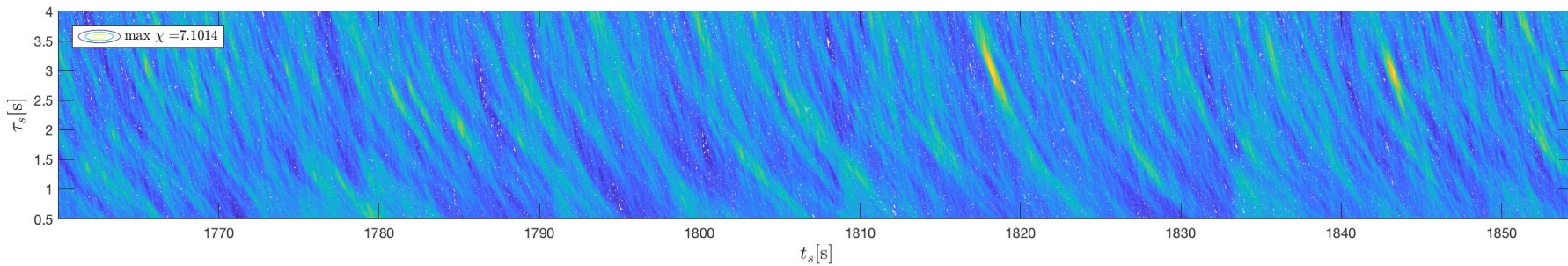
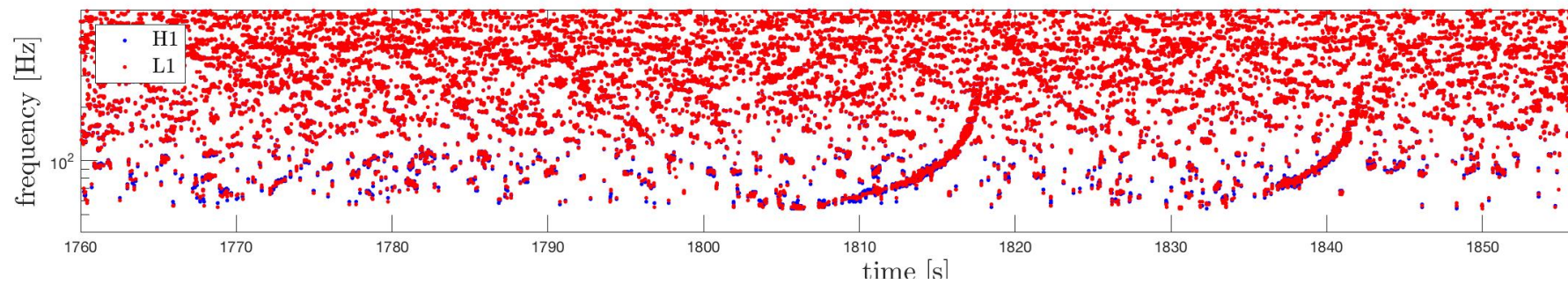
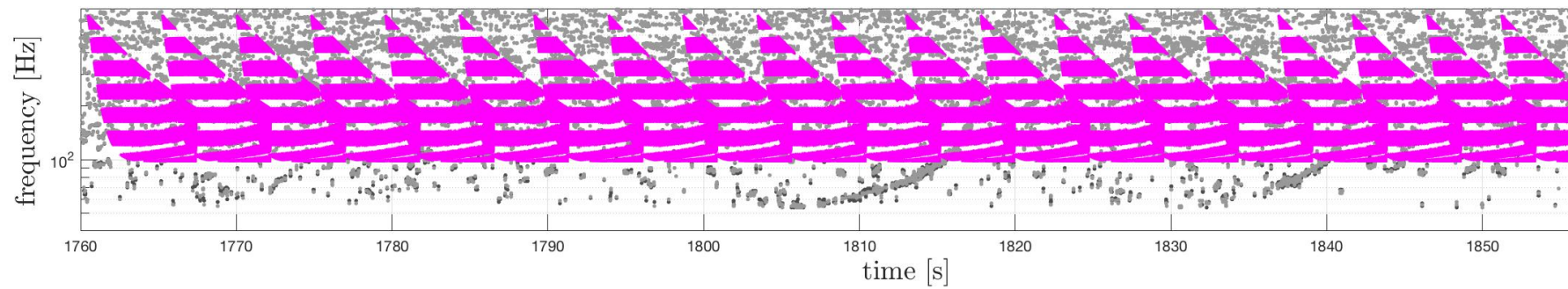
Injection

GW170817EE

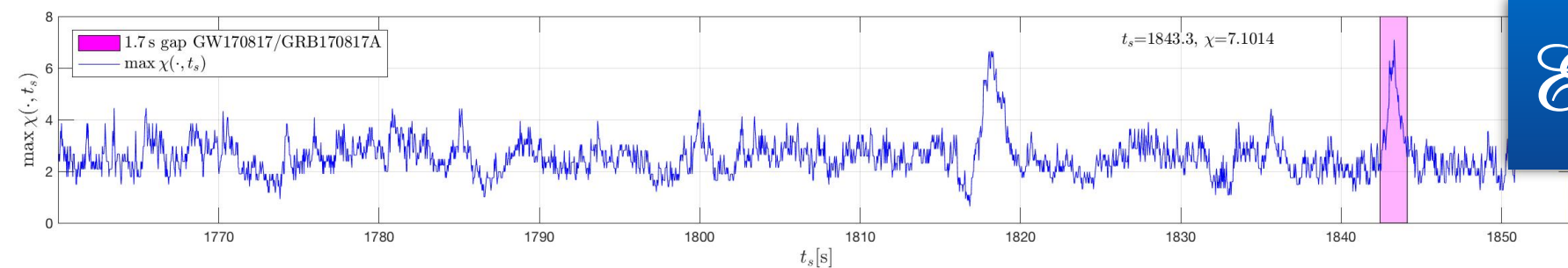
Calibration step: match ascending branches: true-to-observed strain $C_h \sim 0.7$

χ -image analysis: matching peaks

Scan over exponential features



\uparrow τ

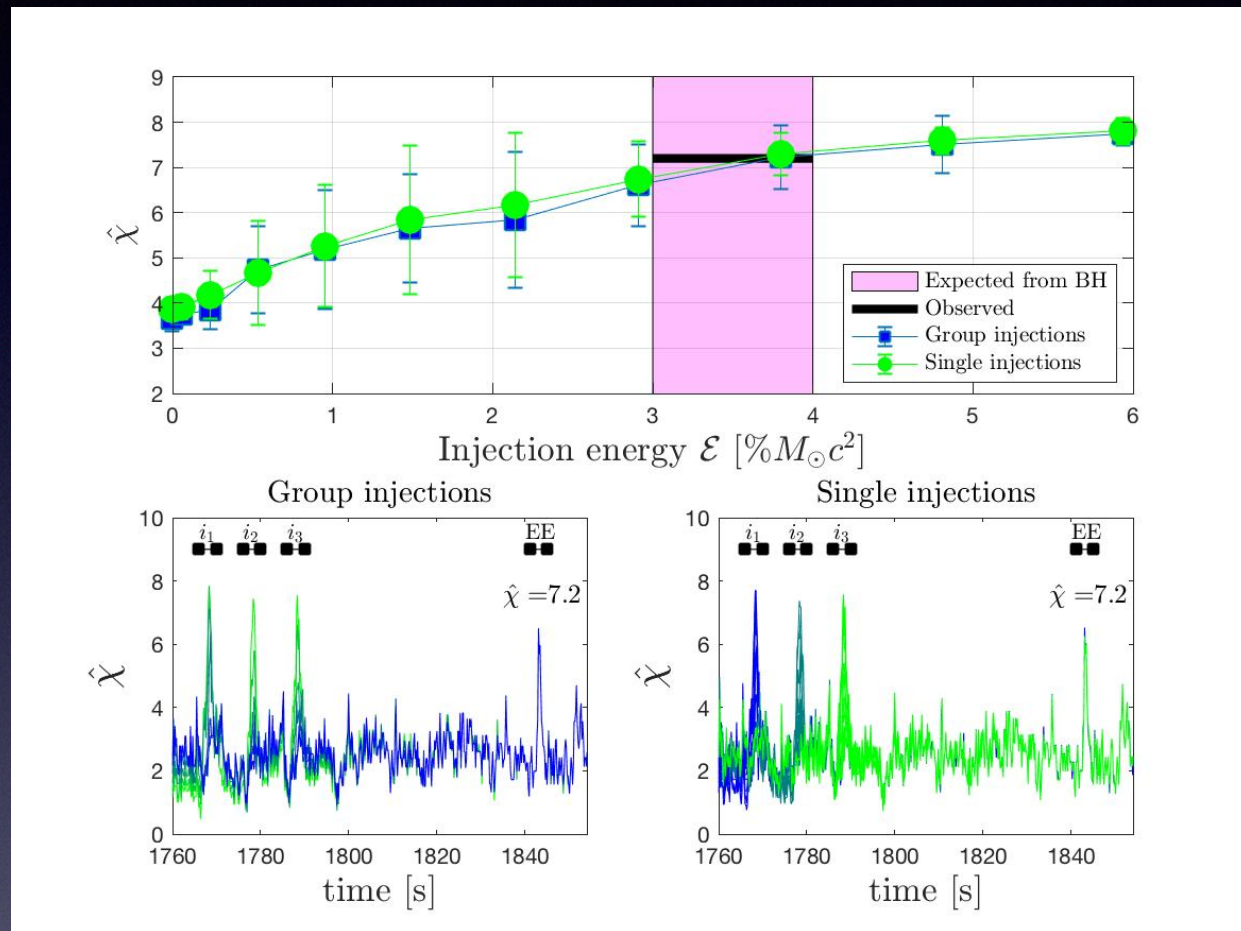


$$\mathcal{E} \simeq 3\% M_{\odot} c^2$$

$$t_s \simeq 0.67 \text{ s}$$

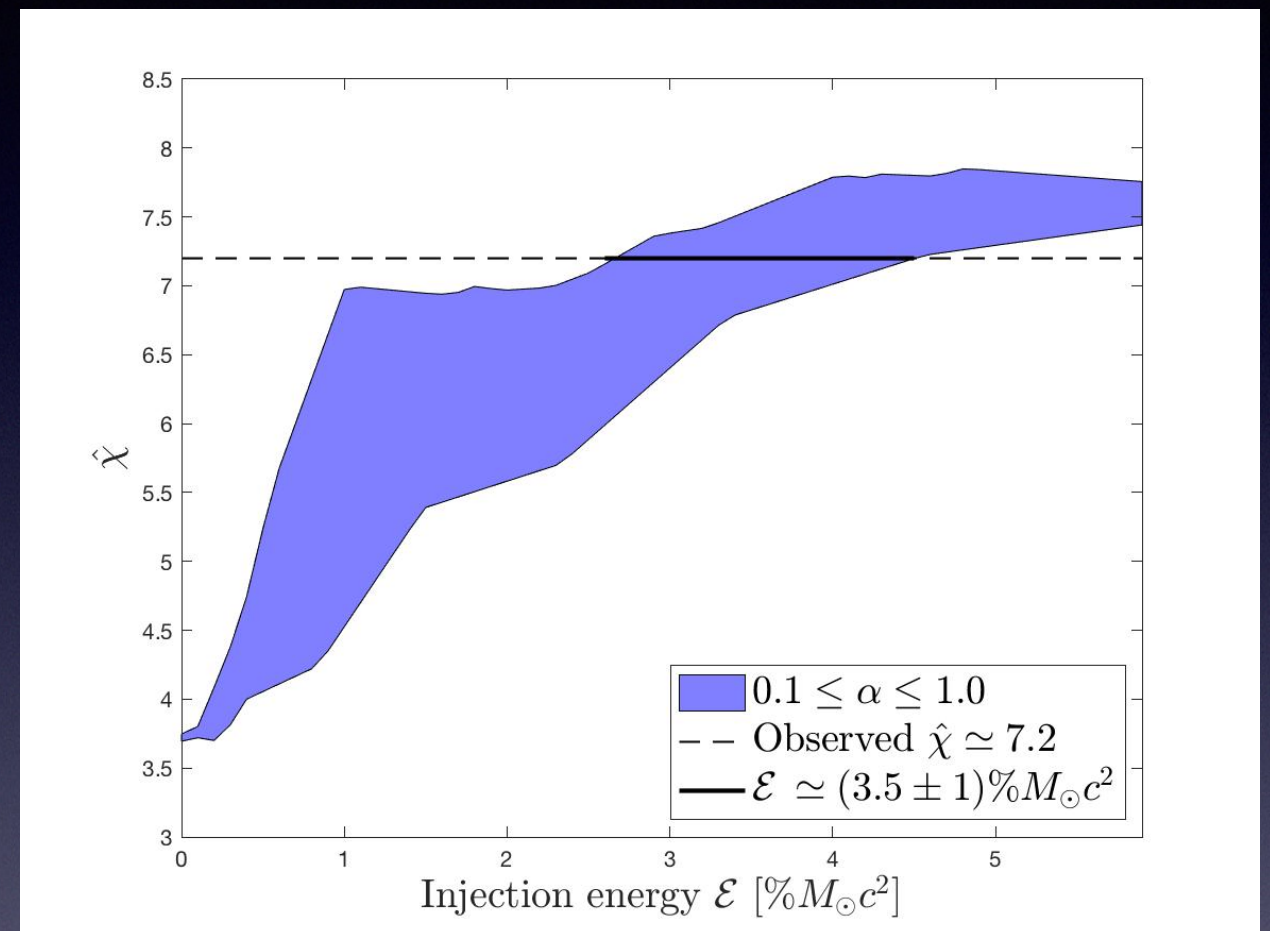
Response curve $\chi(E)$

Single and group injections



No interference between injections

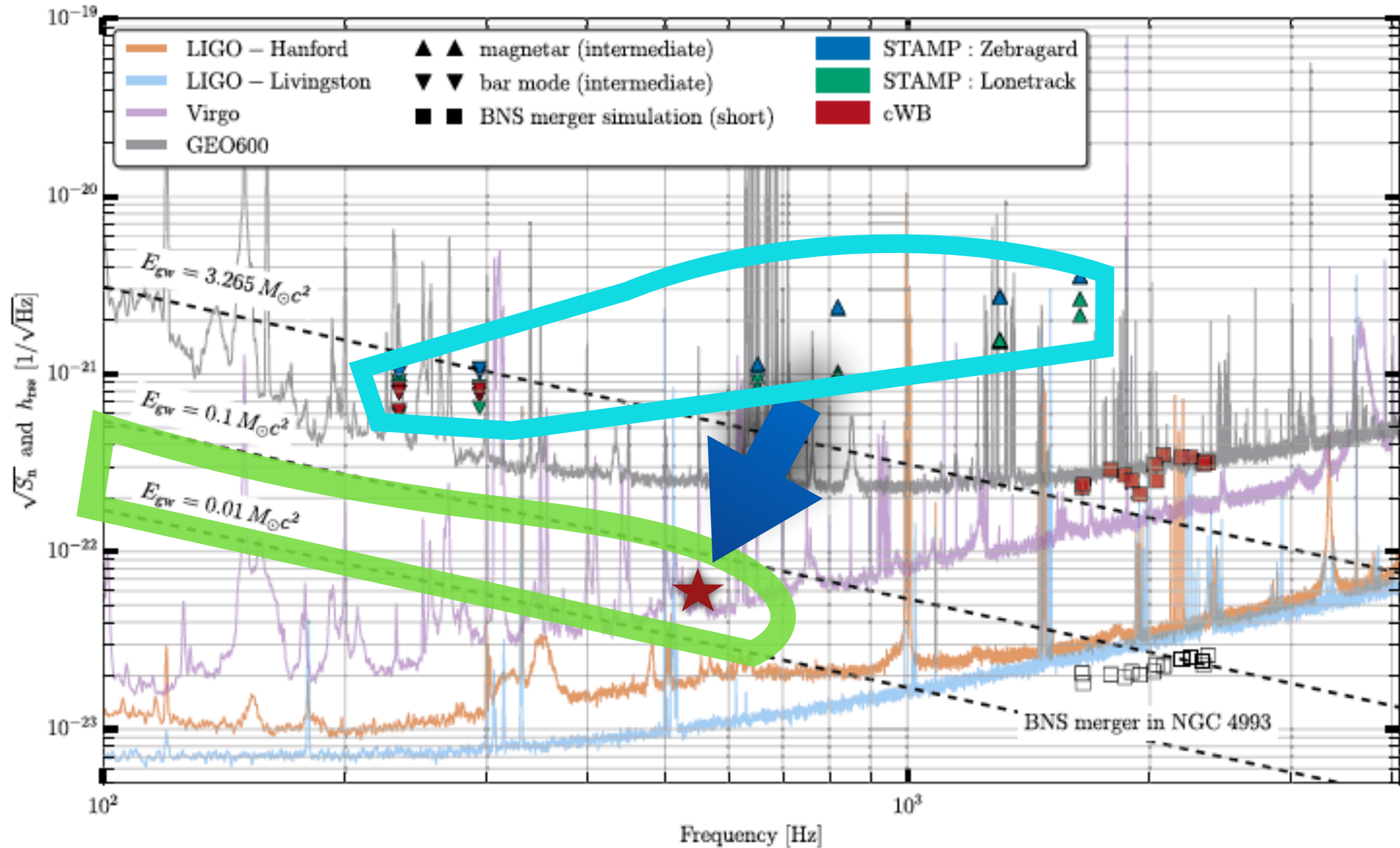
Response function



$$h(f) \sim f^{\alpha} \quad (0.1 \leq \alpha \leq 1)$$

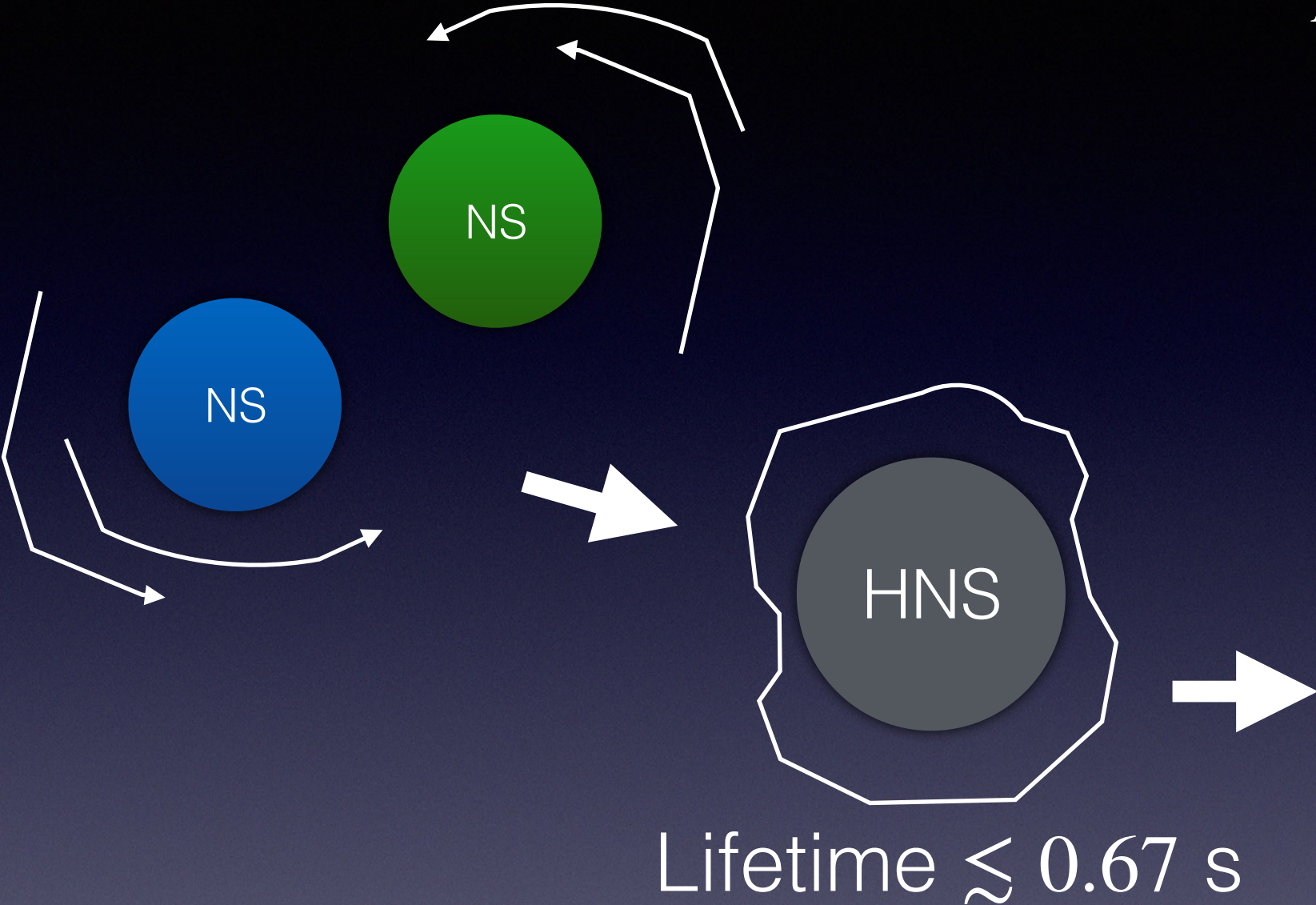
van Putten Della Valle & Levinson, 2019, under review

Shifting the Window...



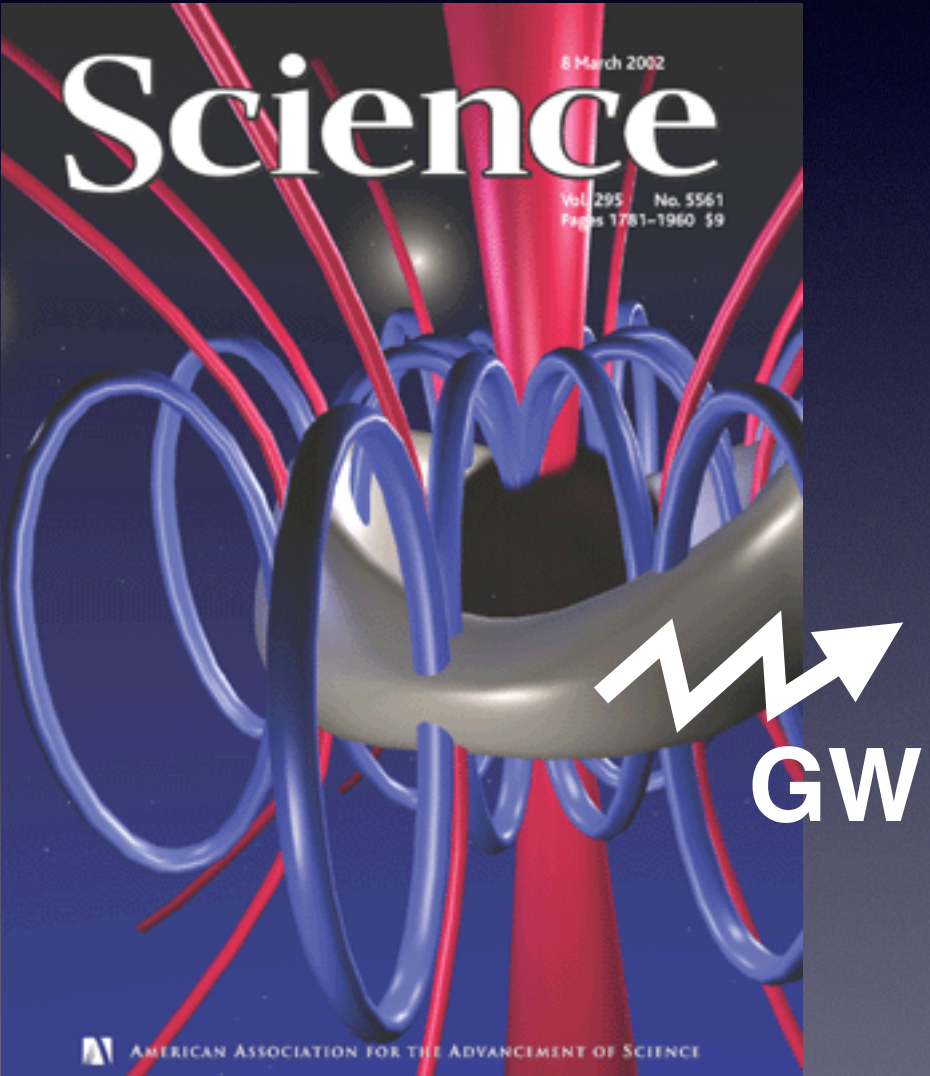
$$h \sim \text{few} \times 10^{-23} \leftarrow h \sim \text{few} \times 10^{-23}$$

Core-collapse greatly enhances E_J



$$E_J \lesssim 1M_{\odot}c^2$$

($\sim 3M_{\odot}$ Kerr BH)



van Putten, & Levinson, 2002, Science, 295,1874

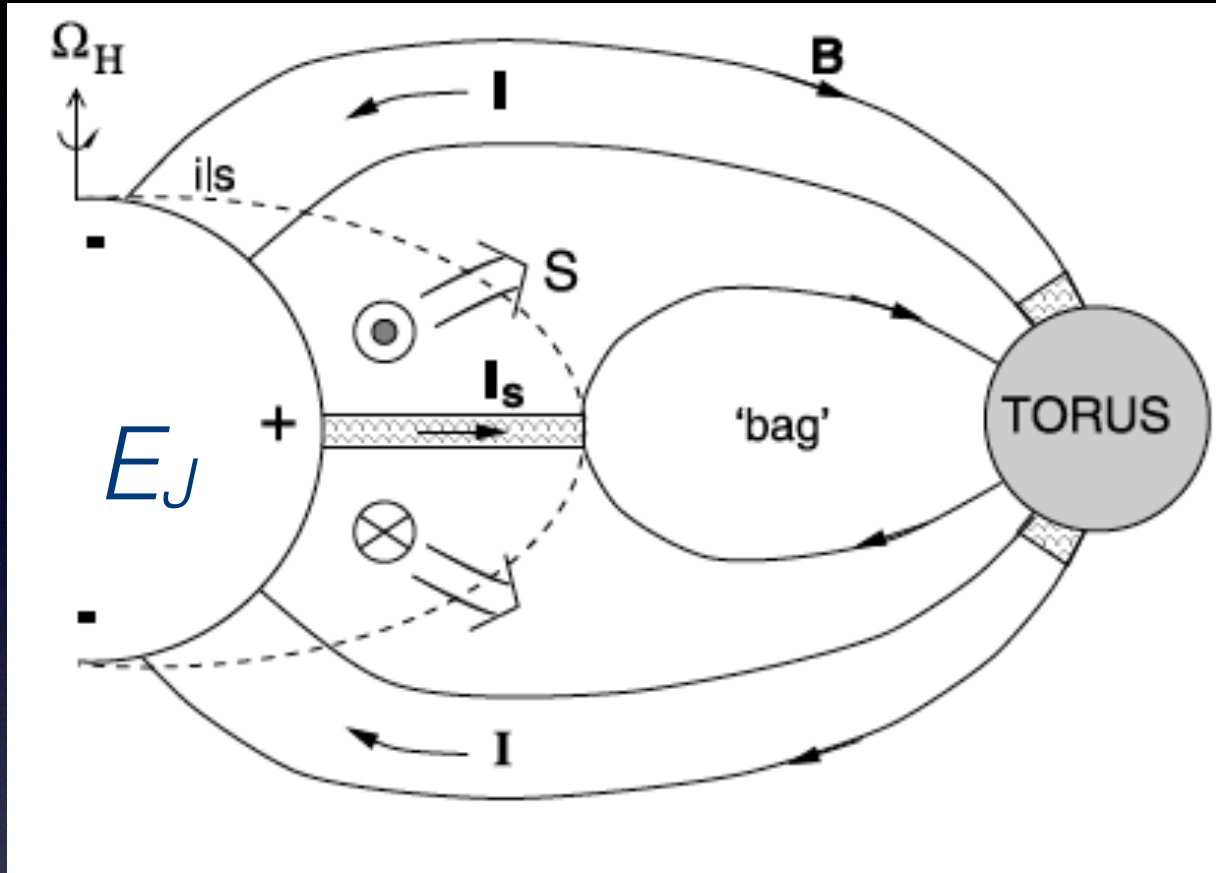
Duration = T_s

cf. $t_c \lesssim 0.9$ s Murguia-Berthier, 2019, GWPop, Aspen

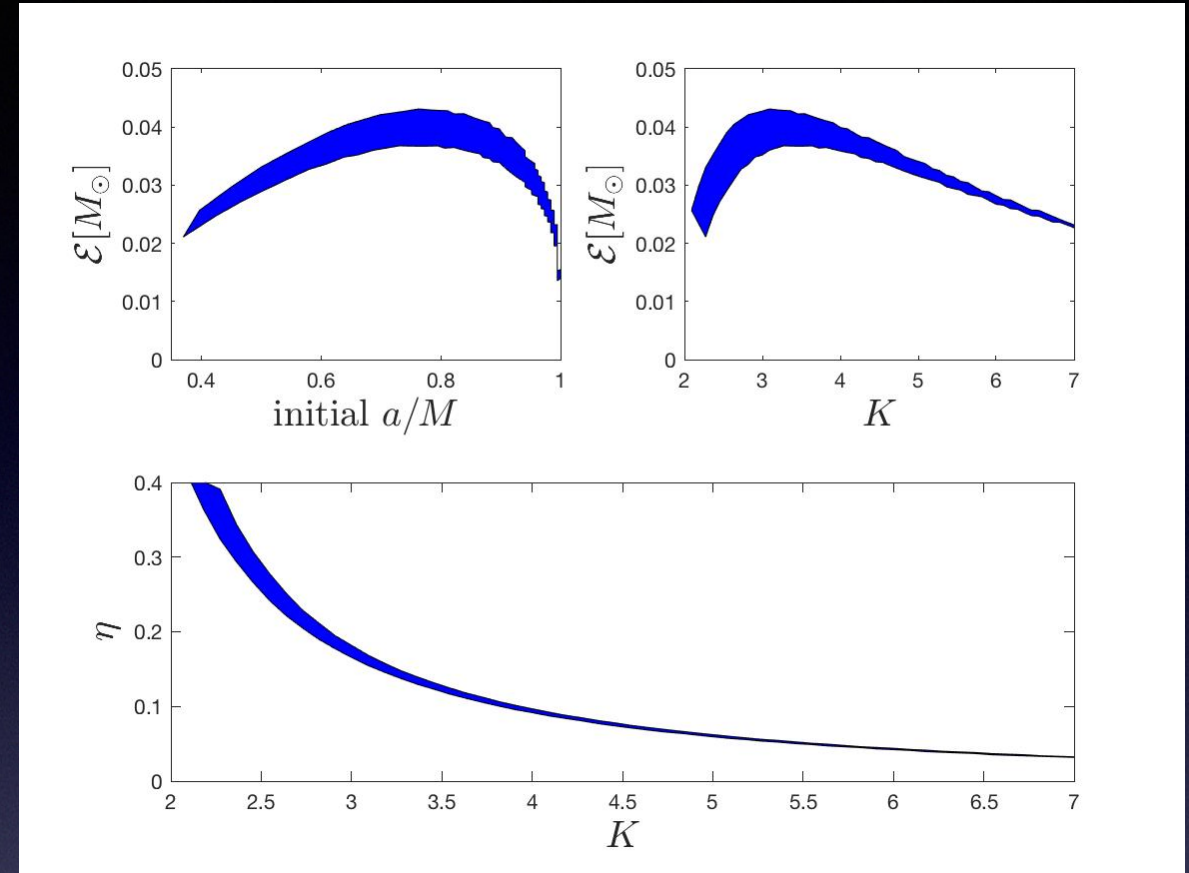
cf. $t_c \lesssim 0.98^{+0.31}_{-0.26}$ s Gill & Rezzolla, 2019, arXiv: 1901.04138

Expected output from a Kerr black hole

van Putten, 1999, Science, 285, 115



van Putten, Della Valle & Levinson, 2019 (under review)



$$L_H = -\dot{M}, T = -J_H$$

$$Kr_{ISCO}$$

$$f_{GW,i} = 650\text{Hz (observed):}$$

$$K \simeq 3, \eta \simeq 15\%$$

$$\mathcal{E} \simeq 3\% M_{\odot} c^2$$

by non-axisymmetric torus of $\sim 3R_{ISCO}$ about a low mass non-extremal BH ($a/M \sim 0.75$)

Theory and injection results agree.

GW170817EE: complex sequence in three Acts



$$E_J < 1\% M_{\odot} c^2 \rightarrow E_J \simeq 0.3 M_{\odot} c^2 \rightarrow \mathcal{E} \simeq 3\% M_{\odot} c^2$$

$J = J_{\text{HNS}}$ conserved in CC

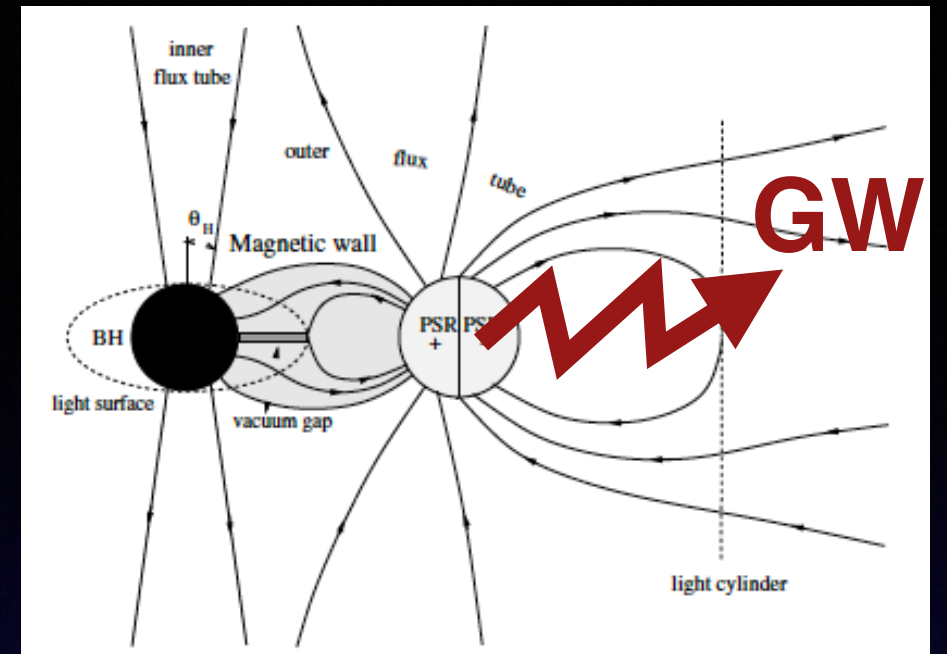
van Putten, Della Valle & Levinson, 2019 (under review)

Burst of MMEE

Duration set by lifetime of spin:

$$T_s \simeq 1.5\text{s} \left(\frac{\sigma}{0.1} \right)^{-1} \left(\frac{z}{6} \right)^4 \left(\frac{M}{M_\odot} \right)$$

$$z = \frac{r}{M}, \quad \sigma = \frac{M_T}{M}$$



van Putten & Levinson, 2003, ApJ, 584, 937

GRB170817A - kilonova:

$$E_j \simeq \frac{1}{4z^4} E_J \simeq 10^{50} \text{erg} \quad E_w \simeq \eta^2 E_J \simeq 10^{52} \text{erg}$$

Agrees with observational constrains (Mooley et al. 2019):

kilonova

$$E_j \simeq 10^{49-50} \text{erg} \quad E_k \simeq 4.5 \times 10^{51} \text{erg}$$

GRB170817A

van Putten, Della Valle & Levinson, 2019 (under review)

Conclusion

Calorimetric evidence of Kerr BHs

$$1\% < \mathcal{E} < 10\%, \quad h \sim \text{few} \times 10^{-23}$$

Multi-messenger Extended Emission

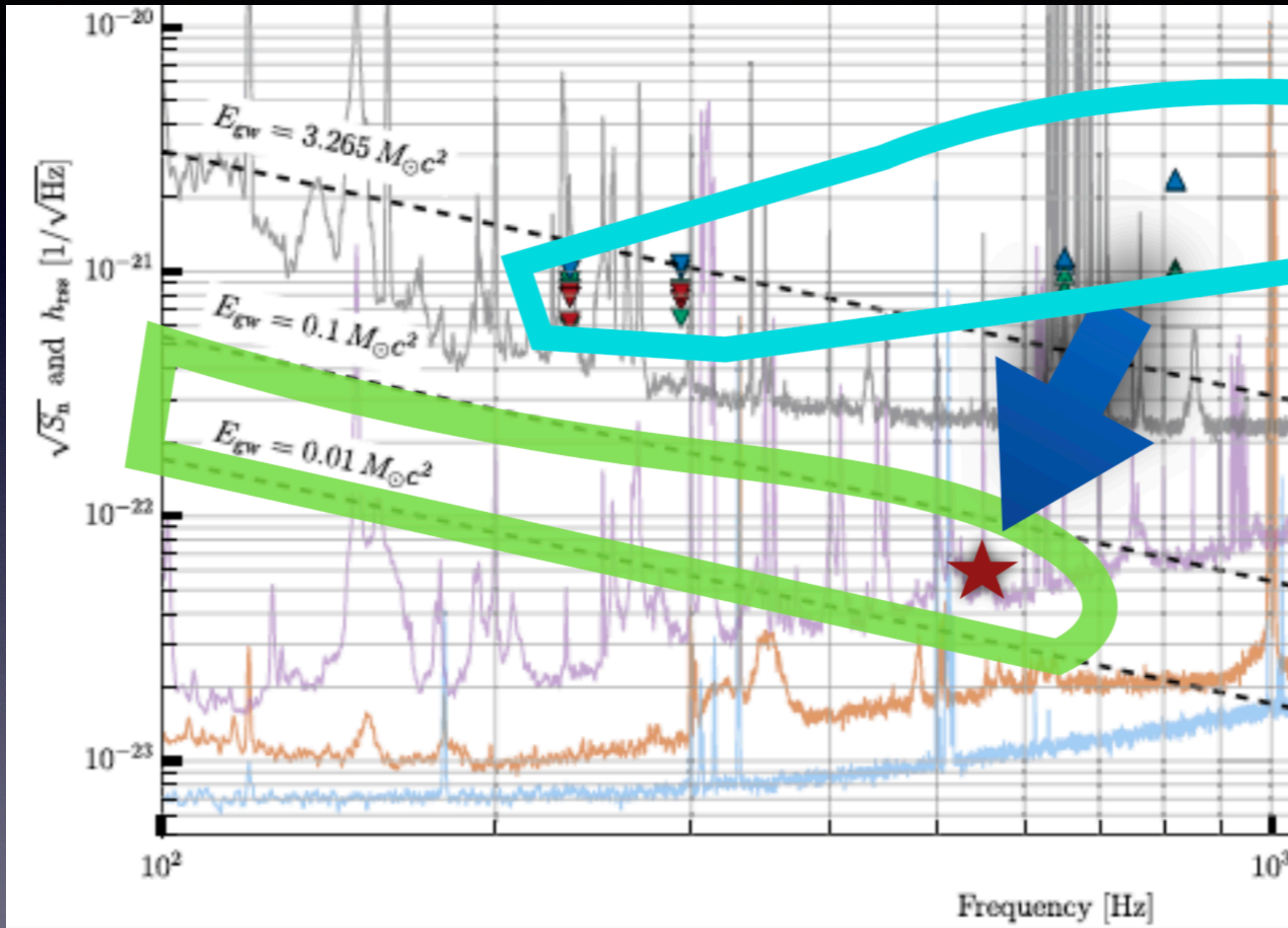
$$\text{GW170817 EE: } \mathcal{E} \simeq 3\% M_{\odot} c^2$$

$$\text{Kilonova: } 0.2\% M_{\odot} c^2$$

$$\text{GRB170817A: } 0.01\% M_{\odot} c^2$$

Shifting the Window:

New Opportunities for **EE to DNS, NS-BH and CC-SNe ...**



$h \sim \text{few} \times 10^{-23}$