Presentation to LIGO-Virgo SN working group

GPU-searches for broadband extended emission in gravitational-waves in nearby energetic core-collapse supernovae

Deep searches for long bursts in gravitational-waves by butterfly filtering

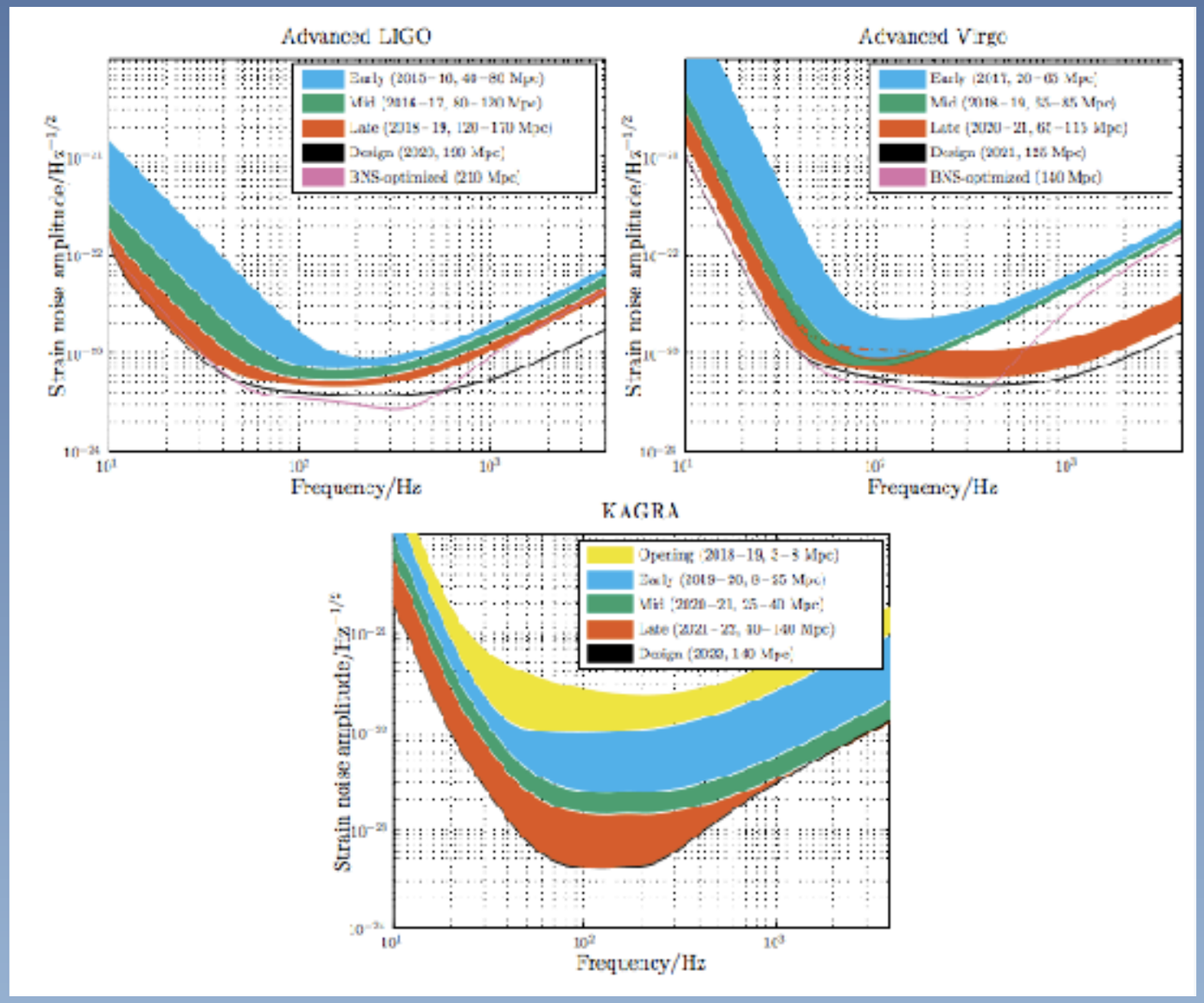
Maurice H.P.M. van Putten

van Putten, Levinson, Frontera, Guidorzi, Amati & Della Valle, 2017, arXiv:1709.04455

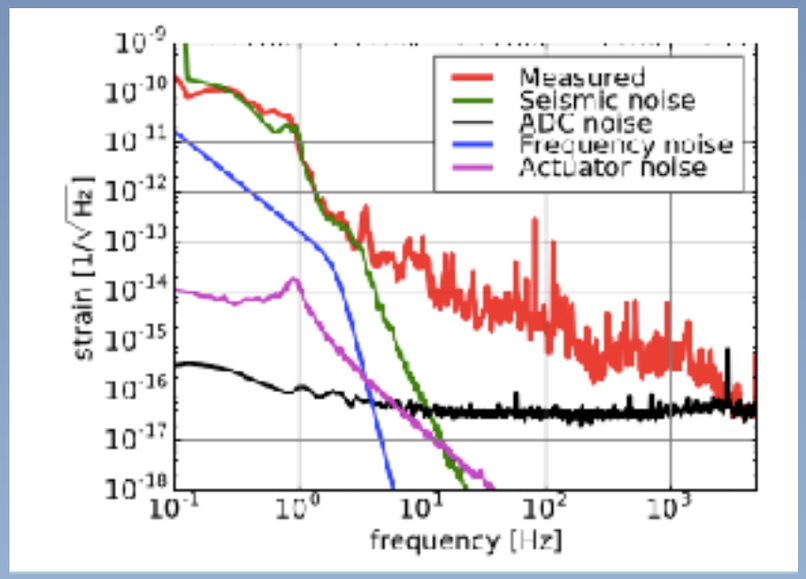
October 2017

Global detector array: LIGO-Virgo & KAGRA

Abbott, B.P., et al. 2017, arXiv:1304.0670



Akutsu et al., 2017, arXiv:1710.0423



-> Deep searches for enigmatic sources with accurate localization

Outline

- *Candidates* of long duration multi-messenger sources: LGRB, SGRBEE and CC-SNe
- *Butterfly filtering*: detecting un-modelled broadband signals by matched filtering against banks of chirp templates
- *GPU-accelerated* butterfly filtering agains banks of millions of chirp templates
- *LIGO S6*: detecting broadband correlations in H1 and L1
- *Conclusions an outlook*

Brief history of GRBs

most relativistic and energetic transients in the sky

- **BATSE**: SGRBs (< 2 s) and LGRBs (> 2 s)
- ***BeppoSAX***: cosmological origin, X-ray afterglows
- ***Swift***: SGRB with Extended Emission (EE)
- GW170817/SGRB NS-NS merger

$$E = E_{52} 10^{52}\,\mathrm{erg}, \delta t = \delta t_{-3}\,\mathrm{ms}$$

$$\alpha_E = \frac{GE}{c^5 \delta t} = 2.75 \times 10^{-5} \left(\frac{E_{52}}{\delta t_{-3}} \right)$$

$$\alpha_E \leq 10^{-4}$$

$$L_\gamma \gg L_{Edd}$$

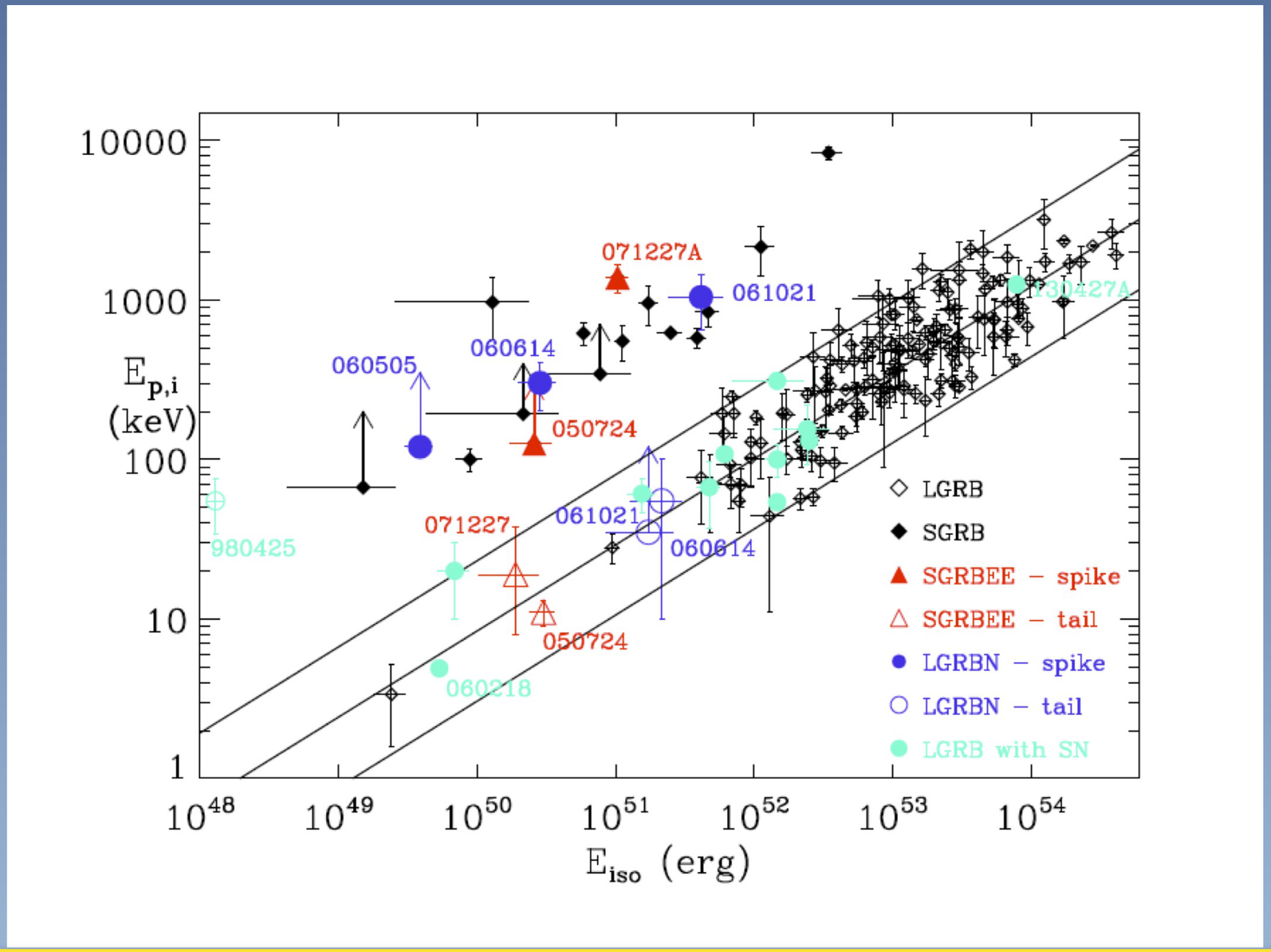
$$E_{res} > E_c^{NS} \text{ (extreme events)}$$

Hyper-energetic events with ms scale variability:

central engine is magnetar or BH

Evidence for a BH central engine

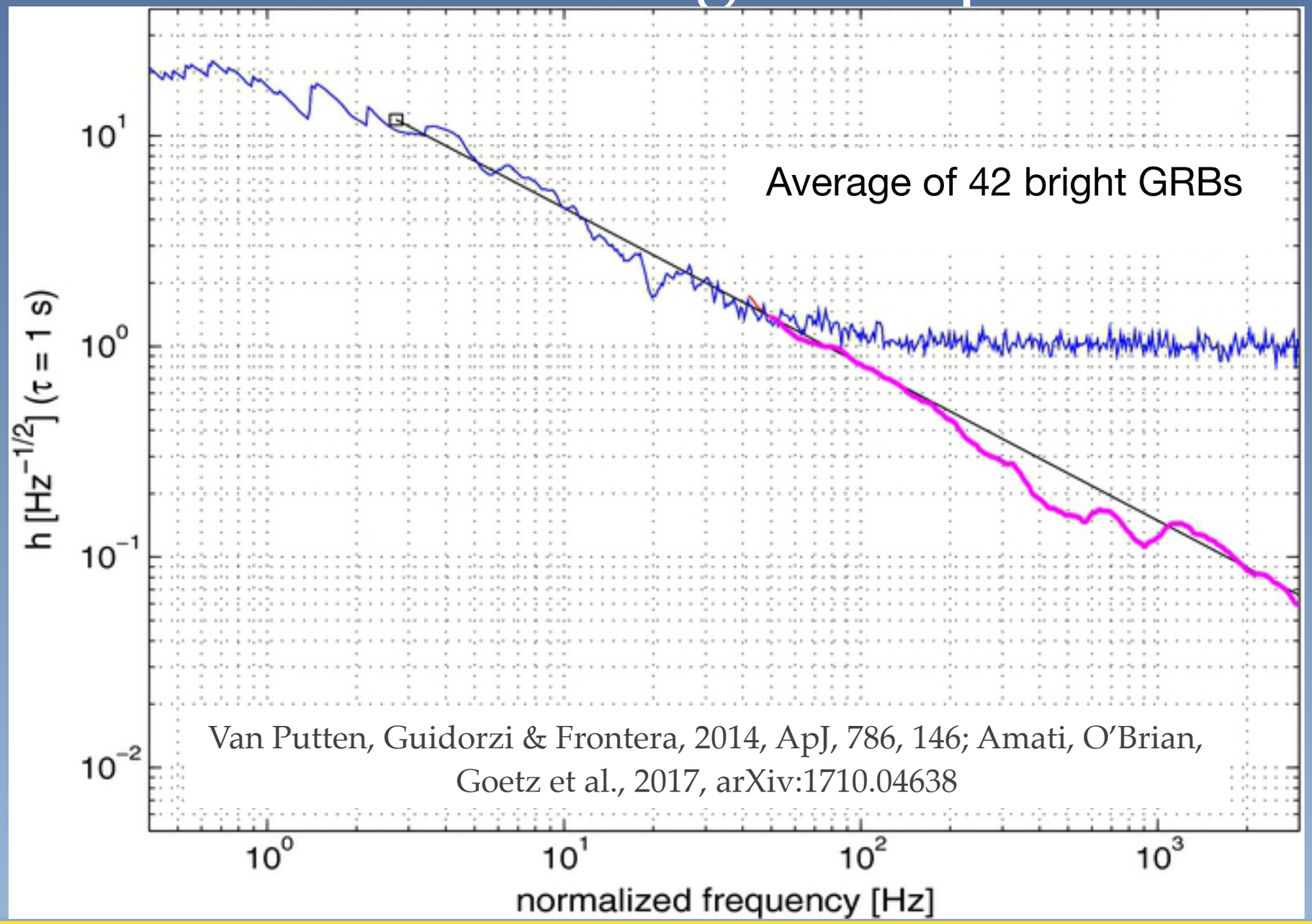
Amati relation



Common inner engine powering Extended Emission to short GRBs and LGRBs

No signature of magnetars

Broadband Kolmogorov spectrum

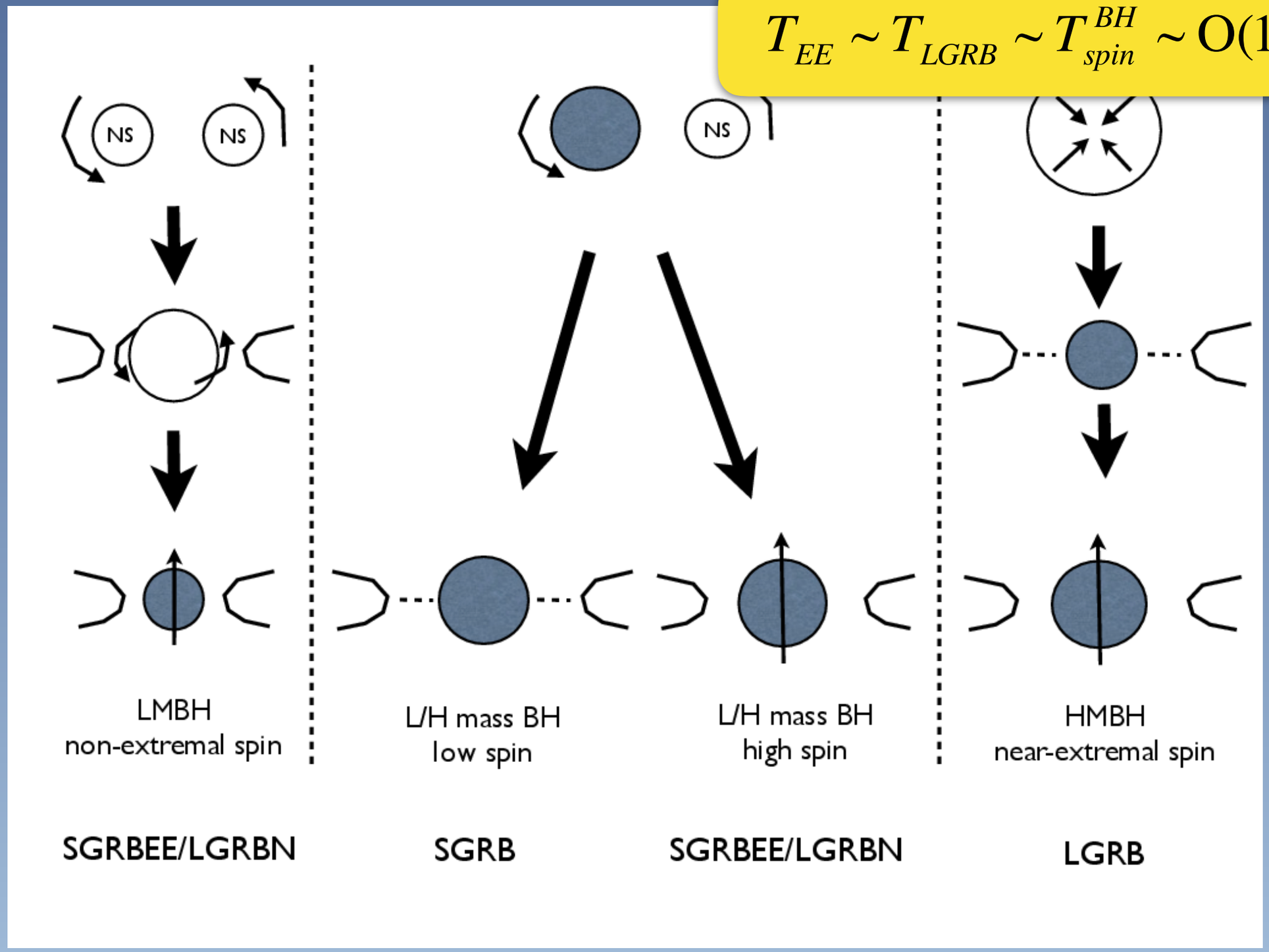


Absent

No "bump" at high frequency: "evidence of no evidence of magnetars"

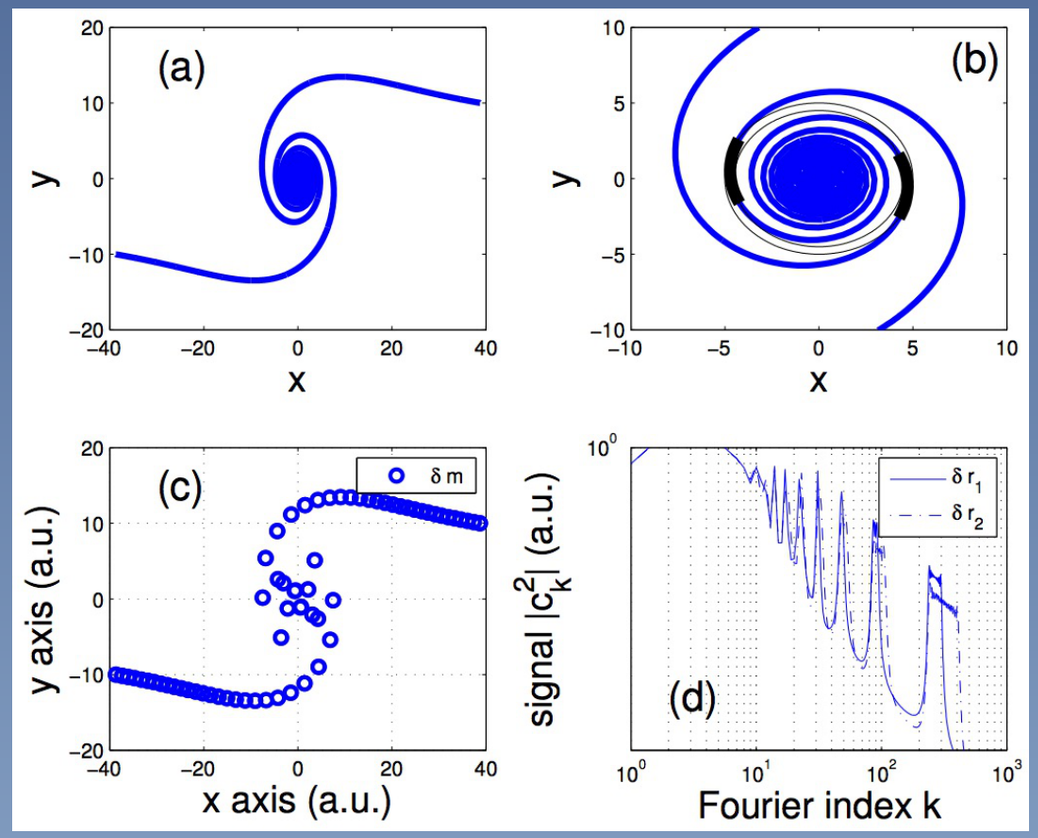
Short/long from slowly/rapidly rotating BHs

$$T_{EE} \sim T_{LGRB} \sim T_{spin}^{BH} \sim \mathrm{O}(10\,\mathrm{s})$$

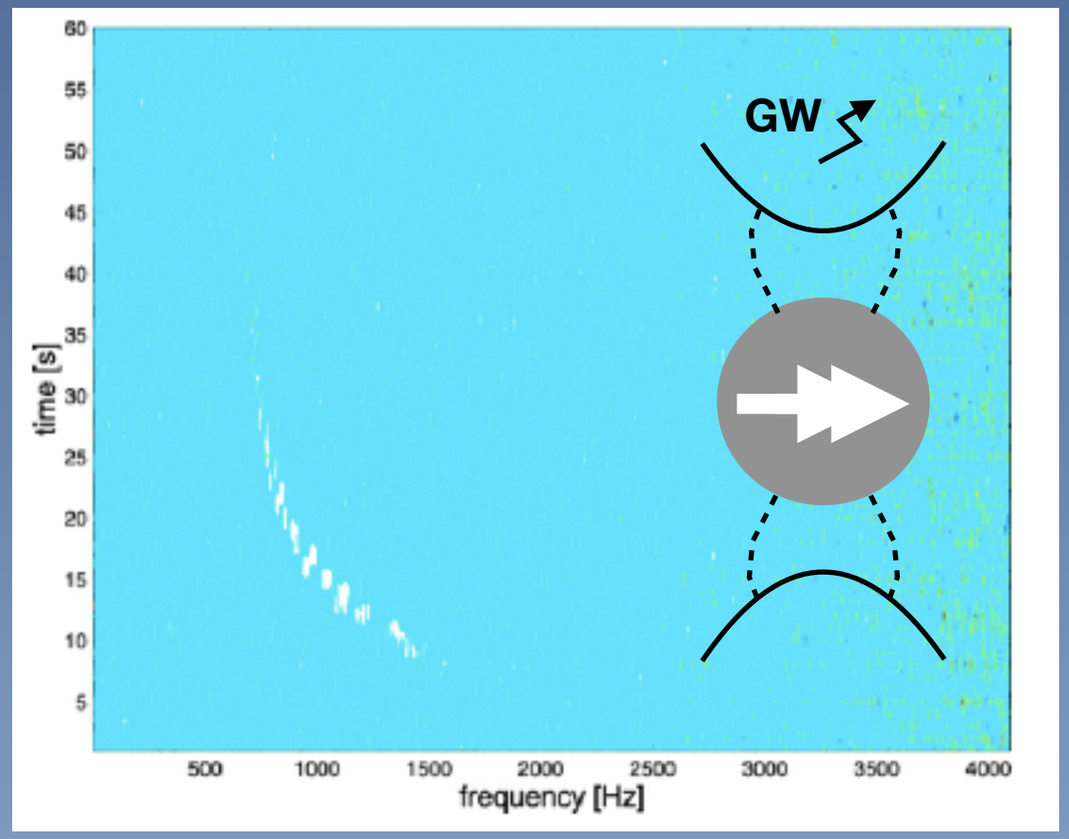


(van Putten & Ostriker, 2001, ApJ, 552, L31; van Putten , 2015, ApJ, 810, 7)

Long duration GW chirps



Levinson, van Putten & Pick, 2015, ApJ, 812, 124



Van Putten, 1999, Science, 284, 115
van Putten & Levinson, 2002, Science, 294, 1837
van Putten & Levinson 2003 ApJ 584 937
Van Putten, 2008, ApJ, 684, L91

$$E \sim U_N \quad \text{(binding energy)}$$

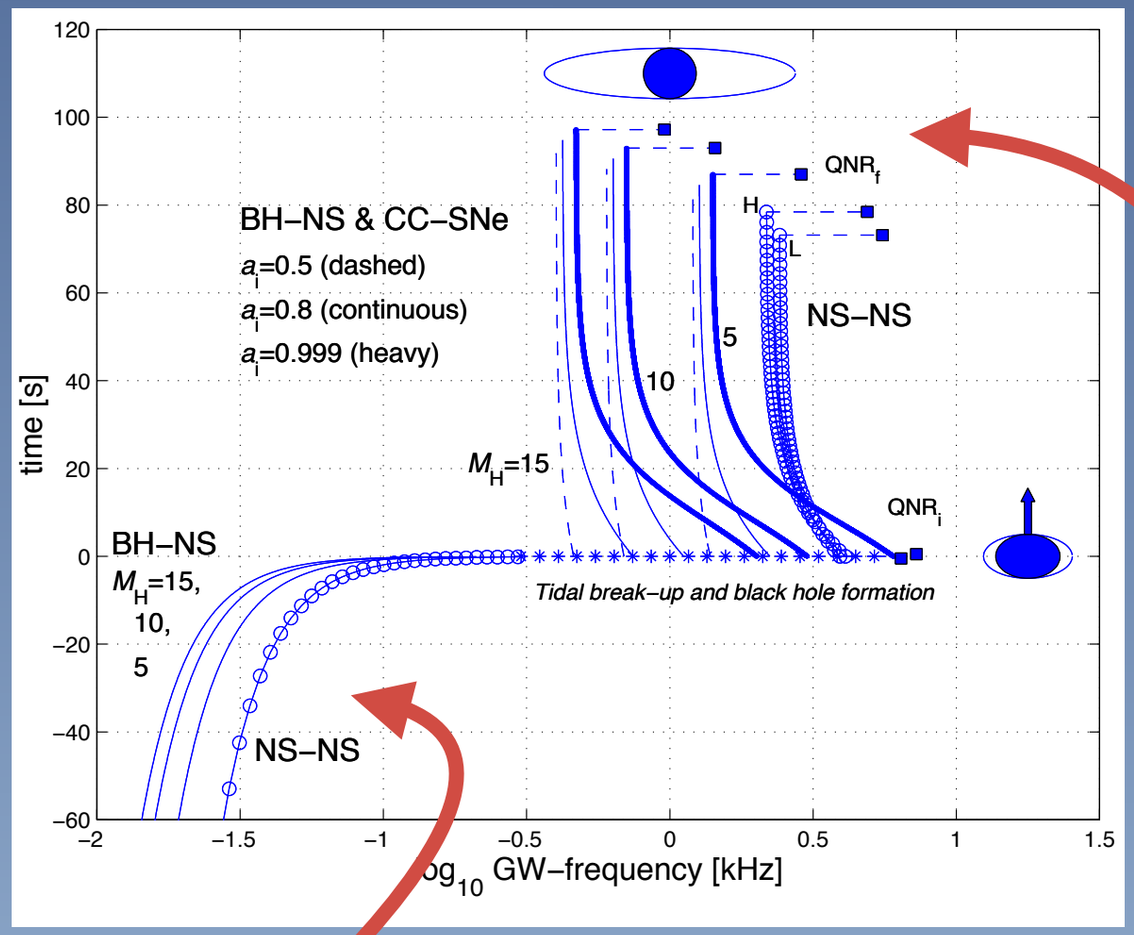
$$f_{GW} \leq 600 - 700\left(\frac{10 M_\odot}{M}\right)$$

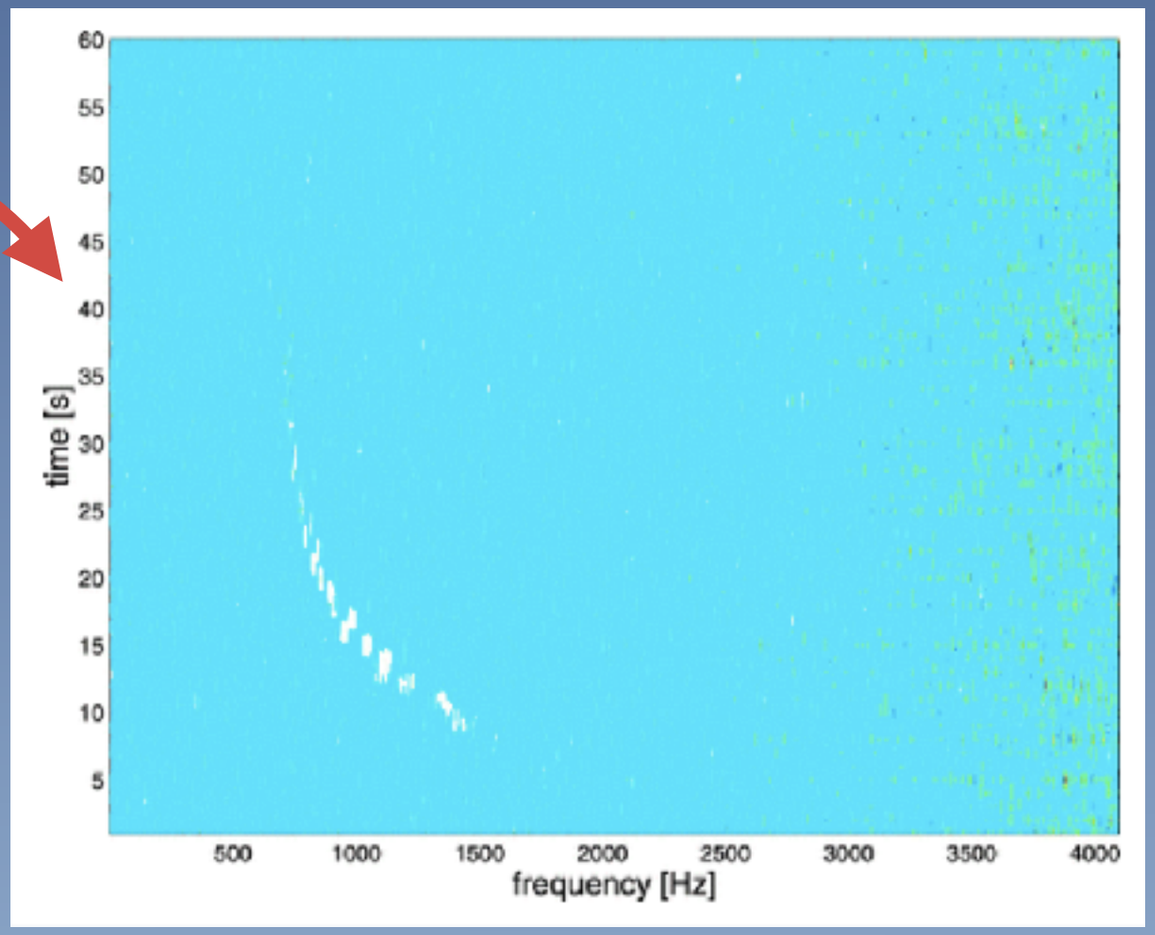
$$E_{res} = few \times 10^{54}\,\text{erg} \gg E_c^{NS}$$

$$f_{GW} \geq 600 - 700\left(\frac{10 M_\odot}{M}\right)$$

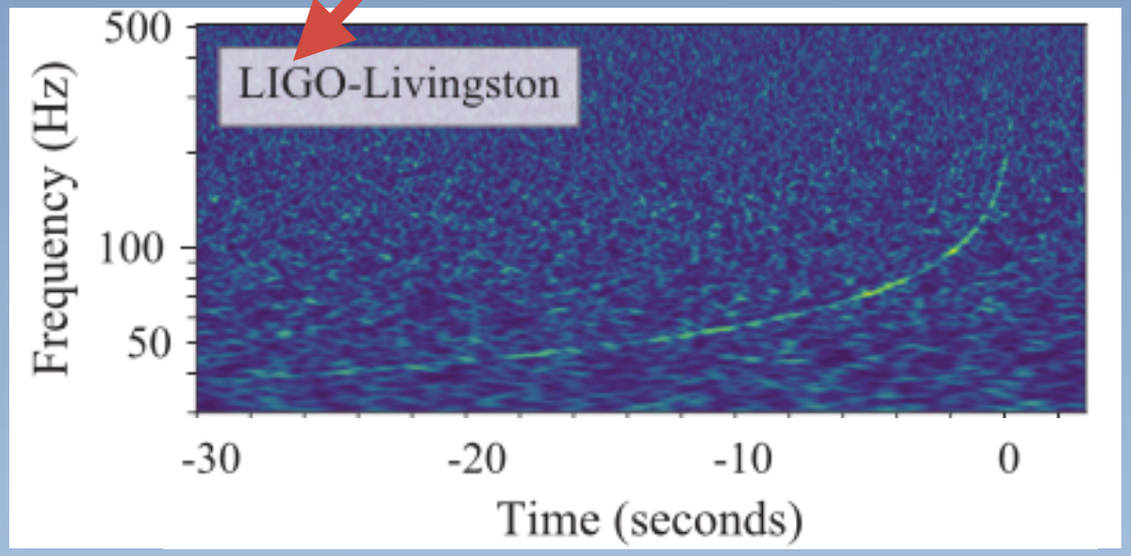
Ascending and descending chirps

van Putten, 2009, MNRAS 396 L81





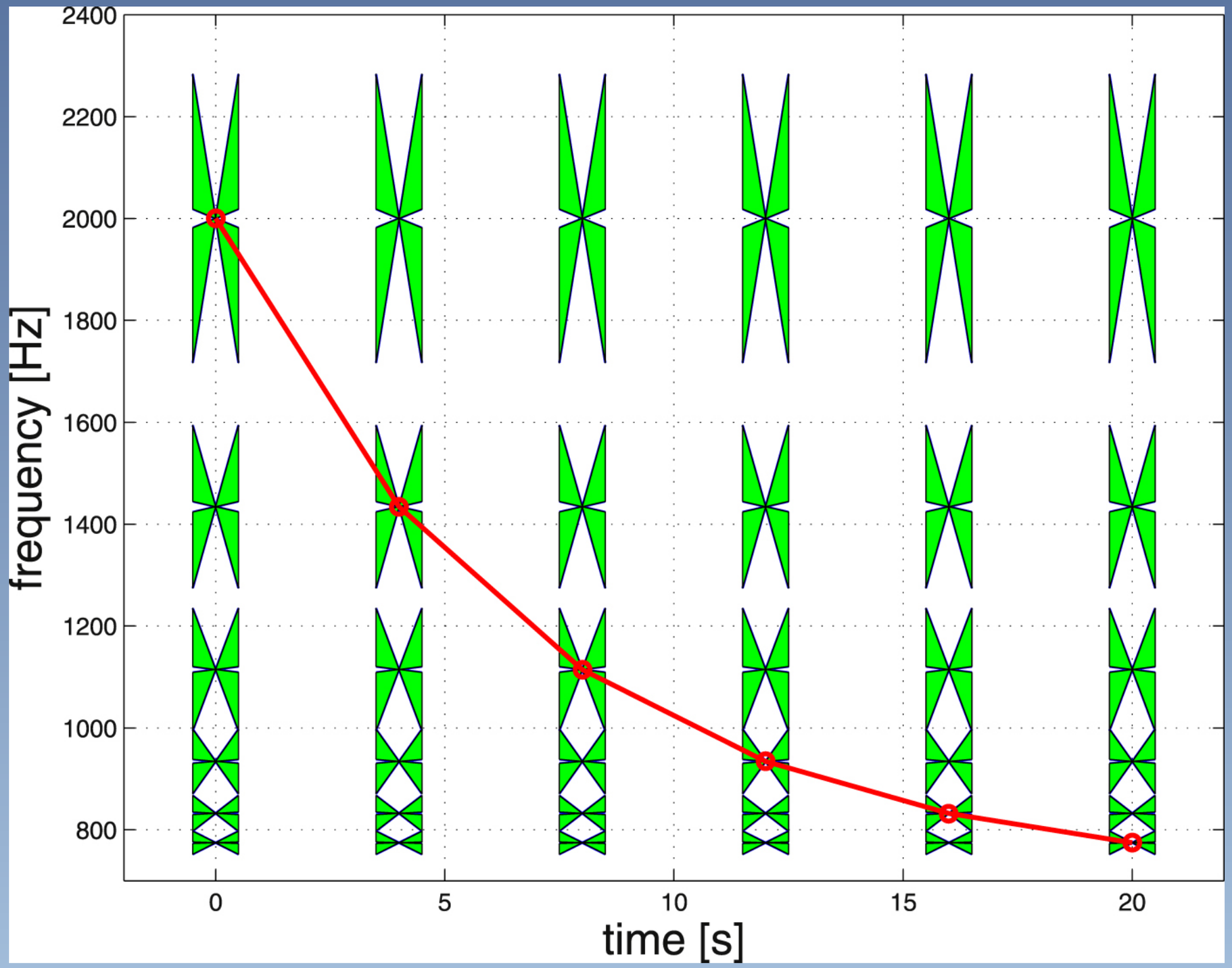
van Putten, 2008, ApJ 648, L91



Abbott et al., 2017, PRL 119, 161101

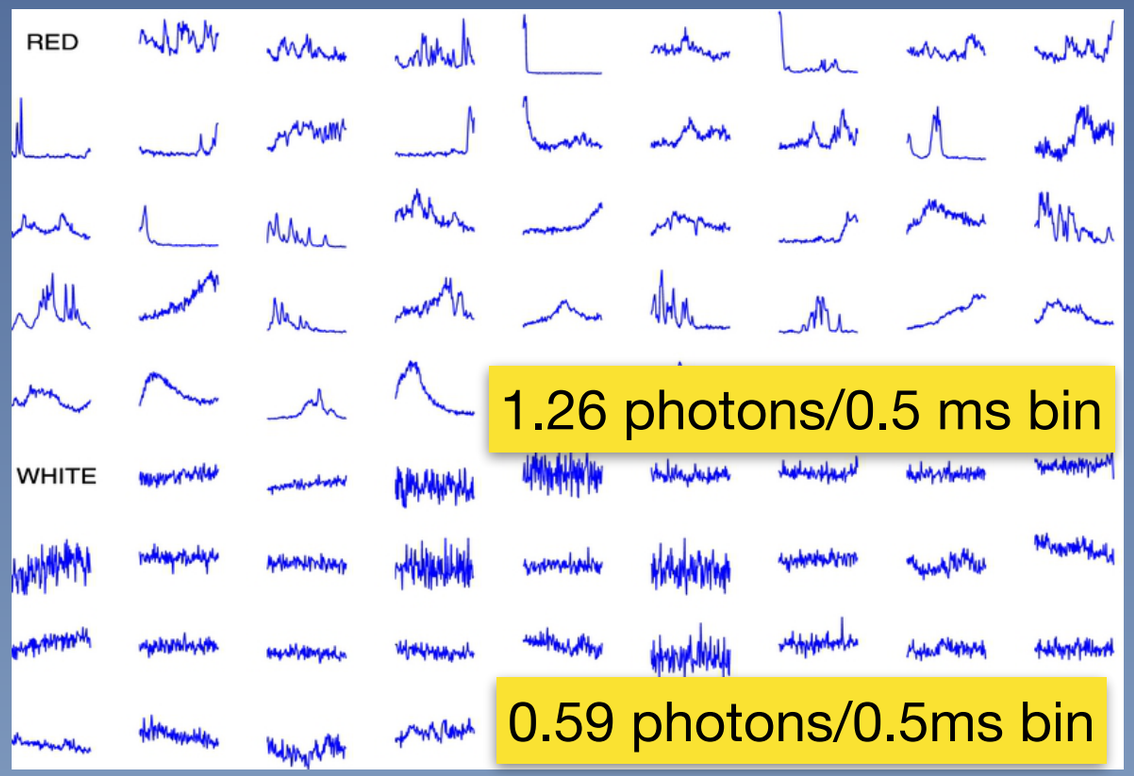
Search by butterfly filtering

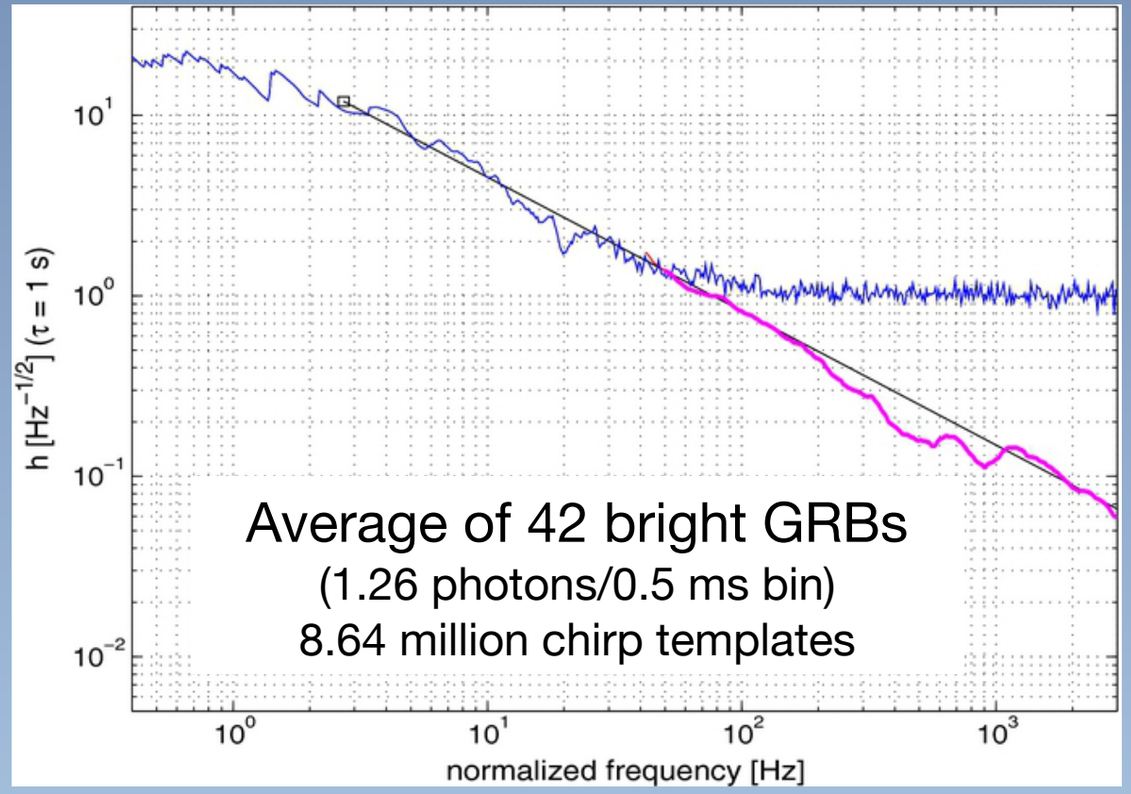
$$\left| df(t)/dt \right| \geq \delta > 0$$



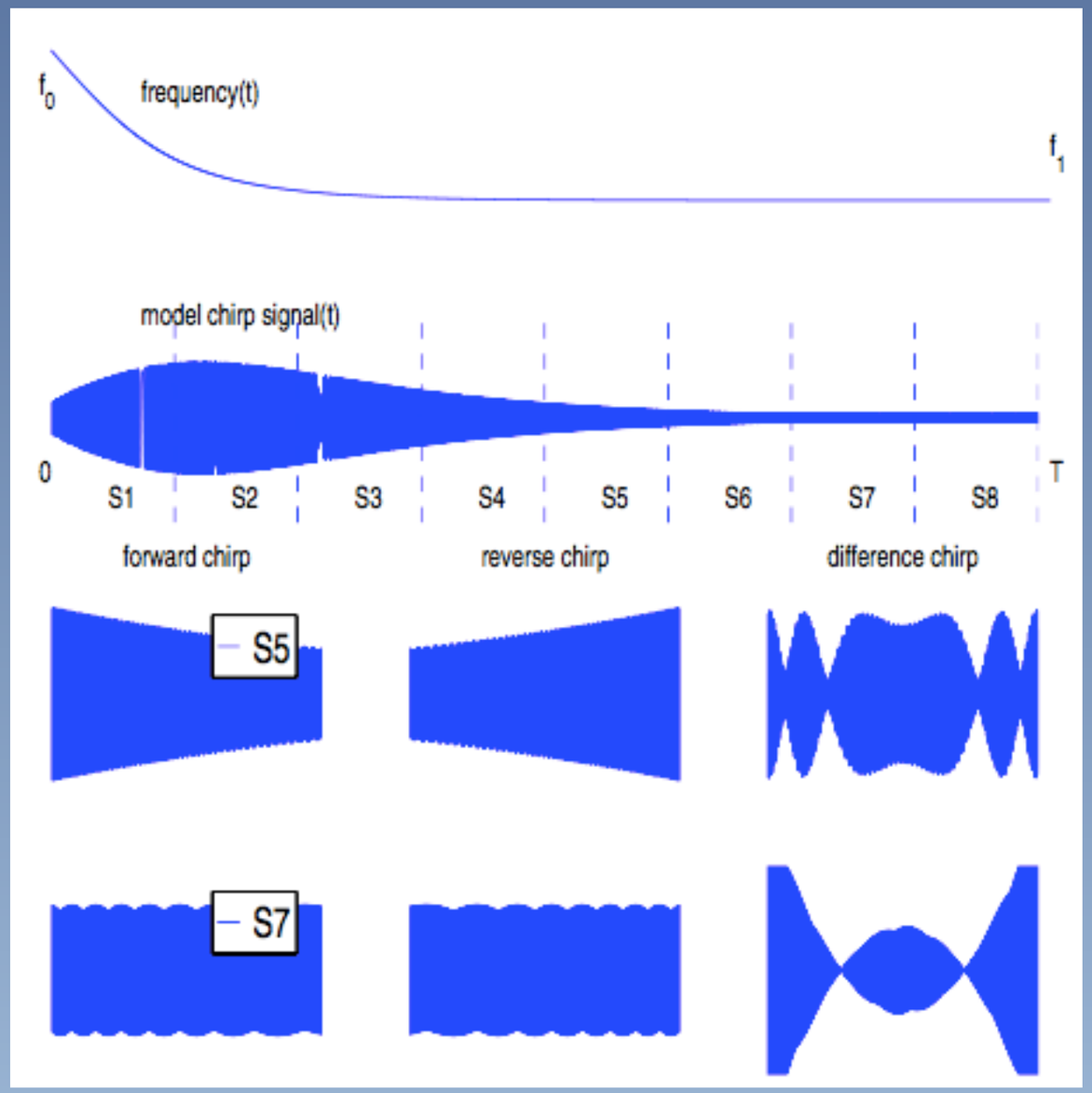
(van Putten, 2016, ApJ, 819, 169)

Application to BeppoSAX



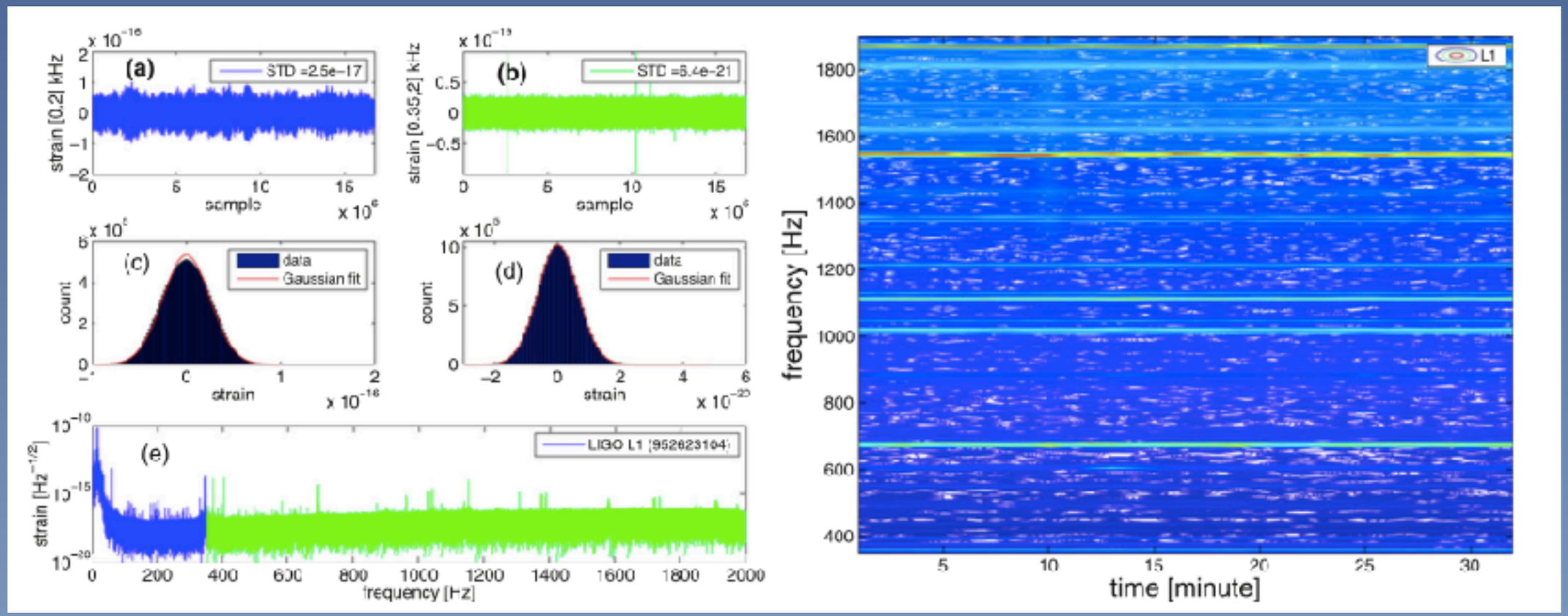


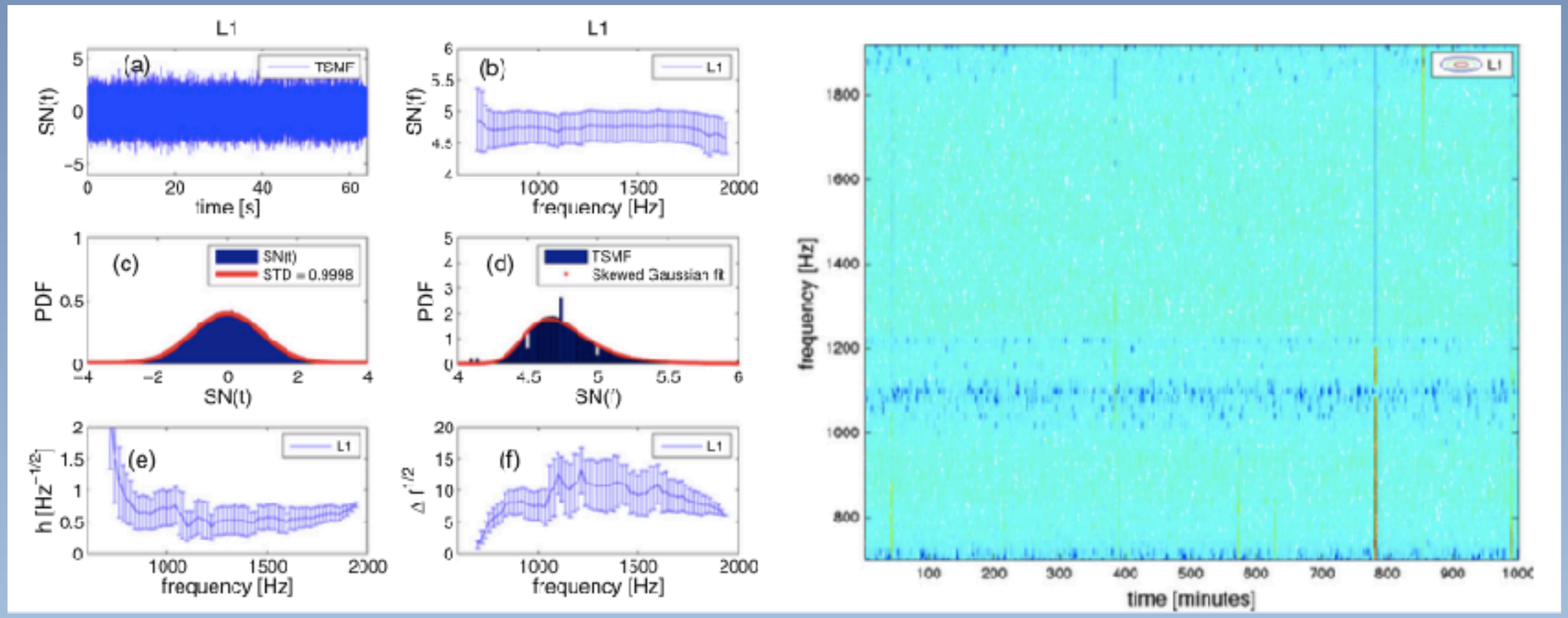
1 s chirp templates



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

Application to LIGO S6: nearly Gaussian (> 350 Hz)



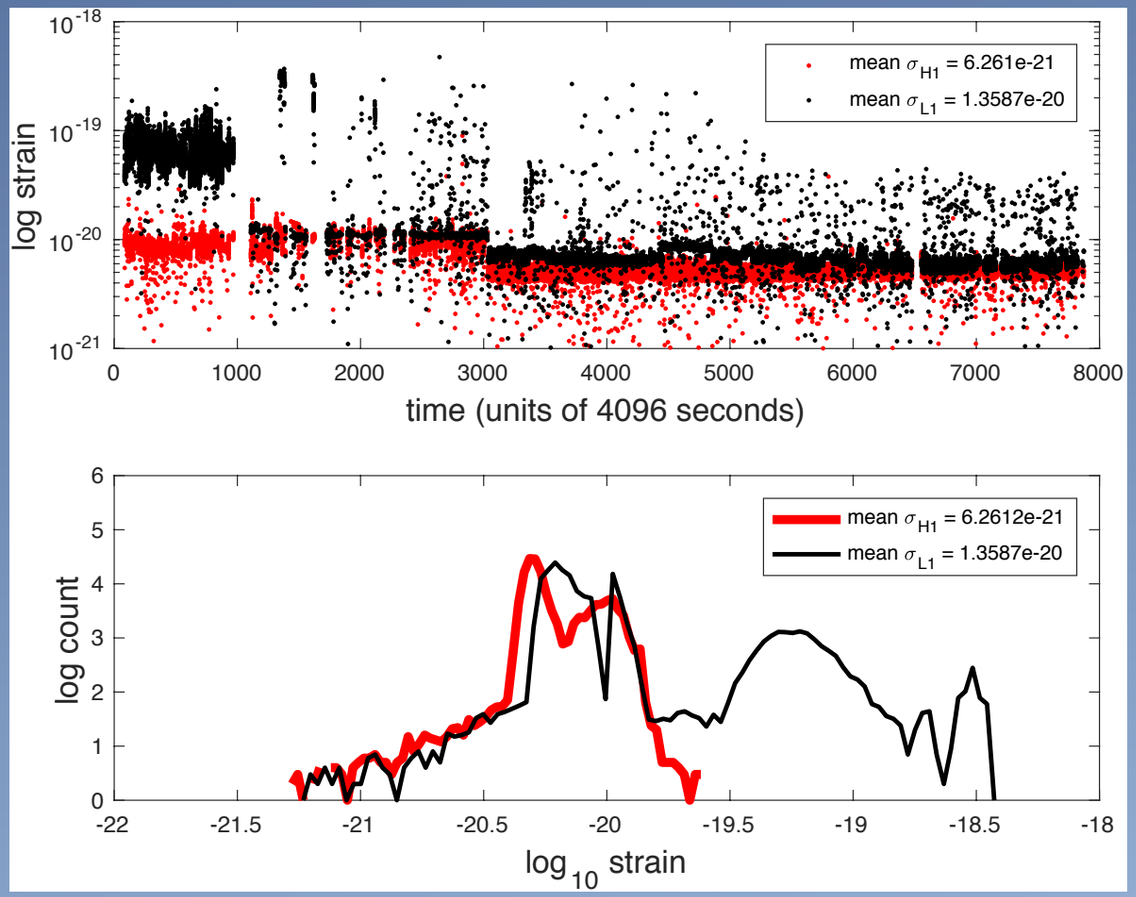


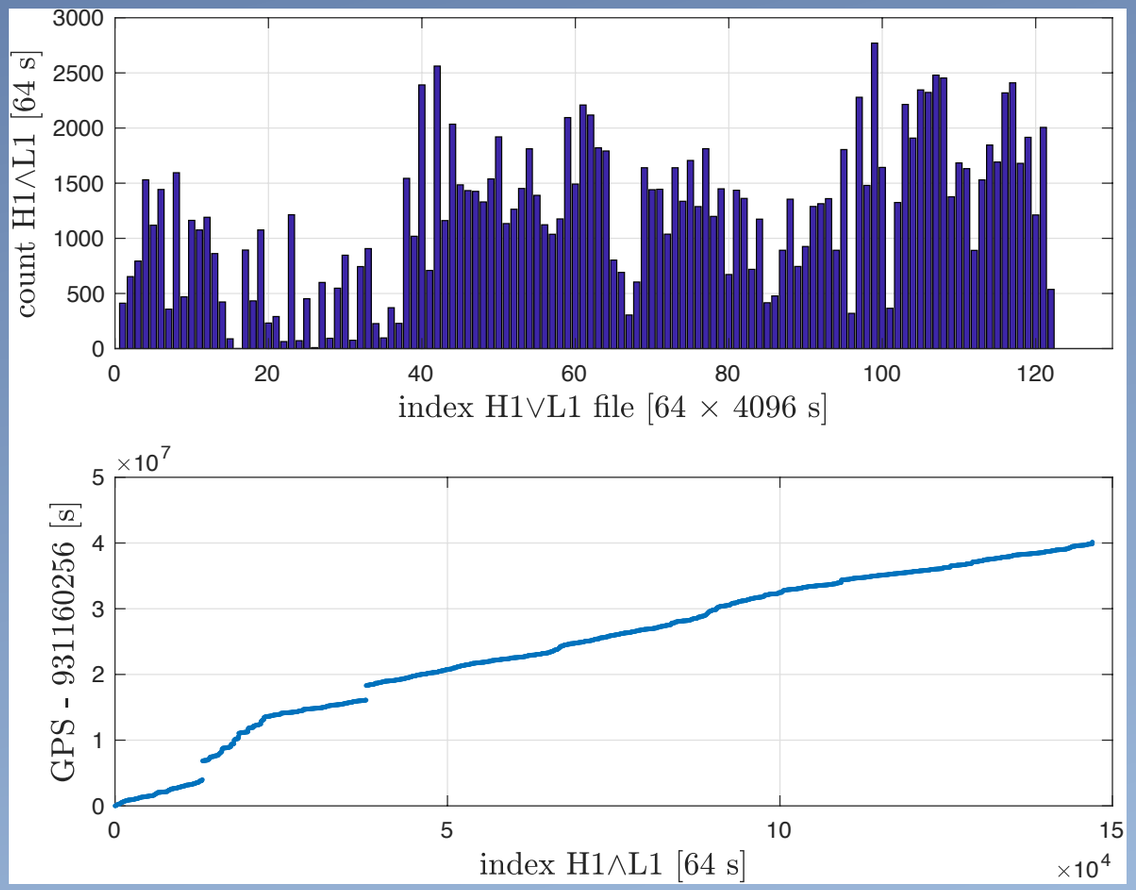
(van Putten, 2016, ApJ, 819, 169

Deep searches: the need for speed

Overview of LIGO S6

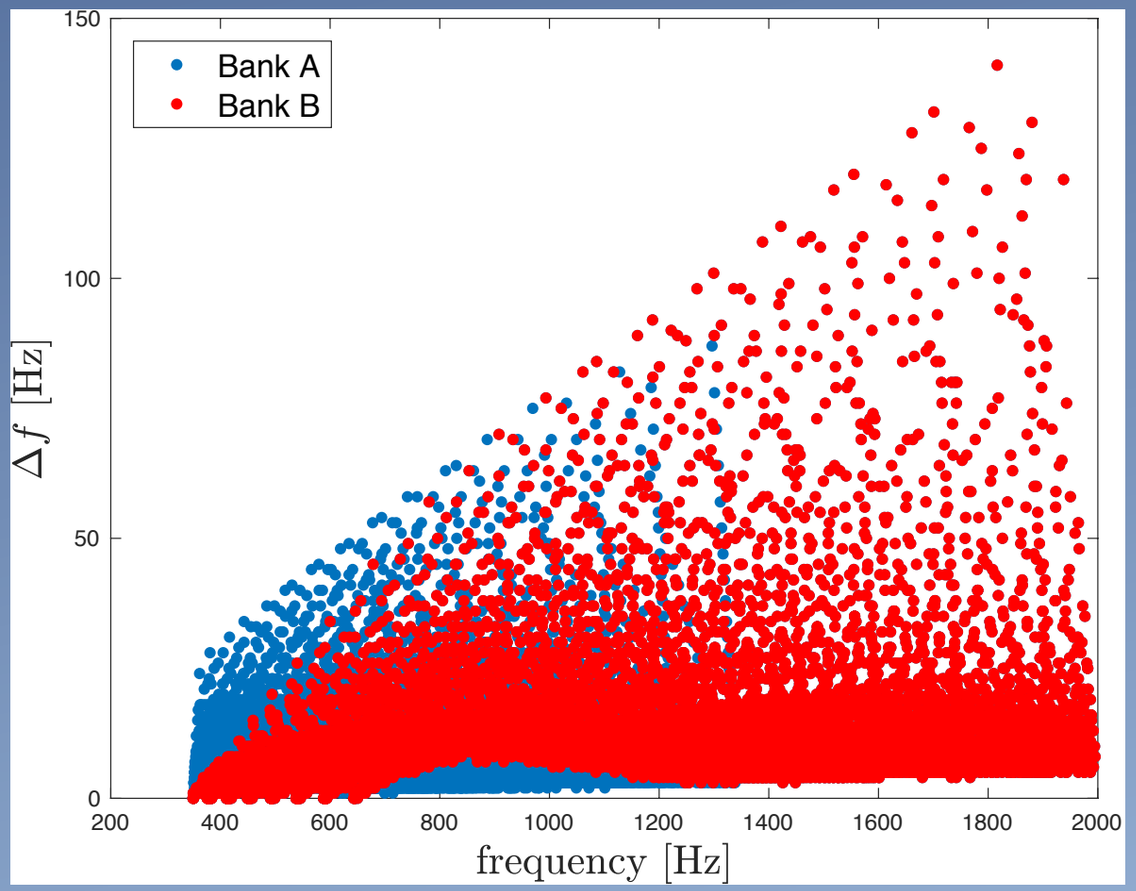
147,000 64 s segments H1 & L1 (29.4%)

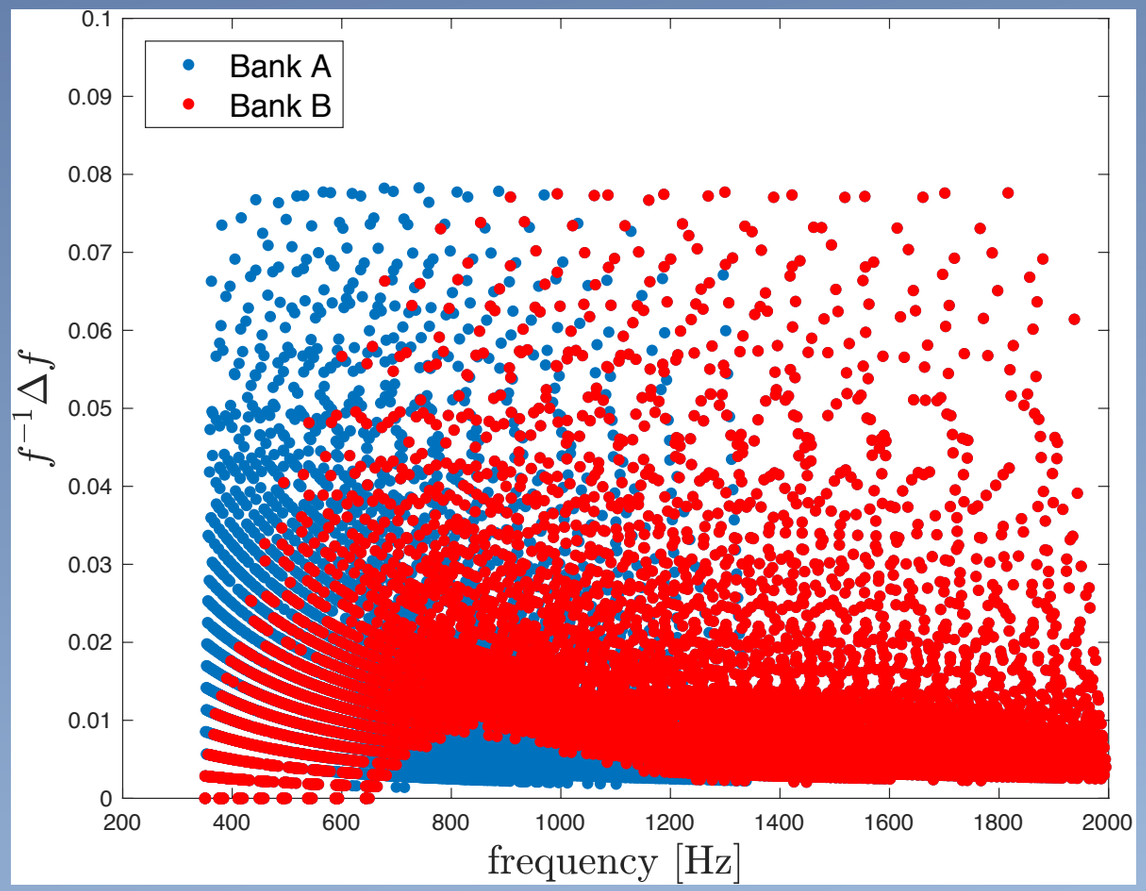




Template banks

Chirp templates



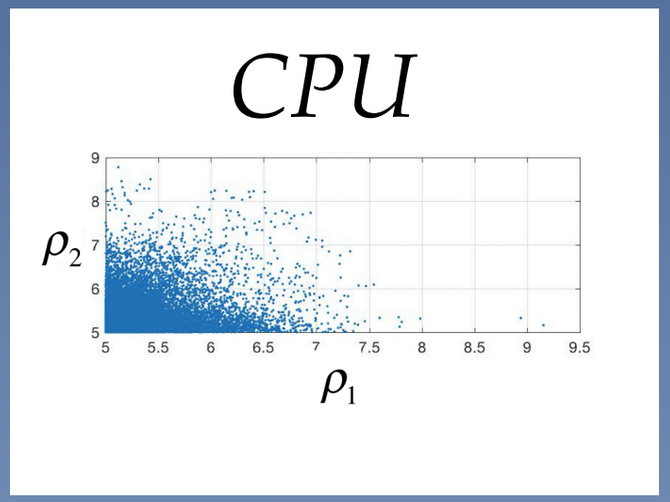


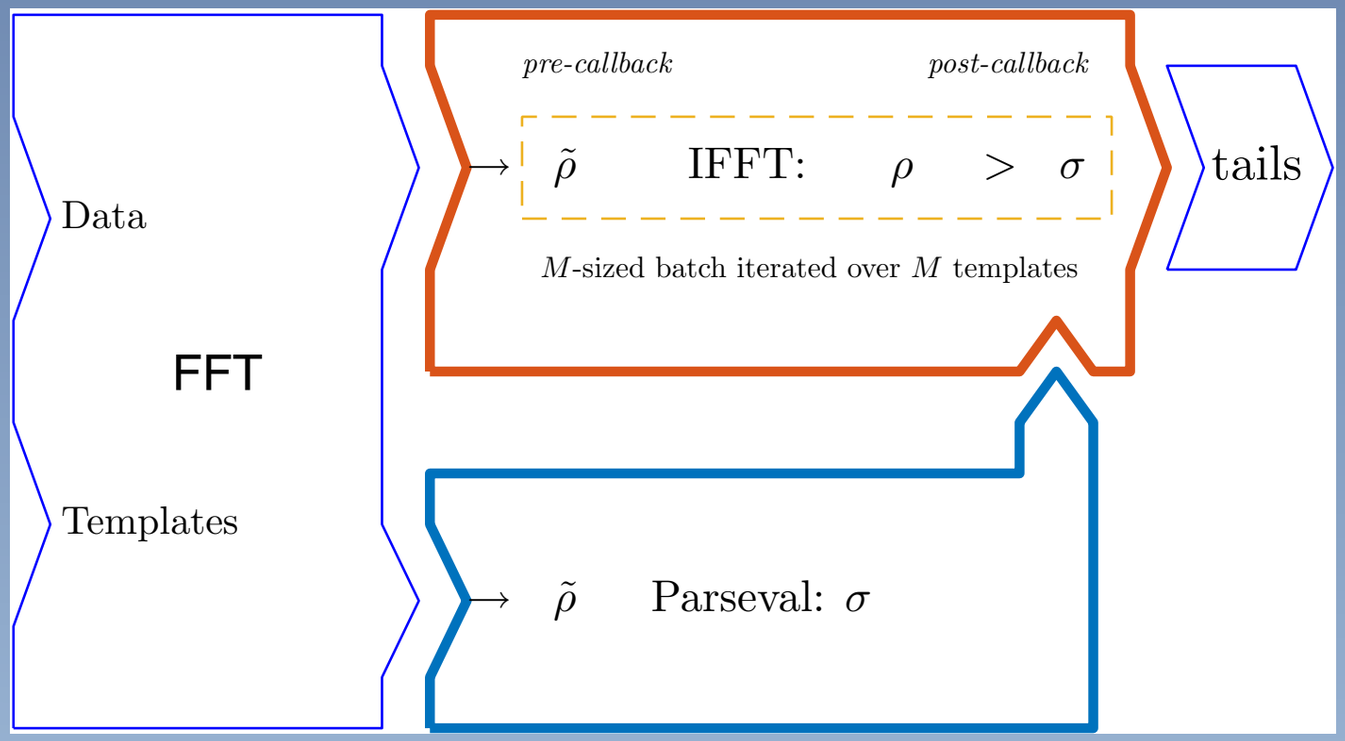
(van Putten, 2017, PTEP, 093F01)

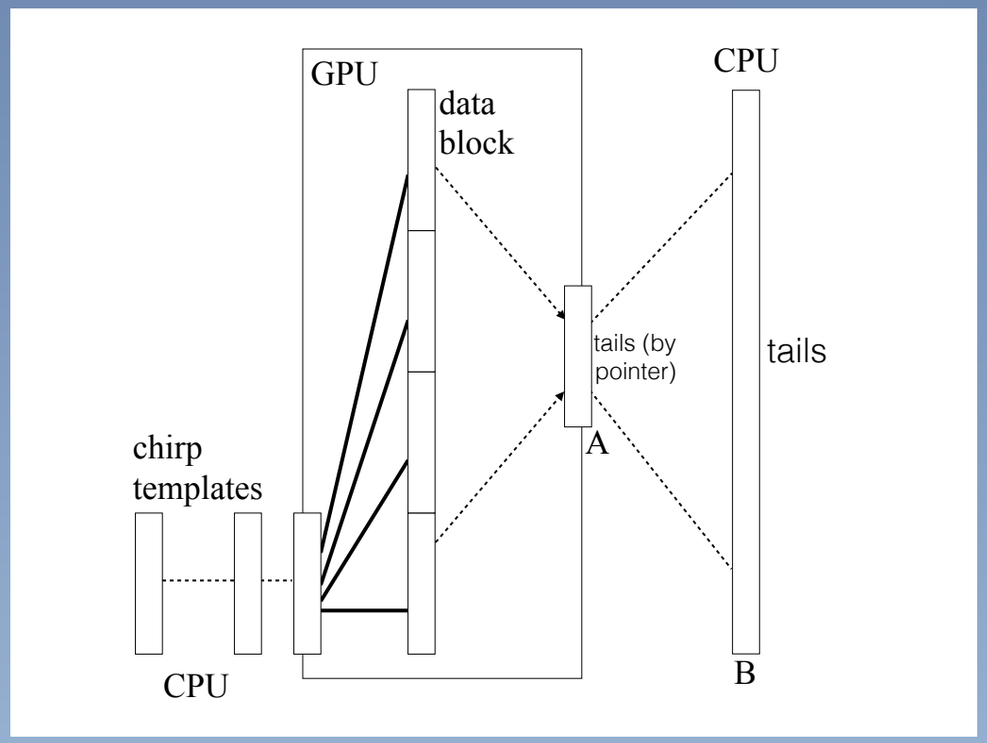
Exploiting near-Gaussian noise by Parseval's Th^m

Reduce GPU-output by

$$\mathrm{erfc}\left(\frac{\kappa}{\sqrt{2}}\right) \quad (\kappa \sim 5)$$







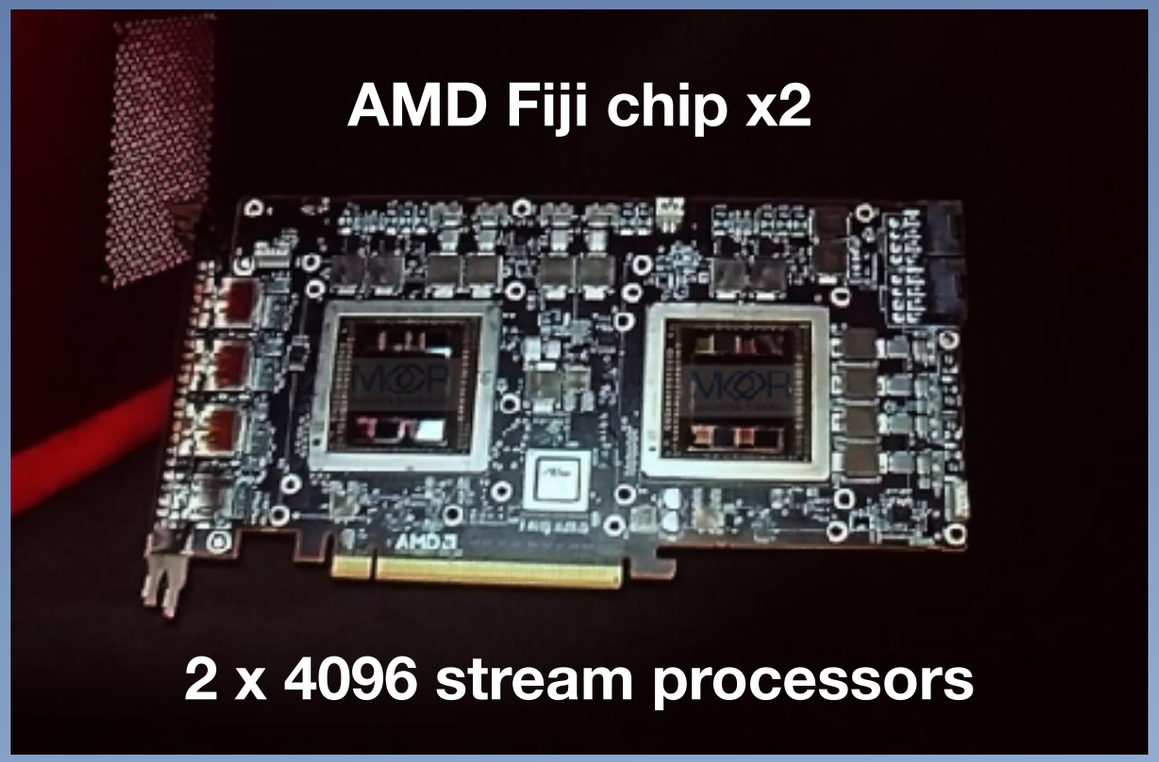
Tails of tens of kB/s down from tens of GB/s

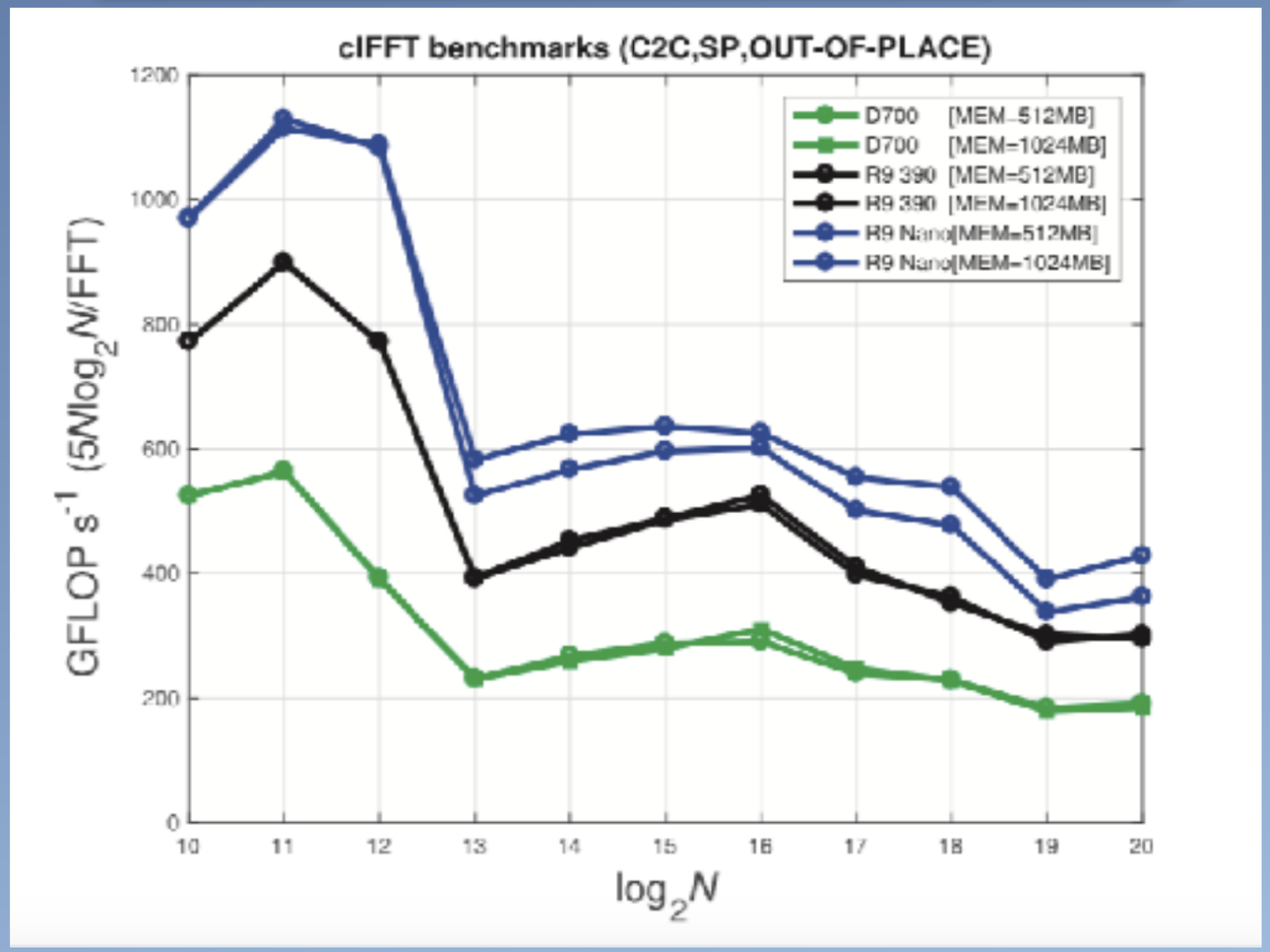
(van Putten, 2017, PTEP, 093F01)

Performance on GPUs with HBM2

~ 100,000 s^{-1} FFT(N=2^{16}) per Fiji chip

Cheaper, greener and faster than CPUs

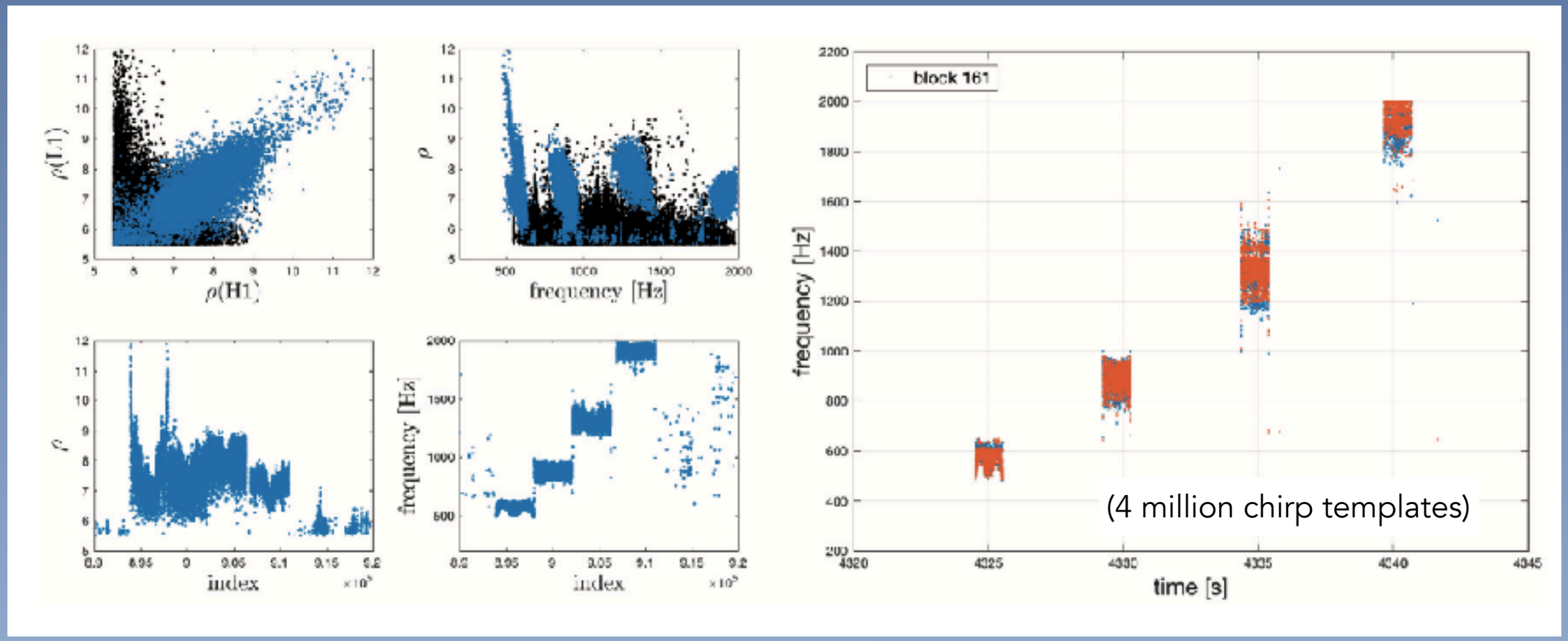




~ 1 million 16 s data correlations s^{-1} on one dozen Fiji chips

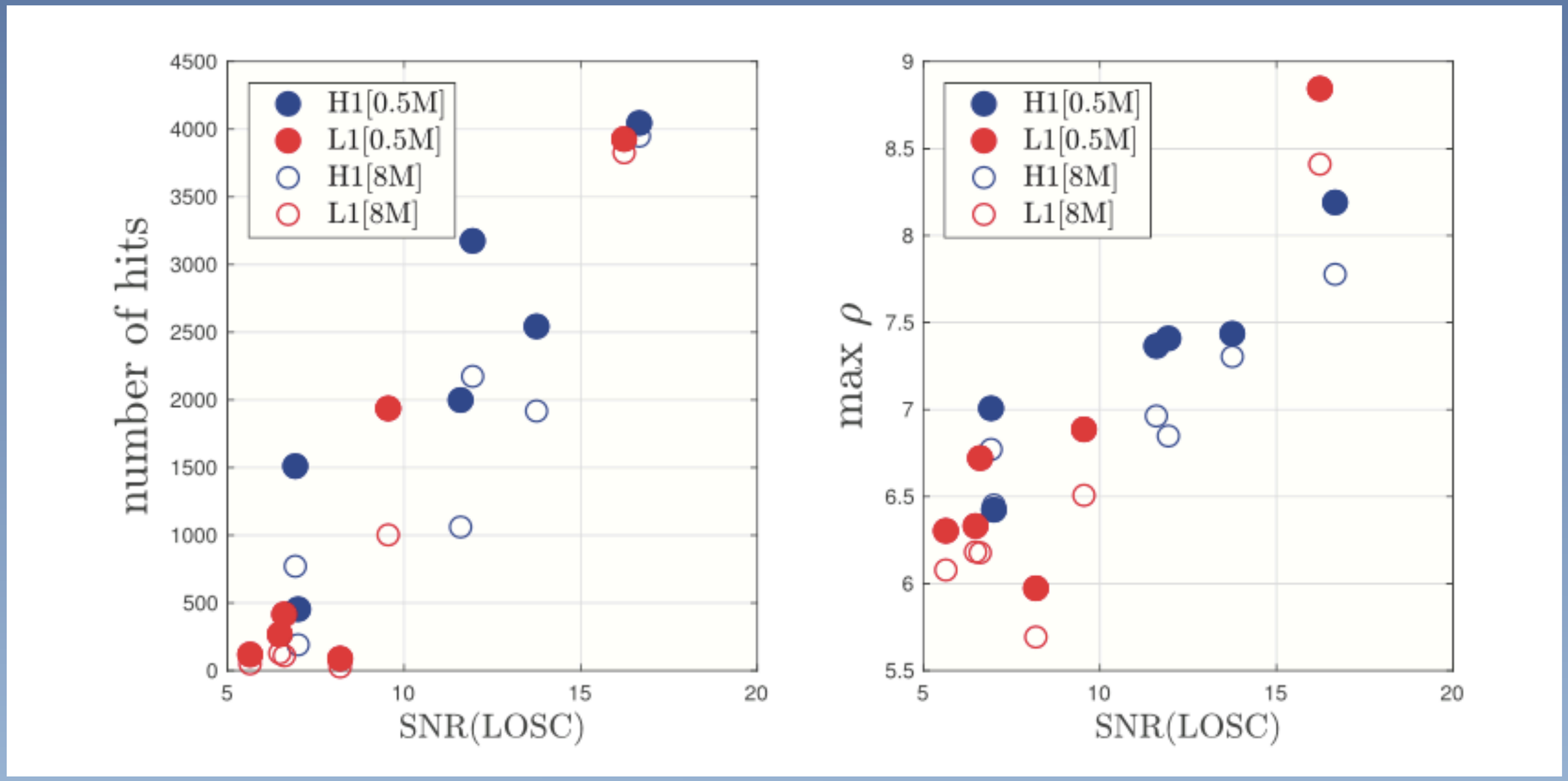
(van Putten, 2017, PTEP, 093F01)

Validation on LIGO Injections



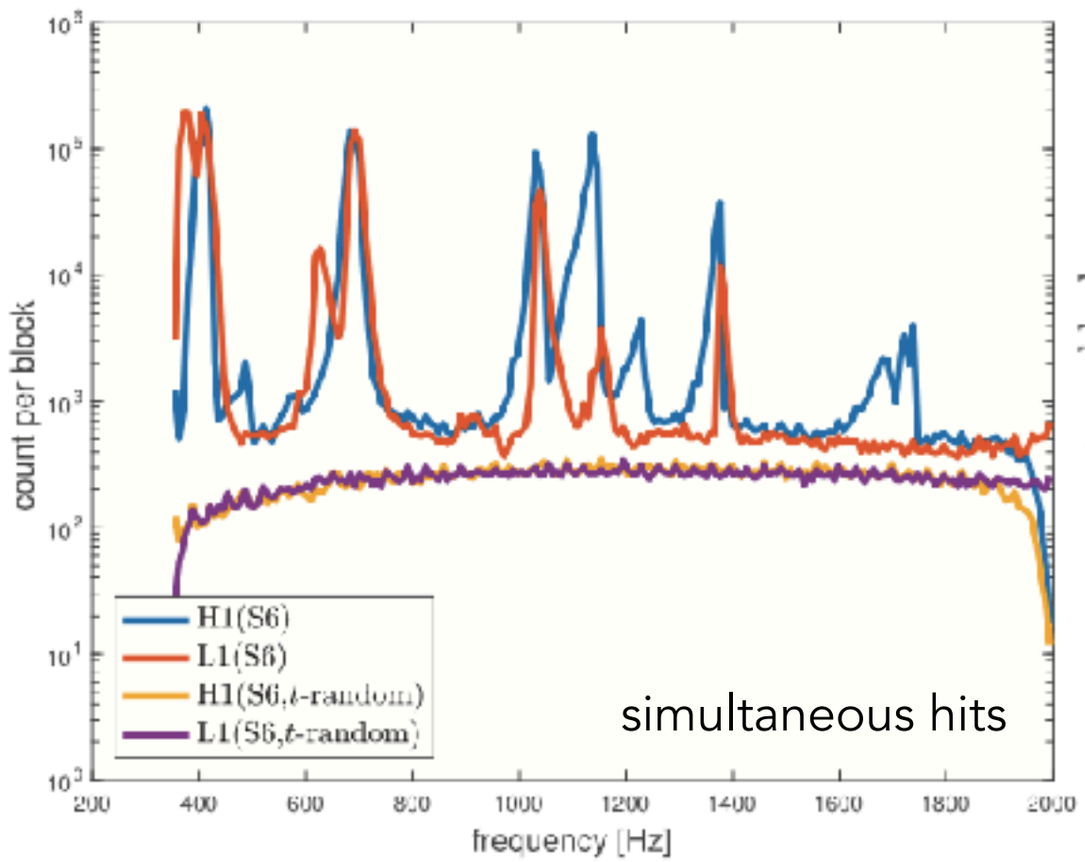
(van Putten, 2017, PTEP, 093F01)

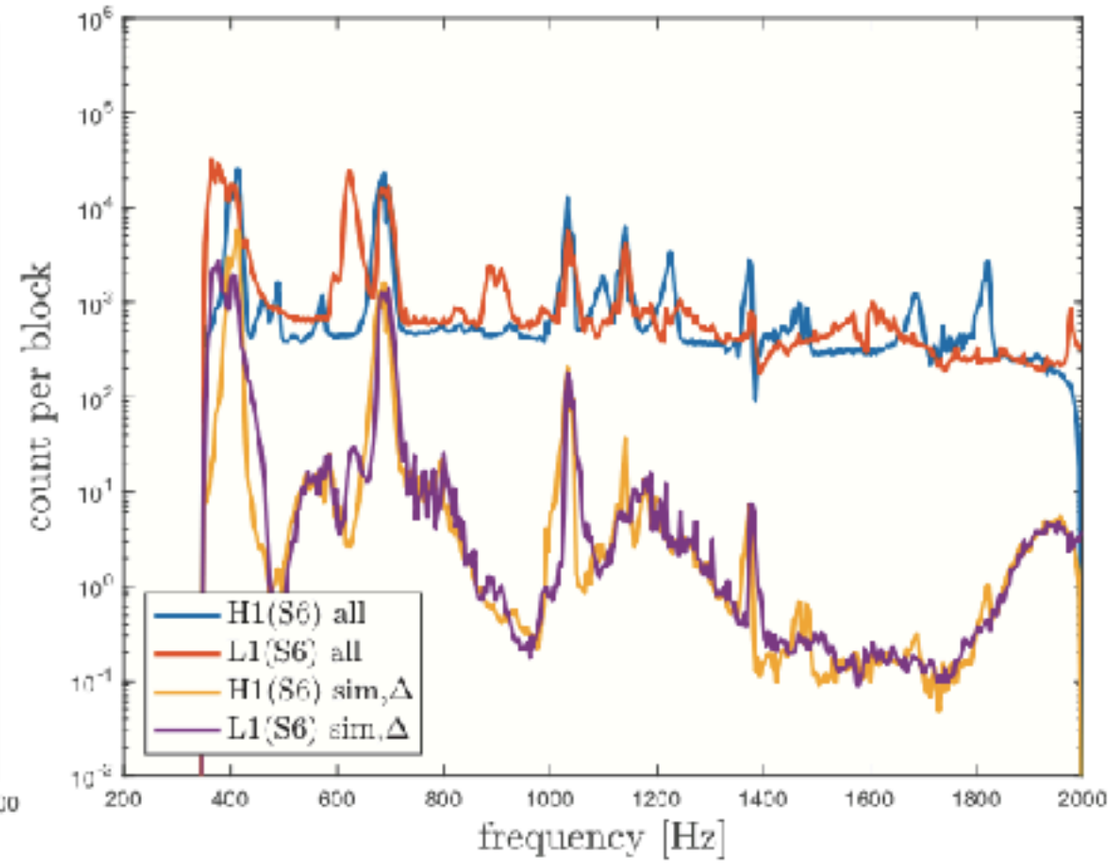
Sensitivity on LIGO Injections



(van Putten, 2017, PTEP, 093F01)

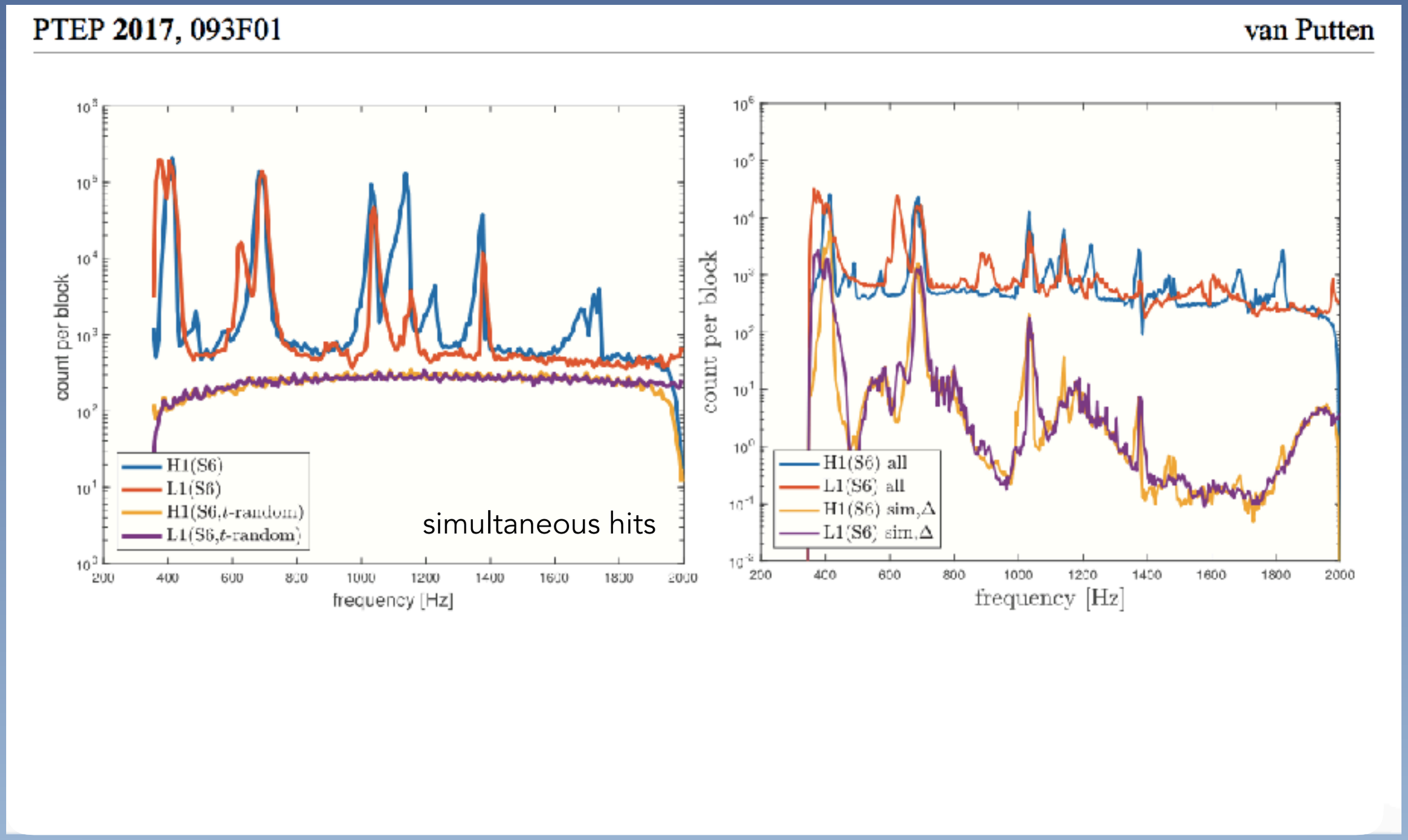
Analysing H1 & L1





(van Putten, 2017, PTEP, 093F01)

Results (I)



(van Putten, 2017, PTEP, 093F01)

Results (II)

$$\mathrm{EPR} \equiv \frac{p_{12}}{p_1 p_2} = 5.11 \pm 0.0268$$

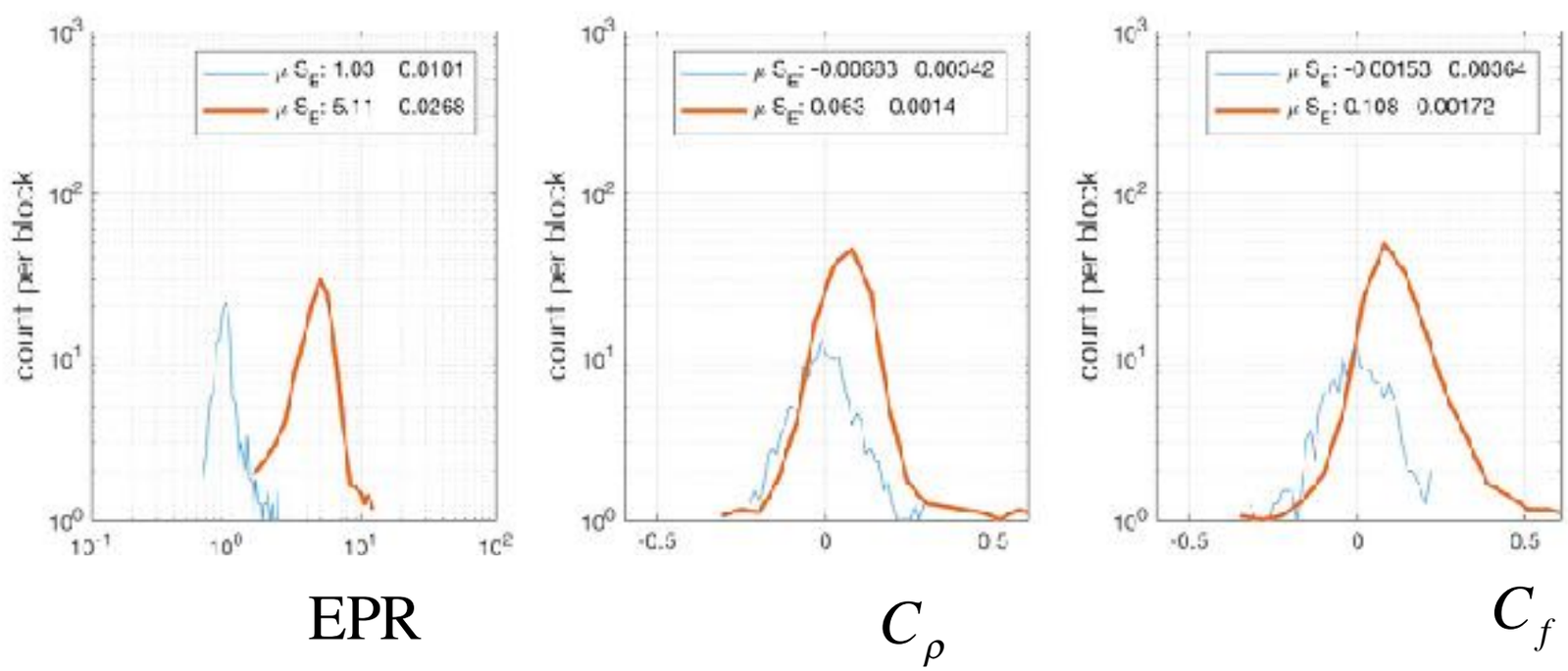
"excess probability ratio"

$$C_\rho = 0.0630 \pm 00014$$

"loudness"

$$C_f = 0.1008 \pm 0.0017$$

"pitch"



van Putten, Levinson, Frontera, Guidorzi, Amati & Della Valle, 2017, arXiv:1709.04455

Conclusions

- *Emerging global network of GW-detectors* will allow for deep probes of enigmatic events, e.g., LGRBs and CC-SNe
- *GPU-accelerated butterfly filtering* enables deep searches at over 1 million correlations per second.
- *Discovery power* demonstrated by identification of broadband Kolmogorov spectrum in BeppoSAX (1.26 photons per 0.5 ms bin) and 511% correlation in LIGO H1L1 (unknown origin).

Outlook - specific questions

- *GW170817: accompanied by Extended Emission in GWs ~ 2500 Hz? (3 MSolar BH losing angular momentum against 1% disk at ISCO.)*
- *Origin of H1L1 correlations in S6?*
- *What are the correlations of LIGO with Virgo in O2? And KAGRA?*