Stacking Gravitational Waves from Soft Gamma Repeater Bursts

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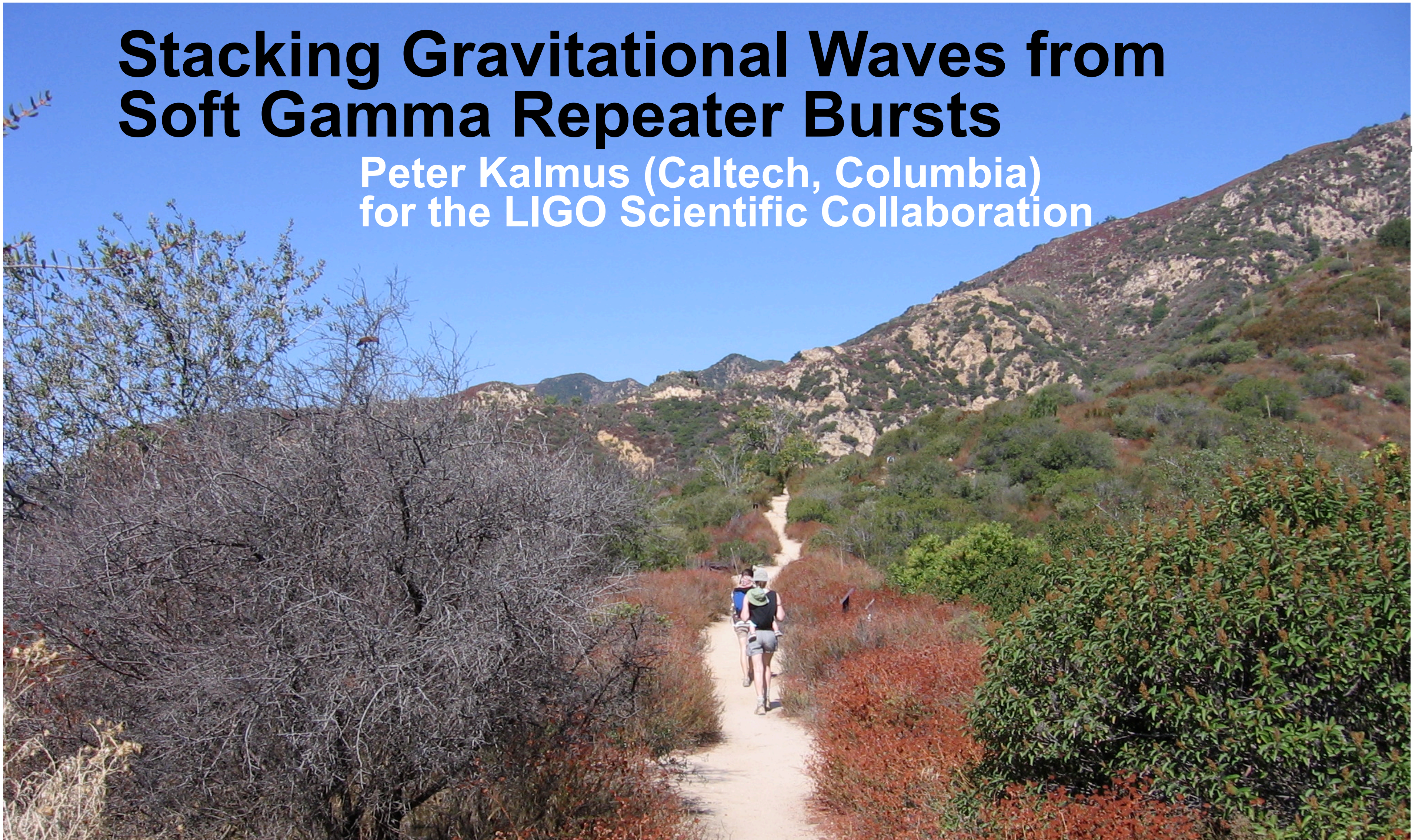
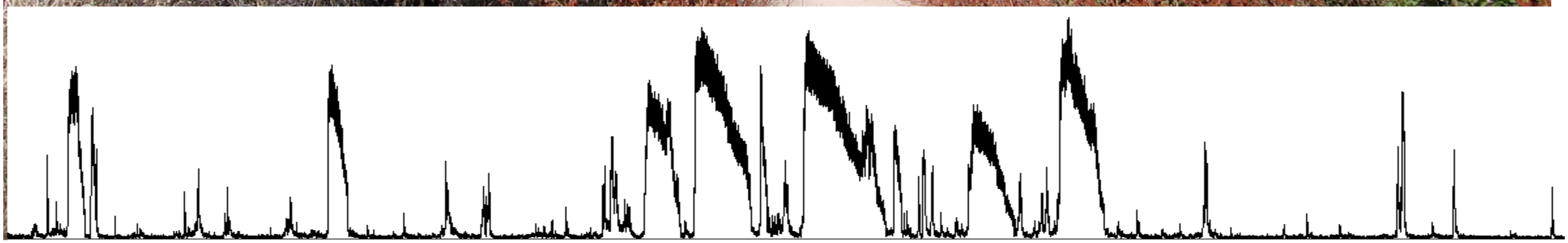
for the LIGO Scientific Collaboration

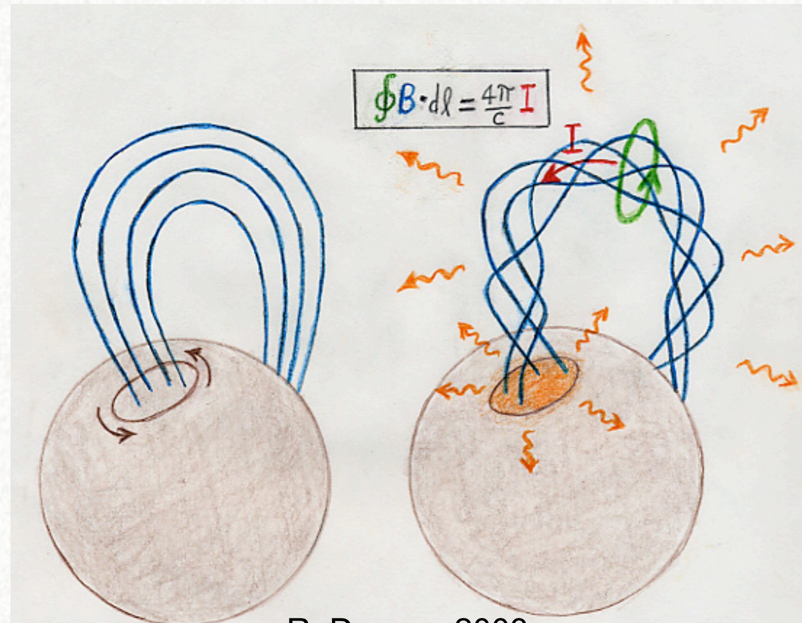




Soft Gamma Repeaters

Burst emission
- Typical bursts: ~100 ms, ~10^{42} erg/s peak [1]
- Rare giant flares have tails, peak up to10^{47} erg/s

Magnetar model
- Neutron stars with B ~10^{15} G [2]
- **Bursts: crustal cracking** [3]
- Possible excitation of f-modes



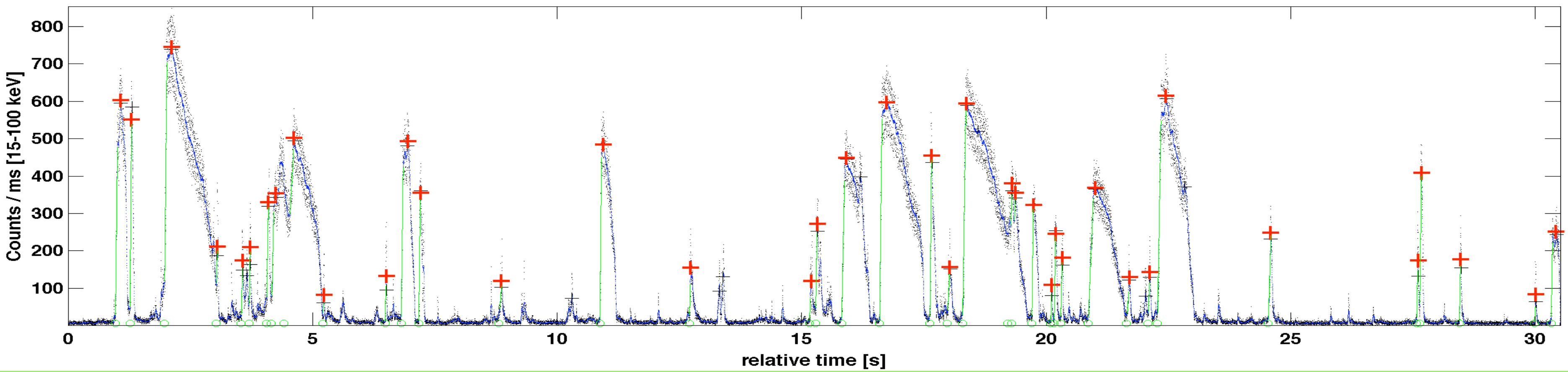
R. Duncan 2003

Search targets:
- **Ringdowns 1– 3 kHz tau=200 ms [4]**
- **WNB below 1 kHz, 11 ms and 100 ms**

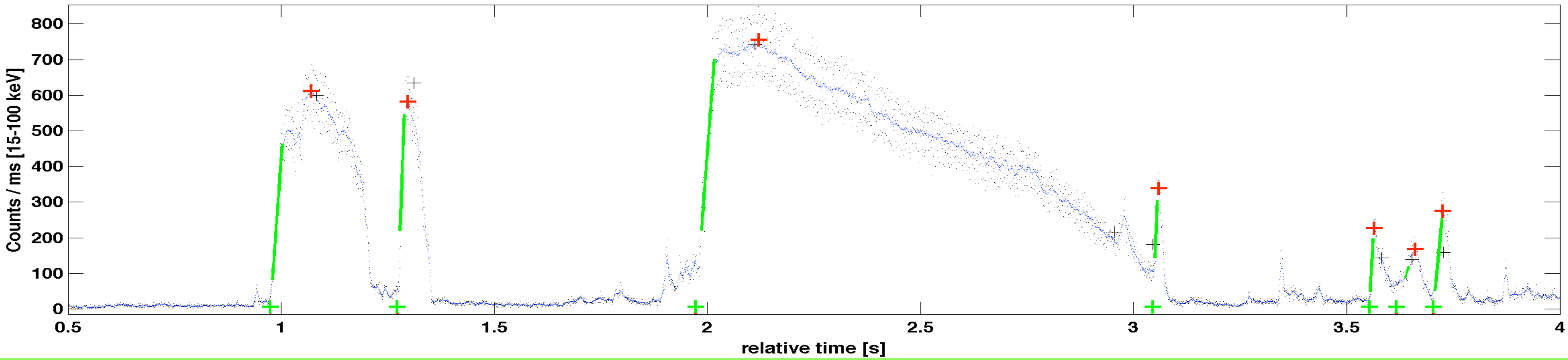
[1] Woods P M and Thompson C 2004 *Compact Stellar X-Ray Sources (*Cambridge University Press)
[2] Duncan R C and Thompson C 1992 Astrophys. J. Lett. 392 L9-L13
[3] Palmer D M et al. 2005 Nature 434 1107-1109
[4] O. Benhar, V. Ferrari, and L. Gualtieri, Phys. Rev. D 70,124015 (2004)

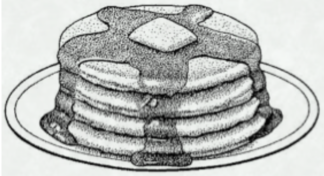
SGR 1900+14 Storm Light Curve

t=0 is 2006 March 29 02:53:09.9±0.5 s UT
all 3 LIGO detectors were taking science data



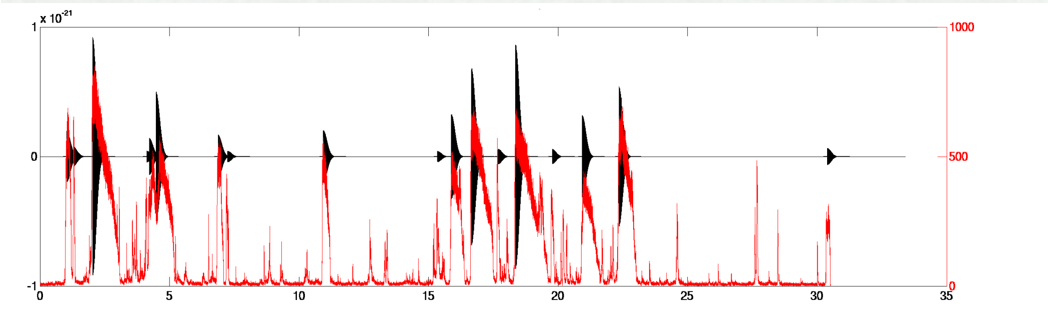
Swift/BAT public data





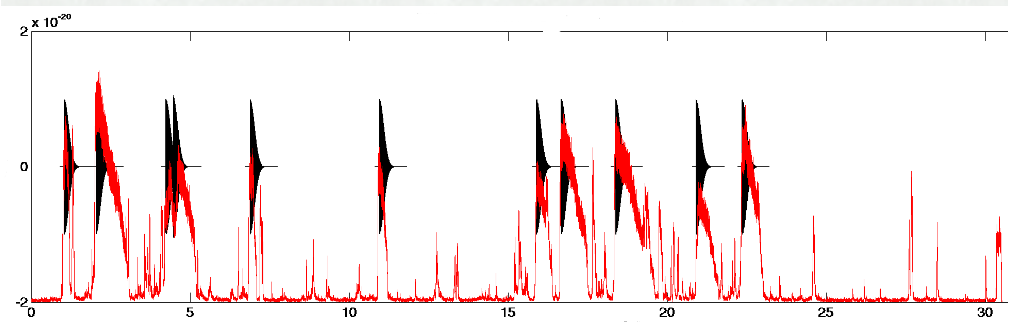
Stacking Models

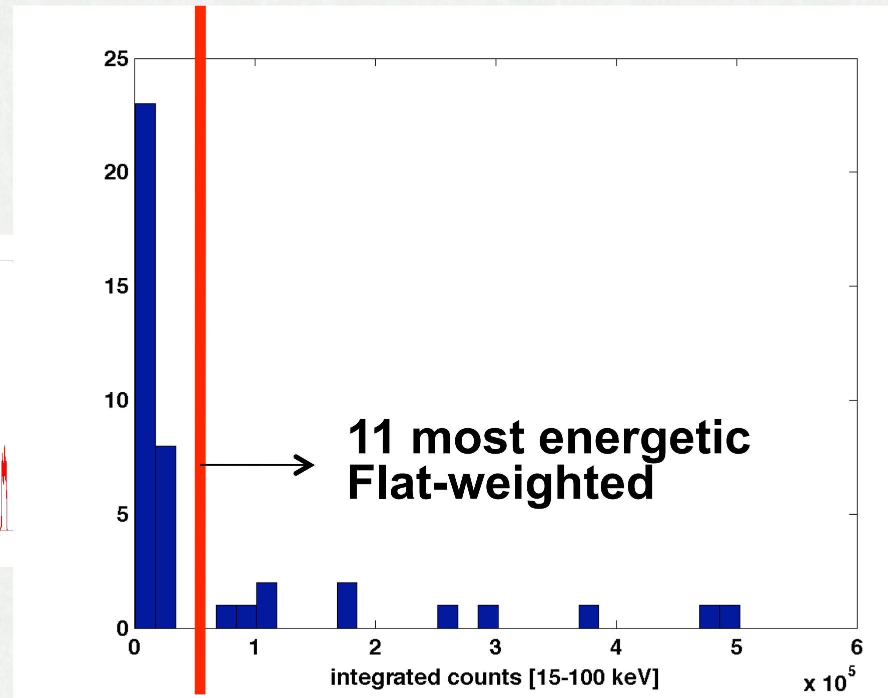
Model 1: Fluence-weighted (N=18)

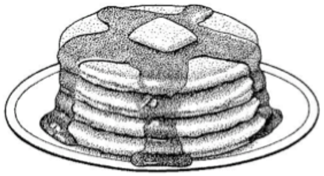


Assume GW—EM time offsets are nearly the same for each burst

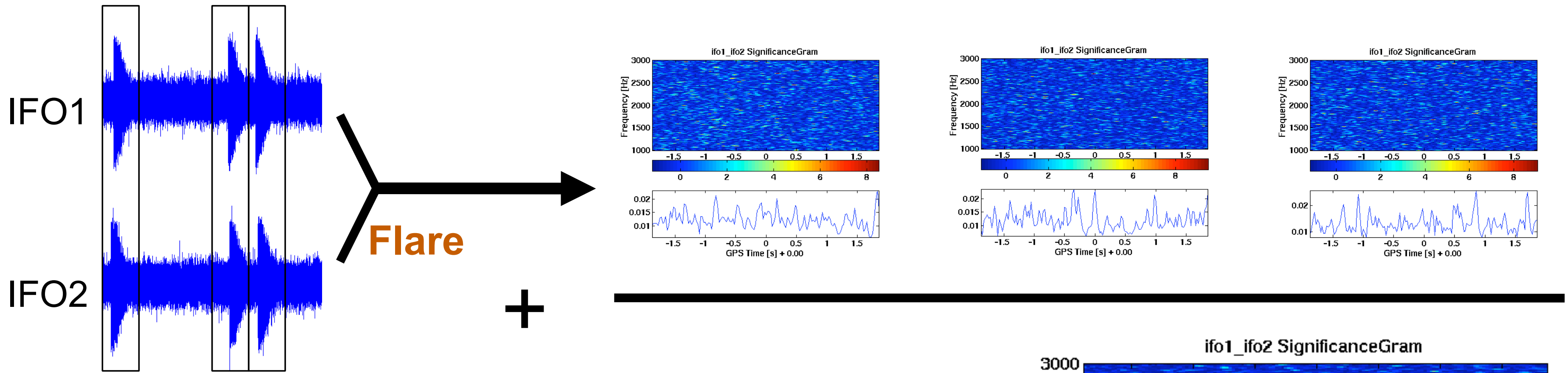
Model 2: Flat-weighted (N=11)

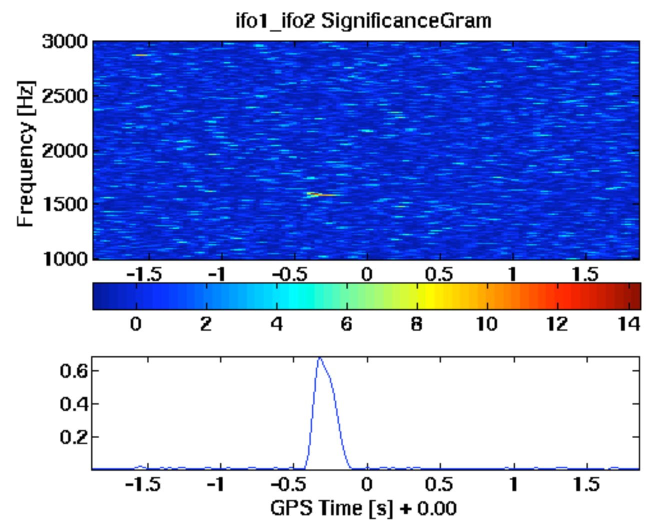






Stack-a-flare Pipeline



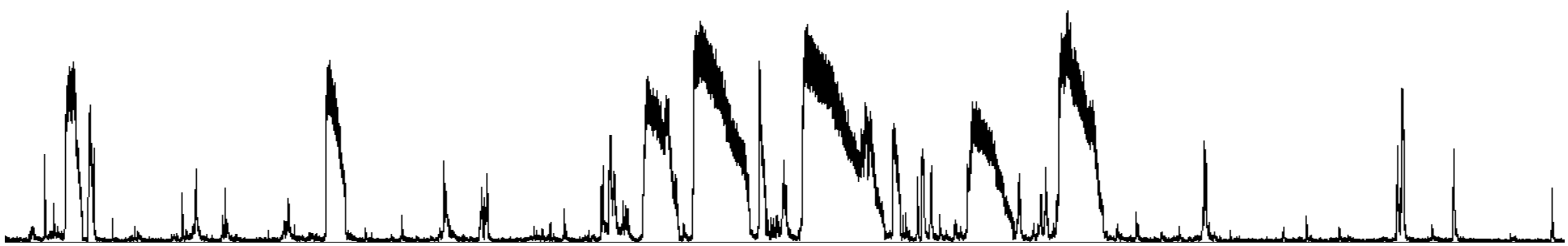


1. Apply Flare pipeline N times at EM burst times
2. Weighted sum of **power significance** tilings

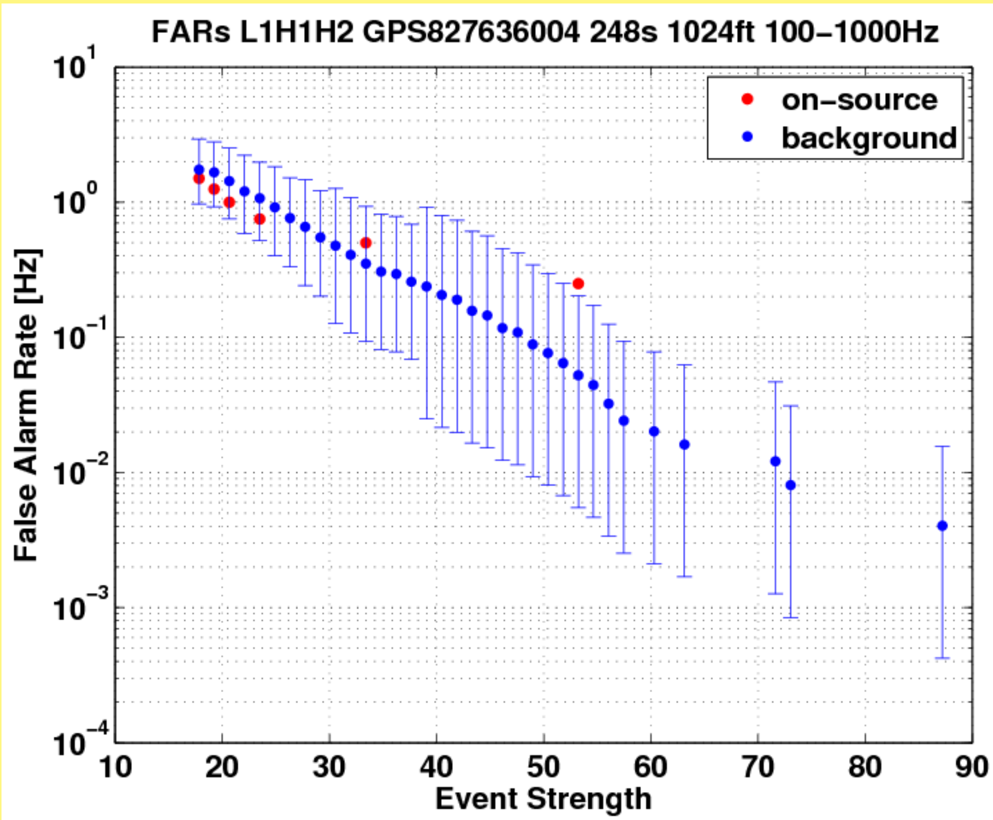
$N^{1/2}$ energy sensitivity gains in white noise

Robust to burst time uncertainties

Apply to one- or two-detector networks



No Detection



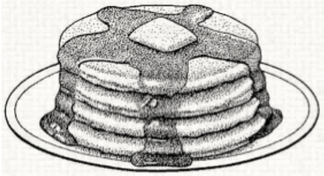
Chance of detection depends on:
our detectors; nature; and…
the right stacking model.

±2 s stacked on-source regions

2 models, 3 frequency bands

Most significant on-source event:
5.0×10^{-2} Hz (1 per 20 s)
Flat model, 100-1000 Hz band

no.	Loudness	FAR	T	DT	F	DF	N
1	5.36e+01	5.01e-02	1.236	0.174	324.9	48.0	13
2	3.34e+01	3.53e-01	0.860	0.187	977.8	48.0	9
3	2.36e+01	1.06e+00	-1.226	0.025	818.7	16.0	6
. . .							



Model-dependent Upper Limits

Model 1: Flat, N=11

E_{GW} of single injection

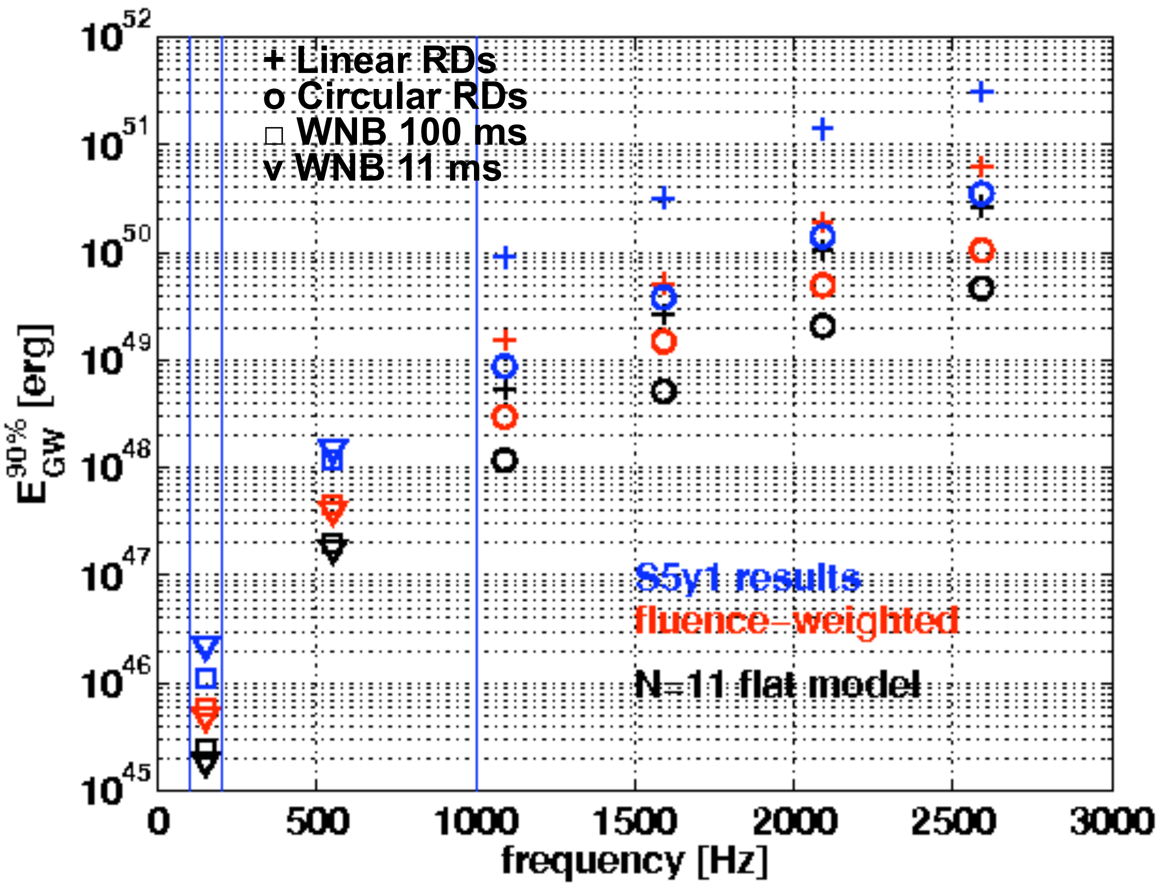
Gain over N=1

Expected: $11^{1/2} = 3.3$

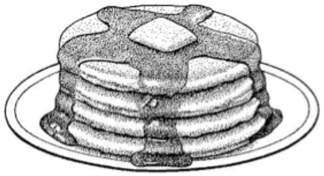
Observed: = 4.0 (mean)

Model 2: Fluence-weighted

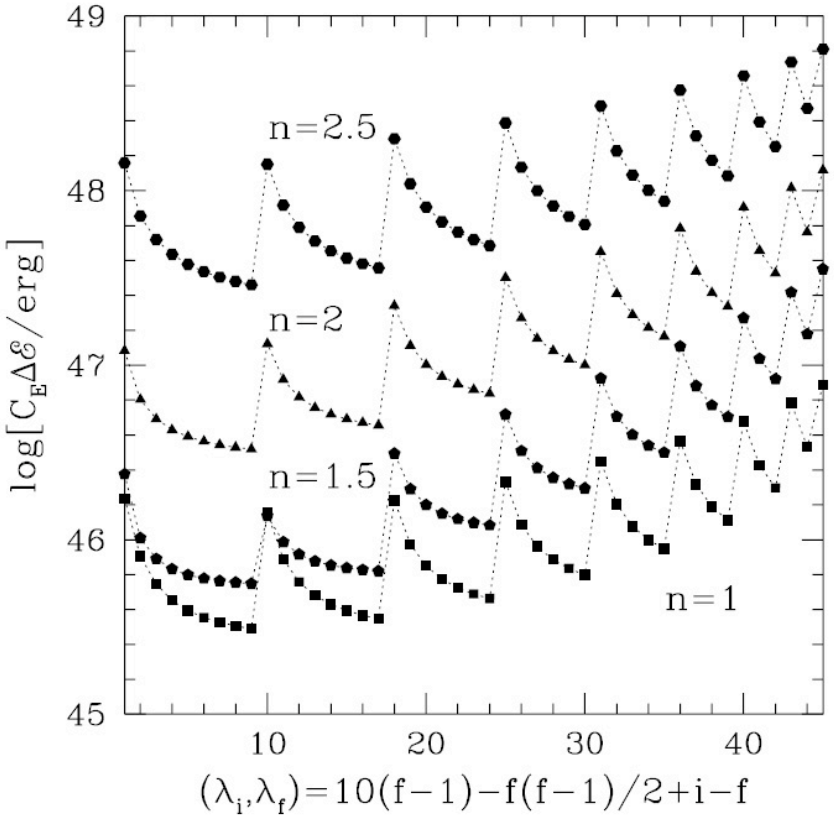
E_{GW} of largest injection



Isotropic GW energy at 10 kpc
90% detection efficiency



Conclusion



K. Ioka. MNRAS, 327:639–662, 2001.

Ioka's model still the most predictive

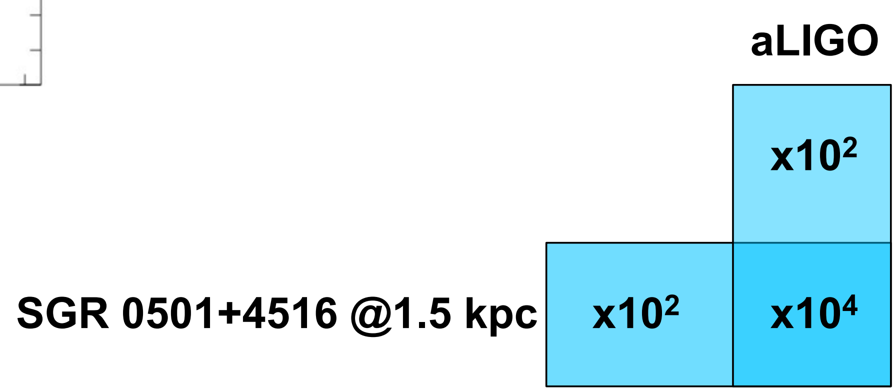
Stack E_{GW} limits dig further into his range

12x deeper than ±20 s S5y1 result

$\gamma \equiv E_{GW} / E_{EM}$

A3 giant flare range:	**$\gamma = 5\times10^{1} – 6\times10^{6}$**
S5 storm stack:	**$\gamma = 2\times10^{4} – 3\times10^{9}$**

Future stacking of storms & normal bursts:



reserve slides

S5y1 Individual SGR Burst Search

PRL 101, 211102 (2008)

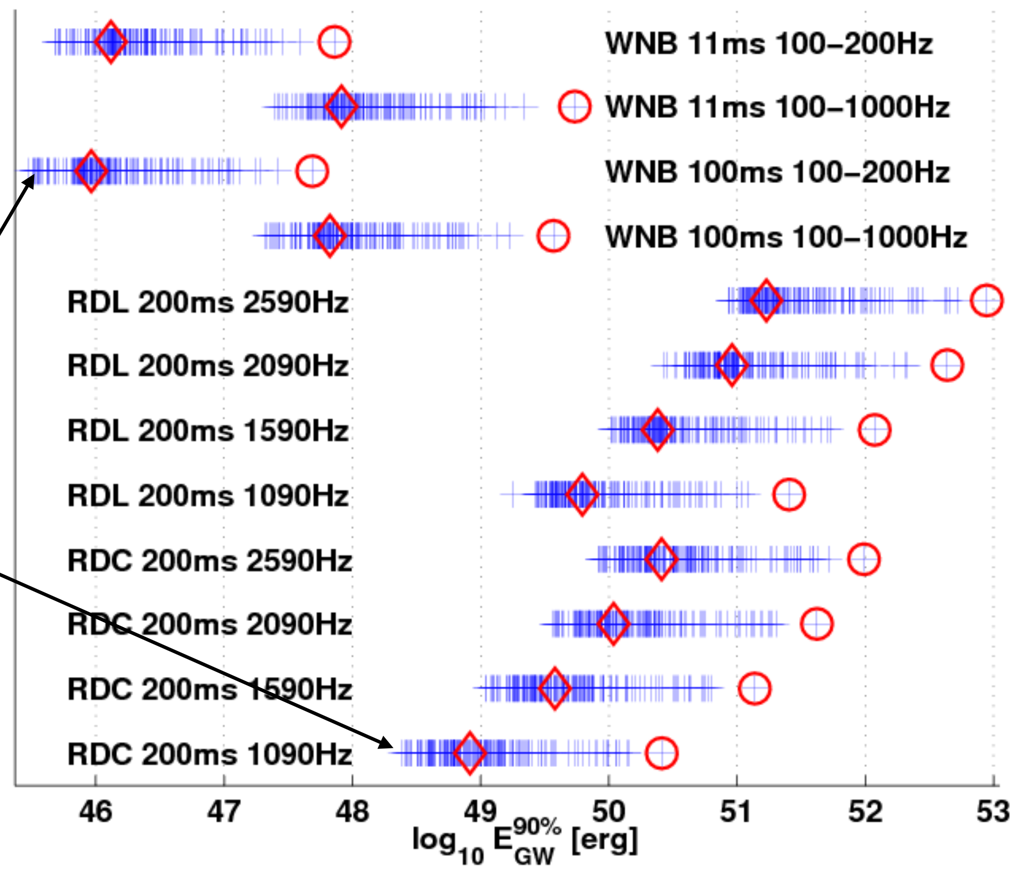
Sensitive to neutron star f-modes
LIGO S5 + A3
191 SGR events including:
- SGR 1806-20 giant flare
- SGR 1900+14 storm

2.9×10^{45} erg

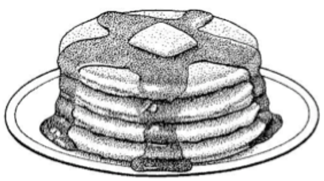
2.4×10^{48} erg

$\gamma \equiv E_{GW} / E_{EM}$
Lowest γ from giant flare
- γ=30, 100—200 Hz WNB
- $\gamma=2\times10^4$, 1090 Hz RDC

Ioka MNRAS 327, 639 (2001)
- Most detailed model
- $\gamma=10^4$ not unreasonable
- $E_{GW}=10^{49}$ erg not unreasonable



Isotropic GW emission upper limits at 10 kpc
Circles: Giant Flare
Diamonds: GRB 060806



Timing Uncertainty

Uncertainty estimated for each burst via linear fit of burst rising edge

Folded into Monte Carlo