Searching for Gravitational Waves from Soft Gamma Repeaters

Peter Kalmus (Caltech, Columbia)
for the LIGO Scientific Collaboration

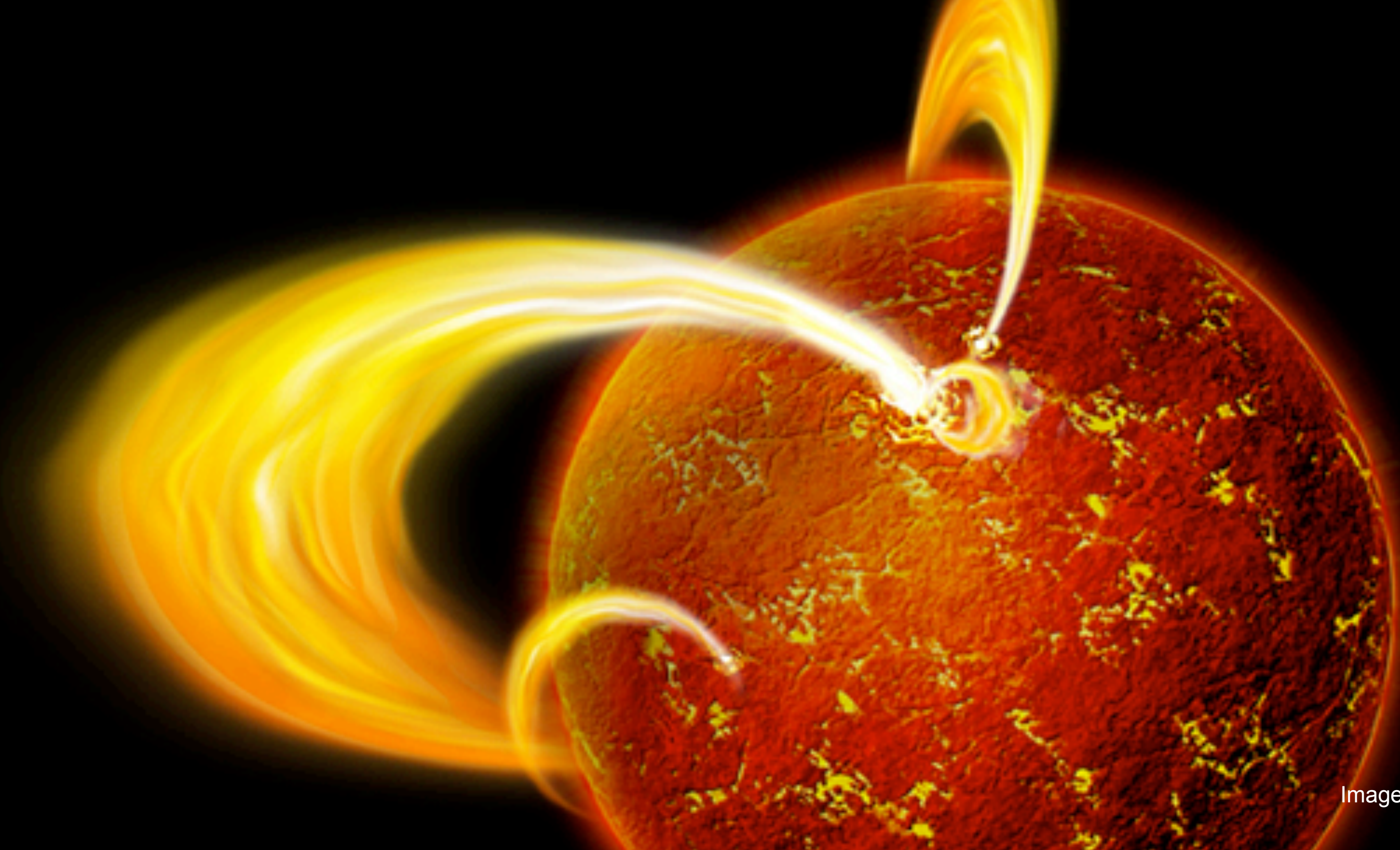
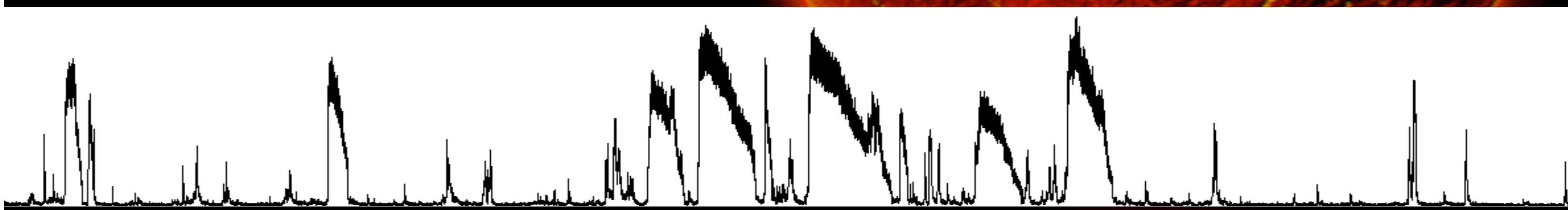


Image: NASA, CXC, M. Weiss



Outline of the Talk

1. Soft Gamma Repeaters (SGRs)
2. Individual SGR burst searches
3. Stacked SGR burst searches
4. Putting upper limits into context
5. Plans

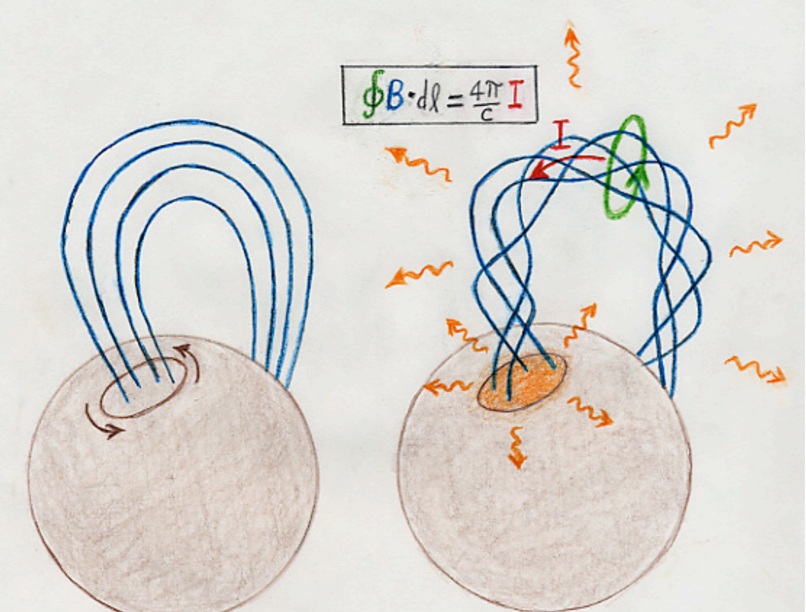
Soft Gamma Repeaters

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



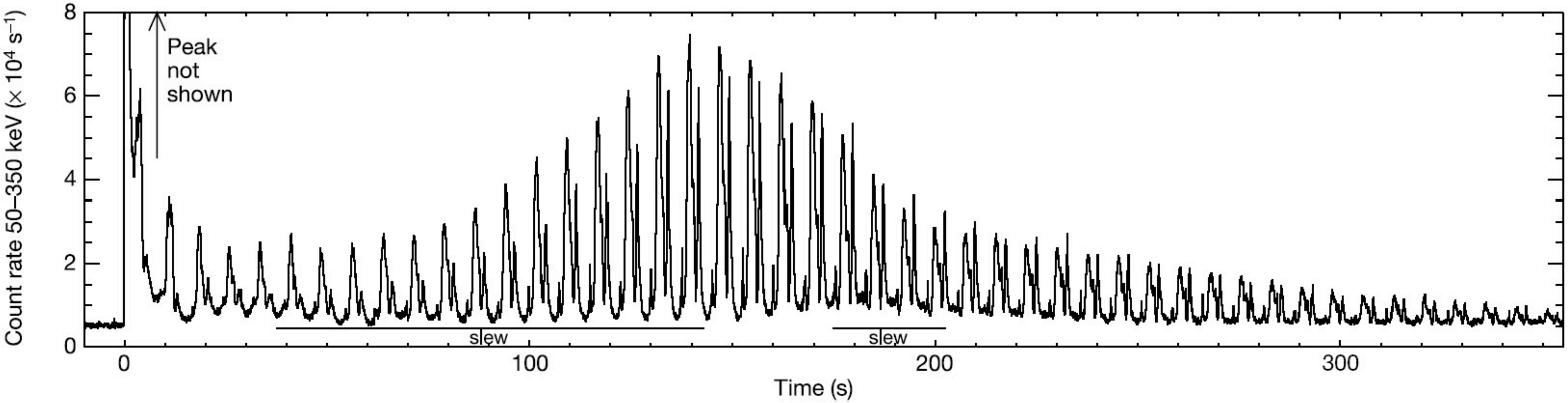
R. Duncan 2003

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)

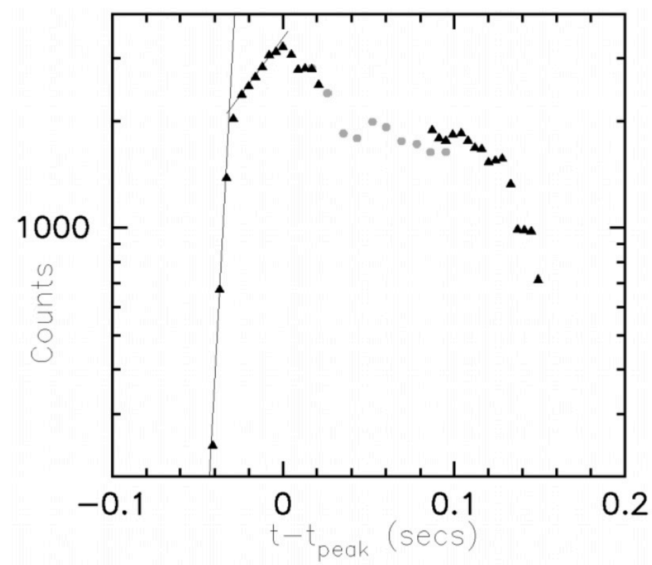
SGR 1806-20 Giant Flare



BAT light curve from D. M. Palmer et al. *Nature*, 434:1107-1109, April 2005.

Spike 15 kpc isotropic energy: (3.7 ± 0.9) x 10^{46} d_{15}^{2} erg [1]
7.56 s rotation period evident in tail
Spike timescales ~5-200 ms

[1] K. Hurley et al. *Nature*, 434:1098-1103, April 2005.



S. J. Schwartz et al. *AstrophysJ. Lett.*, 627:L129-L132, July 2005.

Individual SGR burst searches

Science Goals: LIGO S5 first year individual SGR burst search

Abbott et al. PRL 101, 211102 (2008)

LIGO H1 (4 km), H2 (2 km), L1 (4km) detectors

Goals:
1. detection statement
2. model-dependent upper limits via plausible waveforms
3. use detection / upper limits to make astrophysics statements

Burst sample:
SGR 1806-20 giant flare
2/4 known **galactic** Soft Gamma Repeaters gave over 214 bursts during S5y1

Burst sample

SGR 1806-20 **giant flare**, H1 astrowatch

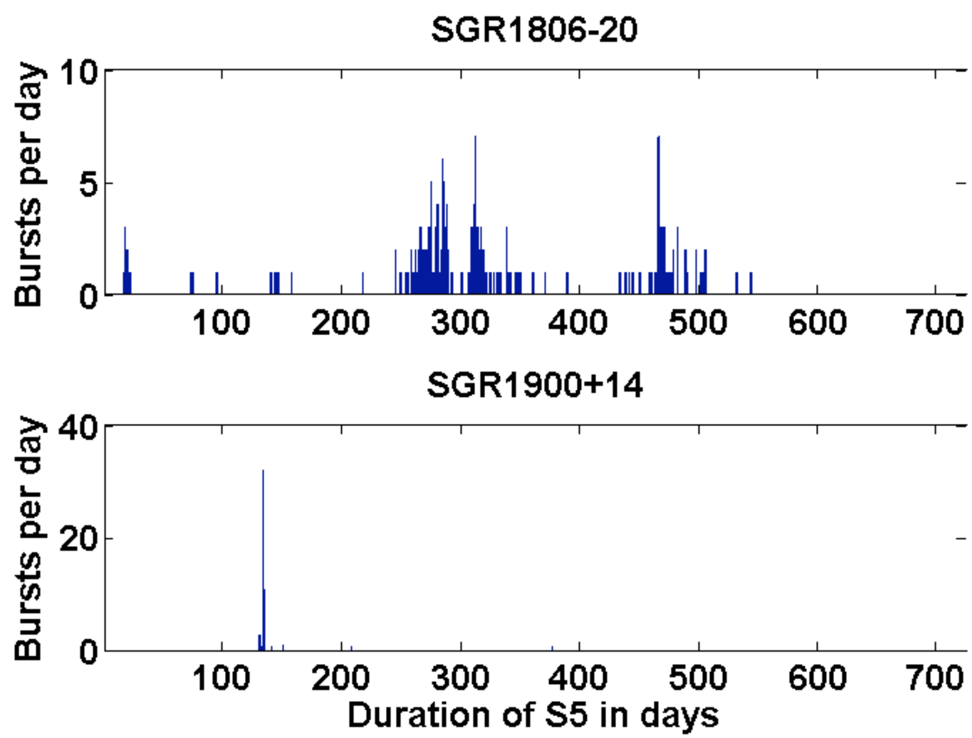
214 S5y1 bursts listed by K. Hurley (IPN3)

152 SGR 1806-20 events:

74	L1H1H2
41	two detectors
18	single detector
19	-

62 SGR 1900+14 events (including a storm):

43	L1H1H2
12	two detectors
2	single detector
5	-

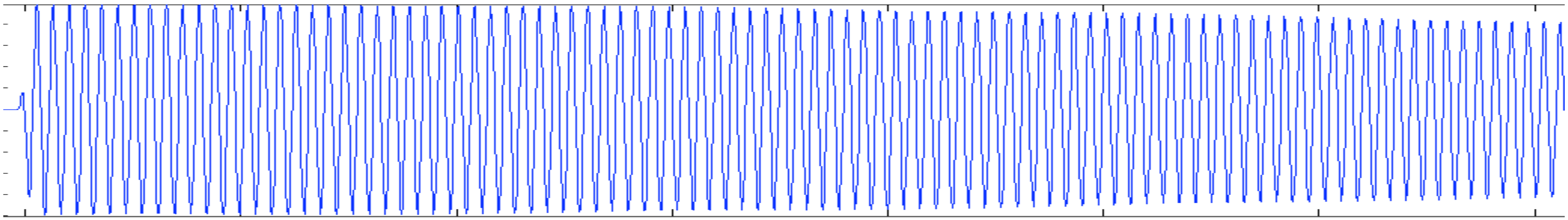


Ringdowns 1 – 3 kHz

…for estimating upper limits

Simulation frequencies: 1090, 1590, 2090, 2590 Hz
- f-mode frequencies depend on star's density
- 3 kHz upper bound: strange quark stars
- 1.5 kHz lower bound: lightweight star with stiff EOS [1]

Simulation tau: 200 ms
- predicted range is 140-380 ms
- we observe <15% sensitivity loss for RDs with tau in range 100-300 ms



[1] O. Benhar, V. Ferrari, and L. Gualtieri, Phys. Rev. D 70,124015 (2004)

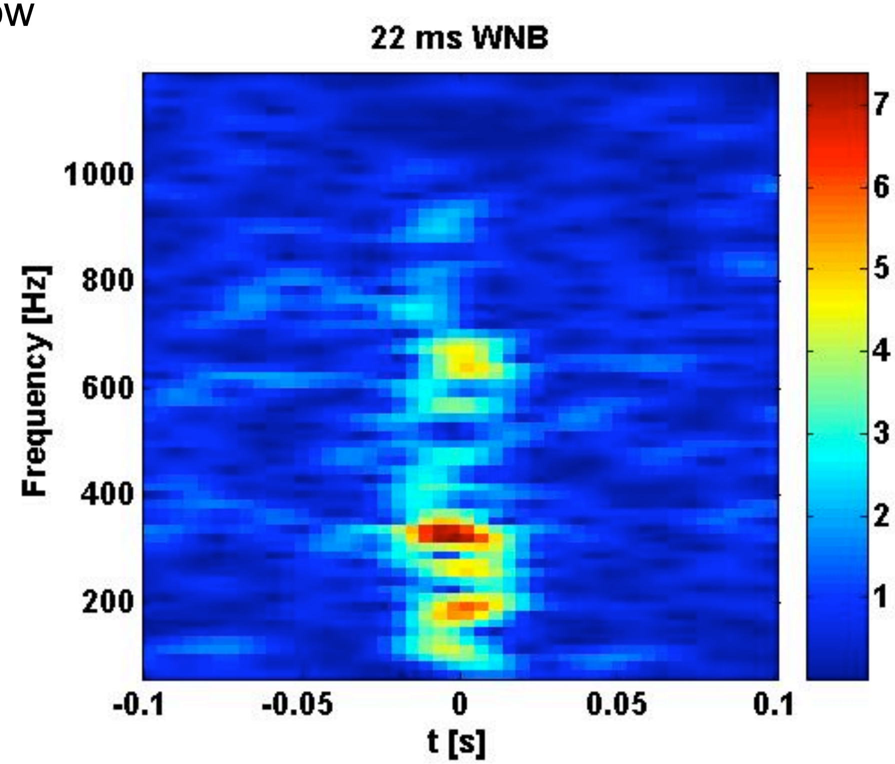
Below 1 kHz: Band- and time-limited White Noise Bursts

…for estimating upper limits

SGR burst timescales set search time window
5 ms – 200 ms

Band-limited to detector's sensitive regions:
- 100 – 200 Hz (small band)
- 100 – 1000 Hz (large band)

WNB injections to estimate upper limits
- 11 ms and 100 ms durations



Search strategy

[-2,2] second **on-source region** for isolated bursts (cat2 DQ)
- accounts for satellite timing uncertainty
- expect GW – EM coincidence <100 ms

[-1000,1000] second **background region** (Data Quality flags removed)
- estimate $\mu(f)$, $\sigma(f)$ used by Flare pipeline
- estimate local false alarm rate (FAR)

2006 March SGR 1900+14 storm handled with large on-source region

Follow up on-source analysis events with significant FAR

No-detection case: loudest on-source event rate should be $1/\Sigma$(on-source durations) Hz

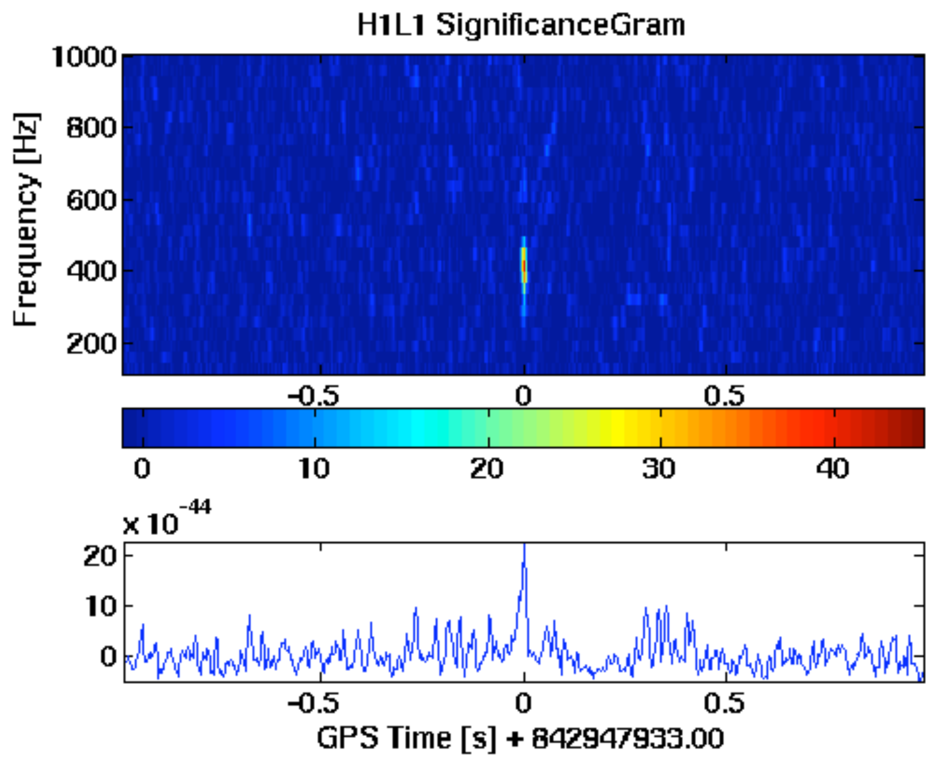
Flare Pipeline

Simple but effective coherent excess power type method

Networks of 1 or 2 detectors

Spectrogram transformation produces excess power time-frequency tilings

$$P_{tf}^{(12)} = \mathrm{Re}\left[T_{tf}^{(1)} T_{tf}^{(2)*} e^{-i2\pi f dt}\right]$$



Clustering applied to bright pixels

On-the-fly simulations or MDCs:

$$\xi_d^{\mathrm{sim}}(t) = F_d^{+}(\theta,\phi,\psi)h_{+}^{\mathrm{sim}}(t) + F_d^{\times}(\theta,\phi,\psi)h_{\times}^{\mathrm{sim}}(t)$$

Gamma ≡ E_{GW} / E_{EM}

Sensitive to neutron star f-modes

LIGO S5 + A3

191 SGR events including:

- SGR 1806-20 giant flare
- SGR 1900+14 storm

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

Lowest γ from giant flare

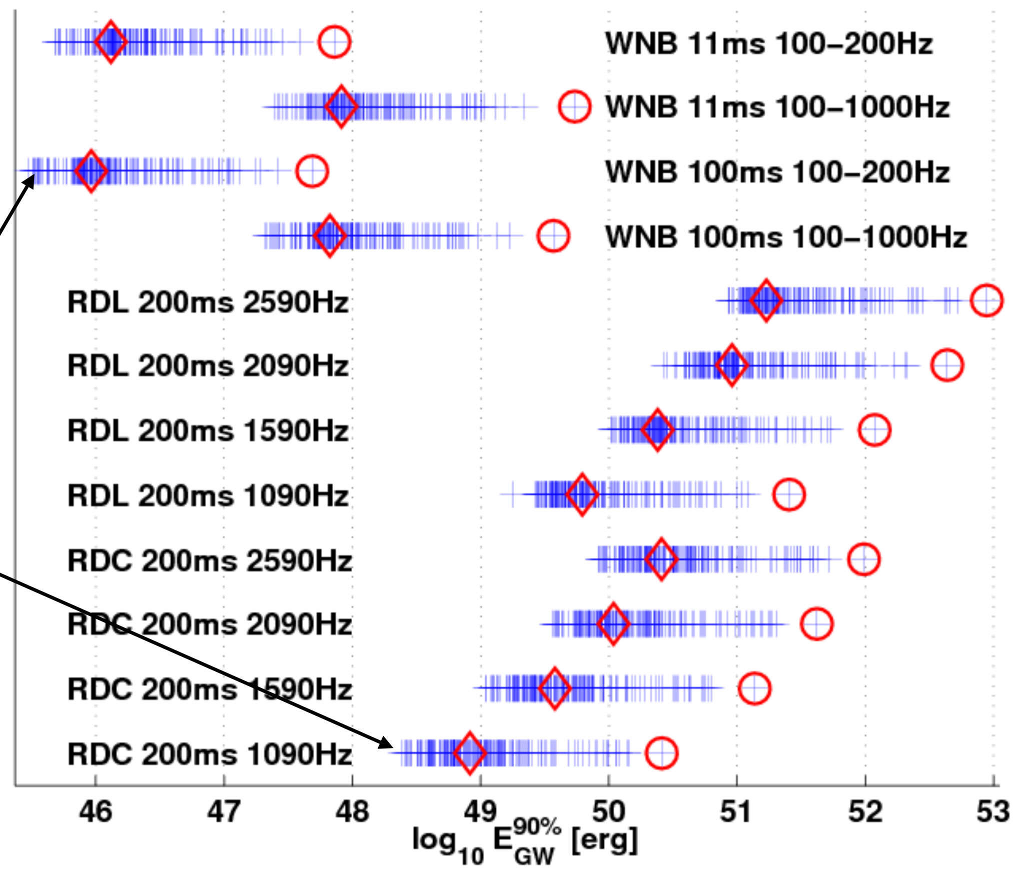
- γ=30, 100—200 Hz WNB
- $\gamma = 2\times10^4$, 1090 Hz RDC

2.9×10^{45} erg

2.4×10^{48} erg

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

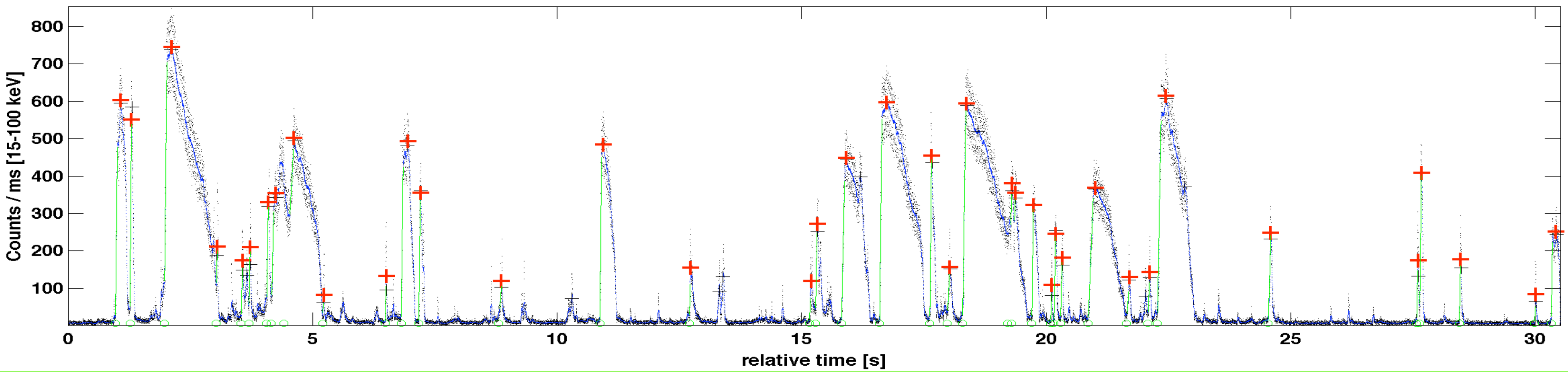
Circles: Giant Flare

Diamonds: GRB 060806

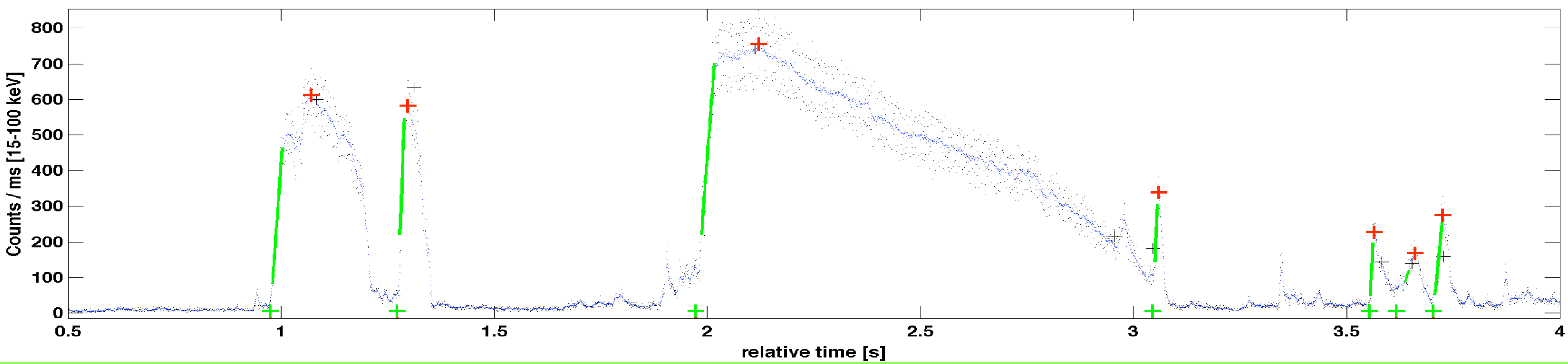
Stacked SGR burst searches

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



Science Goals: LIGO SGR 1900 storm stacked search

Abbott et al. arXiv:0905.0005 (2009), to appear in ApJL

LIGO H1 (4 km), L1 (4km) detectors

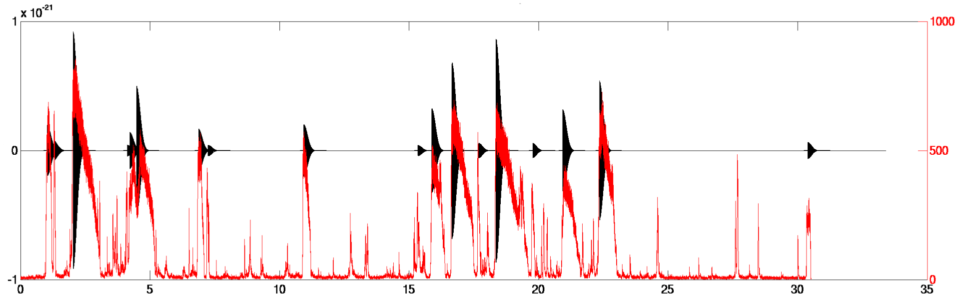
Goals:

1. more sensitive search
2. detection statement
3. model-dependent upper limits via plausible waveforms
4. use detection / upper limits to make astrophysics statements

Burst sample:
March 2006 SGR1900+14 storm

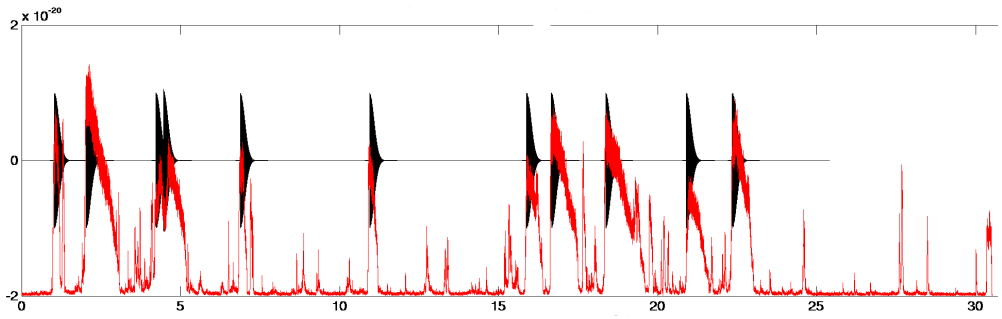
Stacking Models

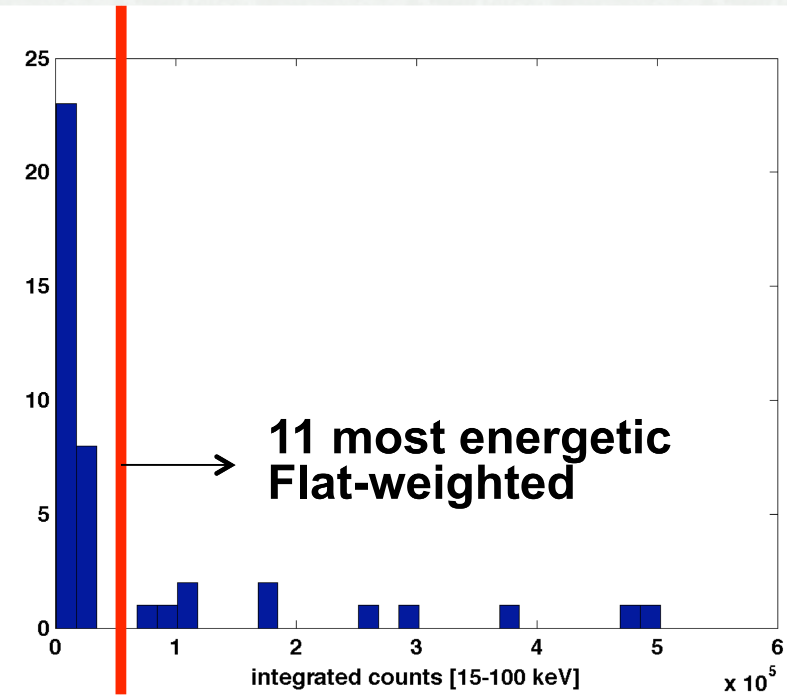
Model 1: Fluence-weighted (N=18)



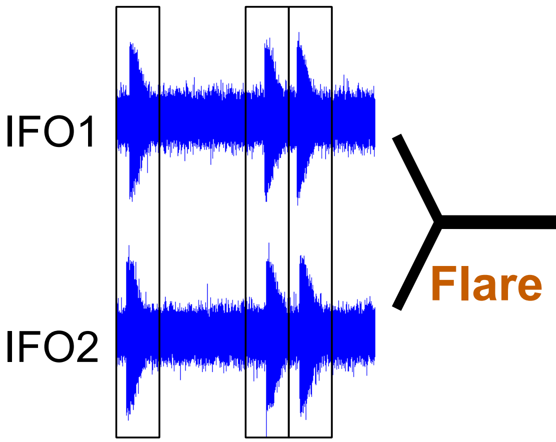
Assume GW—EM time offsets are nearly the same for each burst

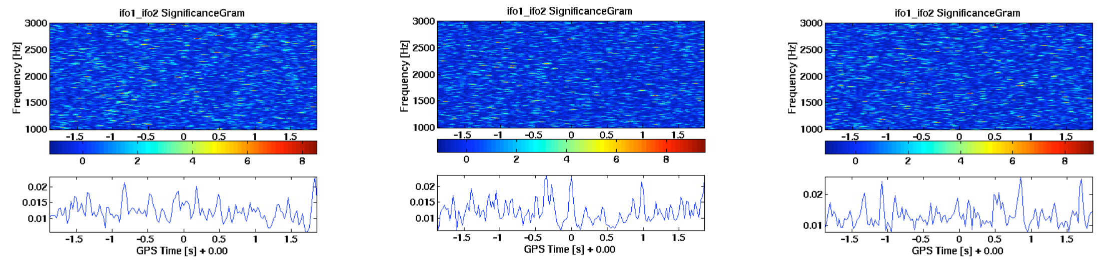
Model 2: Flat-weighted (N=11)





Stack-a-flare Pipeline





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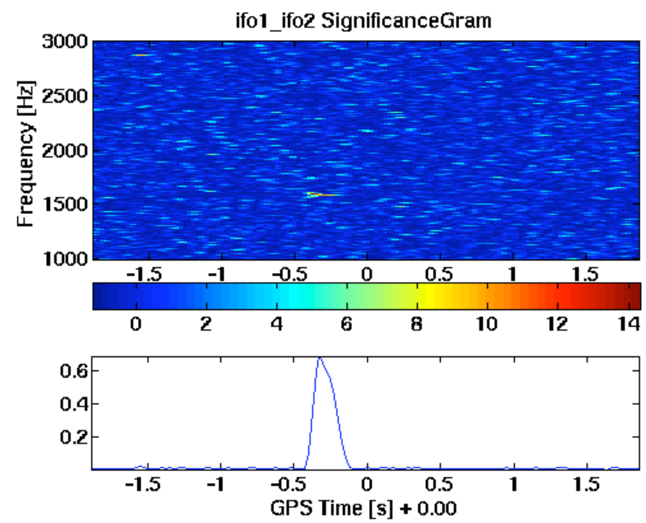
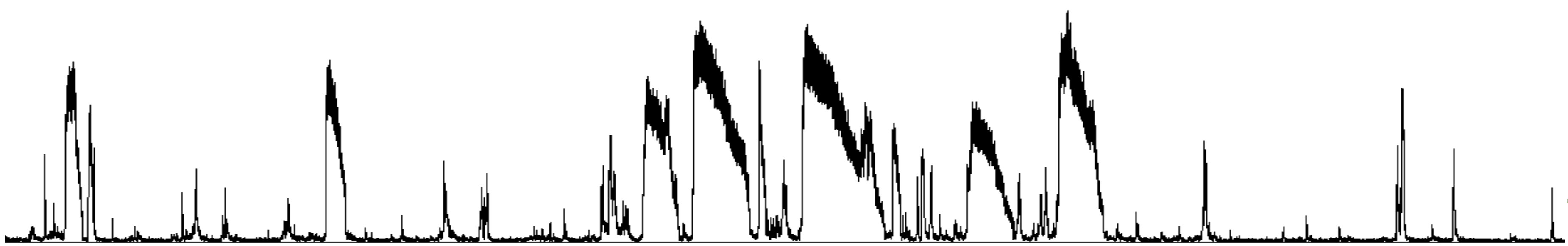


1. Apply Flare pipeline N times at EM burst times
2. Weighted sum of **power significance** tilings

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

Robust to burst time uncertainties

Apply to one- or two-detector networks



Model-dependent Upper Limits

No detection.

3 frequency bands, 2 models

Model 1: Flat, N=11

E_{GW} of single injection

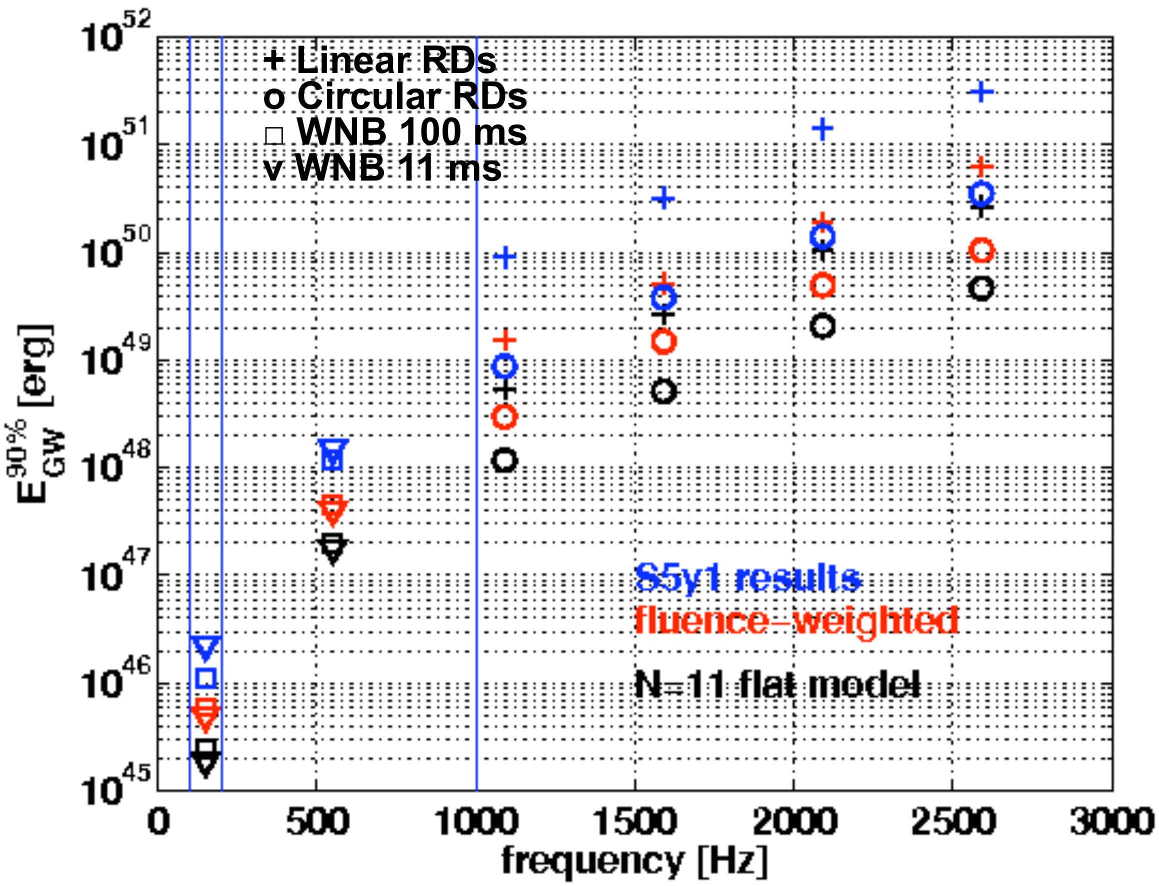
Gain over N=1

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


need help putting
life *in context*?
location
home
work
communication
sensors
groups
activity
on-the-go
put sensory overload to work for you to meet your life goals
our team of experts will monitor the data your life produces–your location, activities, products, conversations, groups–to keep you on track and reach your goals. we'll provide motivation and support when you need it, where you need it.
Dr. Jacqueline Poisson

Conclusion

Context for Upper Limits

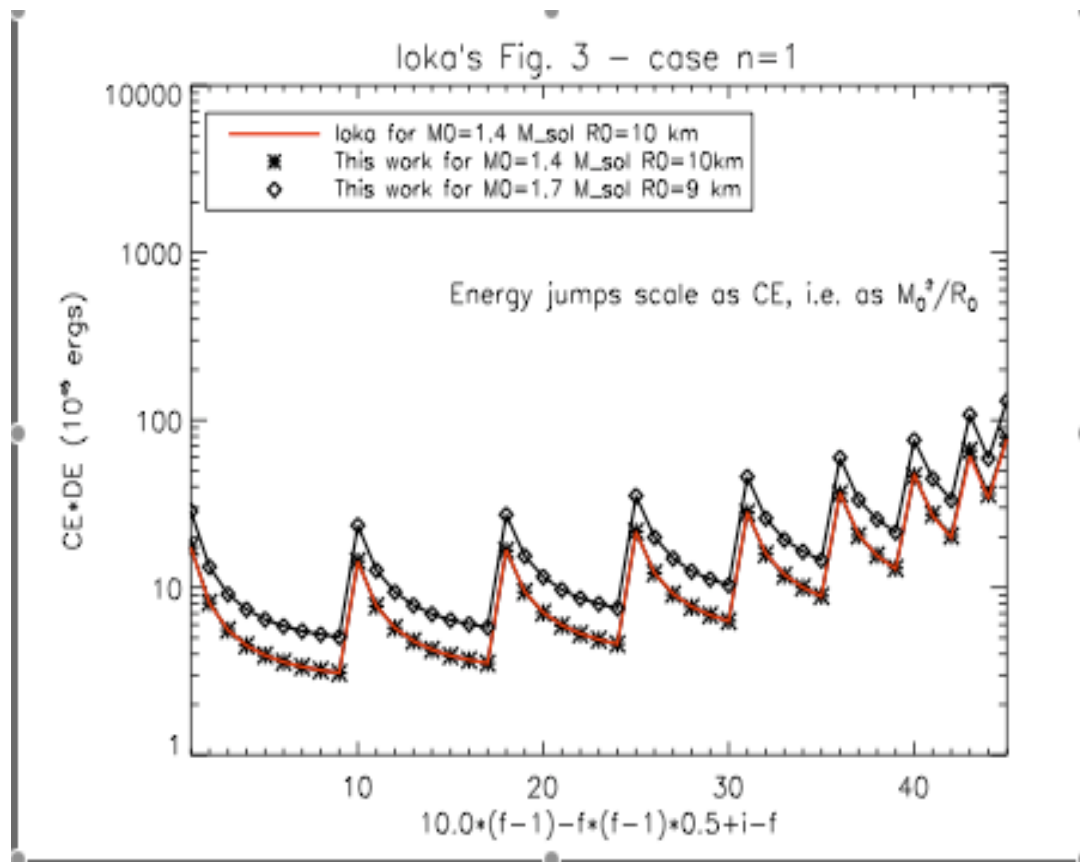
Ioka's model* still the most predictive

- **his model allows total energies of up to 10^{49} erg**

Stack E_{GW} upper limits dig further into his range

- **12x deeper than individual burst result**
- **f-mode ringdowns: as low as 10^{48} erg**
- **WNBs in the "bucket": ~10^{45} erg**

Figure from May 2009 note by A. Corsi and B. Owen. Label on y-axis is ΔE * (10^{45} ergs)



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

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

*K. Ioka. MNRAS, 327:639–662, 2001.

Plans

SGRs keep bursting. Will remain important GW targets.

SGR 0418+5729: **new SGR(?)** discovered 2009 June 5 (2 bursts, Fermi, Atel 2077)

SGR 0501+4516: **new 1.5 kpc SGR** discovered 2008 August, hundreds of bursts (Swift)

SGR 1627-41: a storm after 9.8 years of quiescence in 2008 May (Swift, GCN 7777)

AXP 1E1547.0-5408 → **SGR 1550-5418**: Fermi: 31 bursts 2009 January (GCN 8838)

SGR 1806-20: last observed burst 2008 November

SGR 1900+14: last observed burst 2007 November

SGR 0526-66: last observed burst 1983

SGR GW individual and stacked searches will continue: Virgo, GEO, LIGO

Individual burst searches in progress:

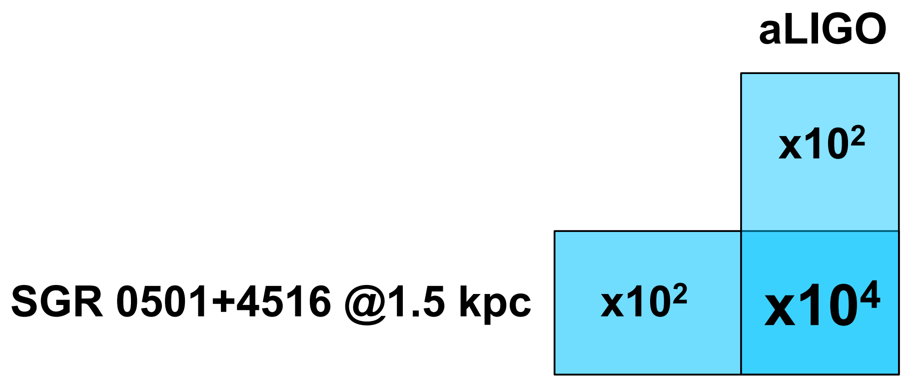
- LIGO S5 second year + Virgo, SGR 1806-20 and SGR 1900+14
- LIGO A5 + GEO, SGR 0501+4516

Modeling seismic excitation of modes in magnetars (with Christian Ott)

goal: advance our understanding of SGR GW burst emission

Future of stacking SGR bursts

E_{GW} sensitivity improvements:



We might get to γ~1 with **normal bursts**, and:
- nearby SGR activity
- aLIGO-generation detectors
- stacking

We might get to $\gamma \sim 10^{-4}$ with a **giant flare**, and:
- nearby SGR activity
- aLIGO-generation detectors

Will this be enough for a detection?

reserve slides

Timing Uncertainty

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

Folded into Monte Carlo