LIGO search for transient gravitational waves from Soft Gamma Repeaters

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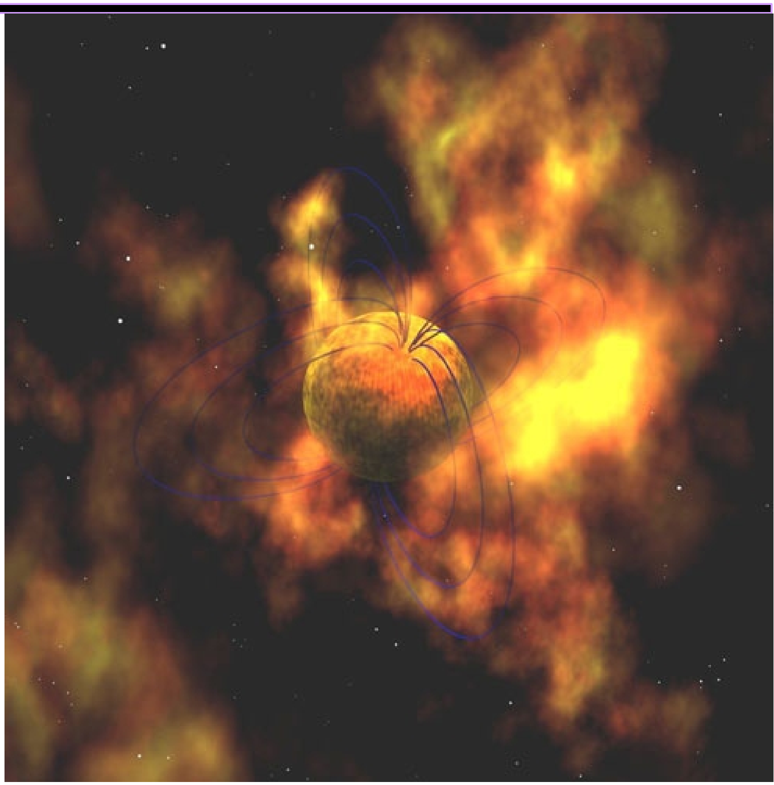
Soft Gamma Repeater Transient GW Search

SGR event sample:

- SGR 1806-20 giant flare 2004 Dec. 27
- 2 out of 4 known **Galactic** SGRs gave over 214 bursts in first year of LIGO's fifth science run (S5y1) 2005 Nov. 11 – 2006 Nov. 11



NASA

Goals:

1. detection statement
2. upper limits via plausible waveforms
3. use detection / upper limits to make astrophysics statements

Soft Gamma Repeaters

- Sporadic gamma ray bursts
  - Typical electromagnetic bursts last ~100 ms with peak luminosities ~10^{42} erg/s [1]
  - Multi-episodic electromagnetic bursts (SGR 1900+14 “storm”)
  - Rare giant flares have tails, peak luminosities up to10^{47} erg/s
- Observations consistent with a relaxation system:
  - “crustquakes” with multiple seismic zones [2]
- Candidate for short hard GRB progenitor [3]
- Conventional model: Magnetar
  - Neutron stars with B ~10^{15} G [4]
  - Bursts: interaction of B with solid crust leads to crustal cracking [5]
- Alternative model: Solid quark star
  - Bursts caused by starquakes [6]

[1] Woods P M and Thompson C 2004 *Compact Stellar X-Ray Sources* (Cambridge University Press)
[2] Palmer, D. 1999 *Astrophysical Journal* 512:L113-L116
[3] Hurley, K. et al. 2005 Nature 434 1098-1103
[4] Duncan R C and Thompson C 1992 Astrophys. J. Lett. 392 L9-L13
[5] Palmer D M et al. 2005 Nature 434 1107-1109
[6] Xu R X 2006 Mon. Not. R. Astron. Soc. 373, L85–L89

Burst sample

SGR 1806-20 giant flare -- H1 *astrowatch*
detector commissioning period

214 S5 bursts listed by K. Hurley (IPN)

152 bursts from SGR 1806-20:

73	L1H1H2
42	two detectors
17	single detector
20	-

62 bursts from SGR 1900+14:

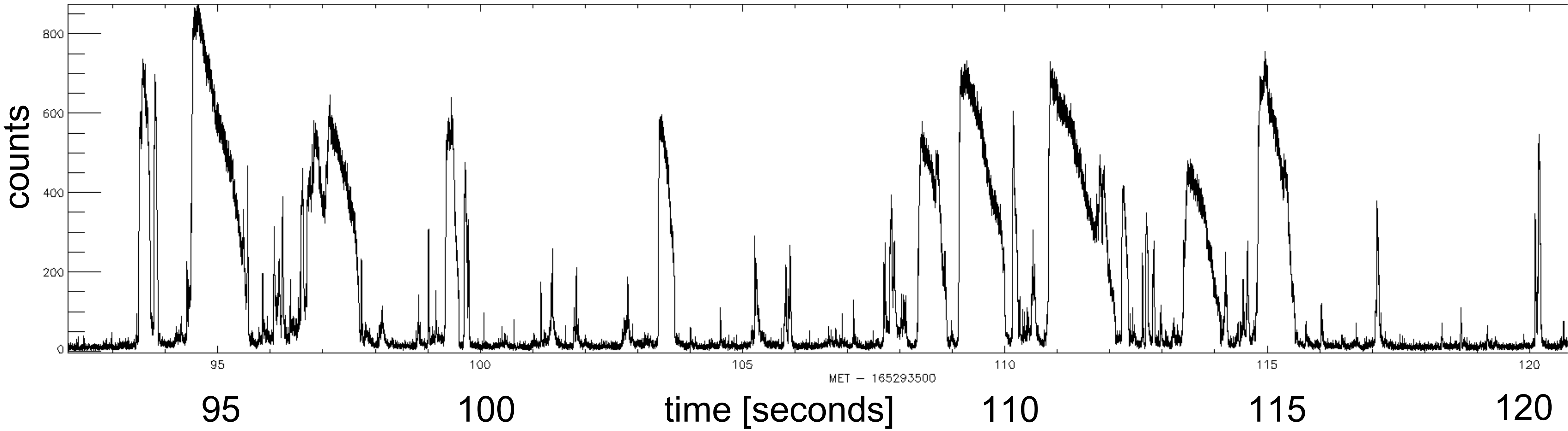
43	L1H1H2
12	two detectors
2	single detector
5	-

H1 – LIGO Hanford 4 km detector
H2 – LIGO Hanford 2 km detector
L1 – LIGO Livingston 4 km detector

Hanford, Washington

Livingston, Louisiana

SGR 1900+14 storm



Swift/BAT
http://gcn.gsfc.nasa.gov/gcn/other/SGR1900+14_swift_bat.html

Search strategy

Model-independent burst pipeline: Flare pipeline [1]

[-2,2] second on-source region for isolated bursts (category 2 data quality flags)
  accounts for satellite timing uncertainty
  expect GW – EM coincidence <100 ms
[-1002,-2] U [2,1002] second background region (category 2 data quality flags)
  estimate background statistics used by Flare pipeline
  estimate local false alarm rate (FAR)

multi-episodic burst treated with extended on-source regions

follow up loudest on-source event candidates with significant FAR

[1] Kalmus et al., Class. Quantum Grav. 24 (2007) S659–S669

Loudest event upper limits

Depend on waveform for injections

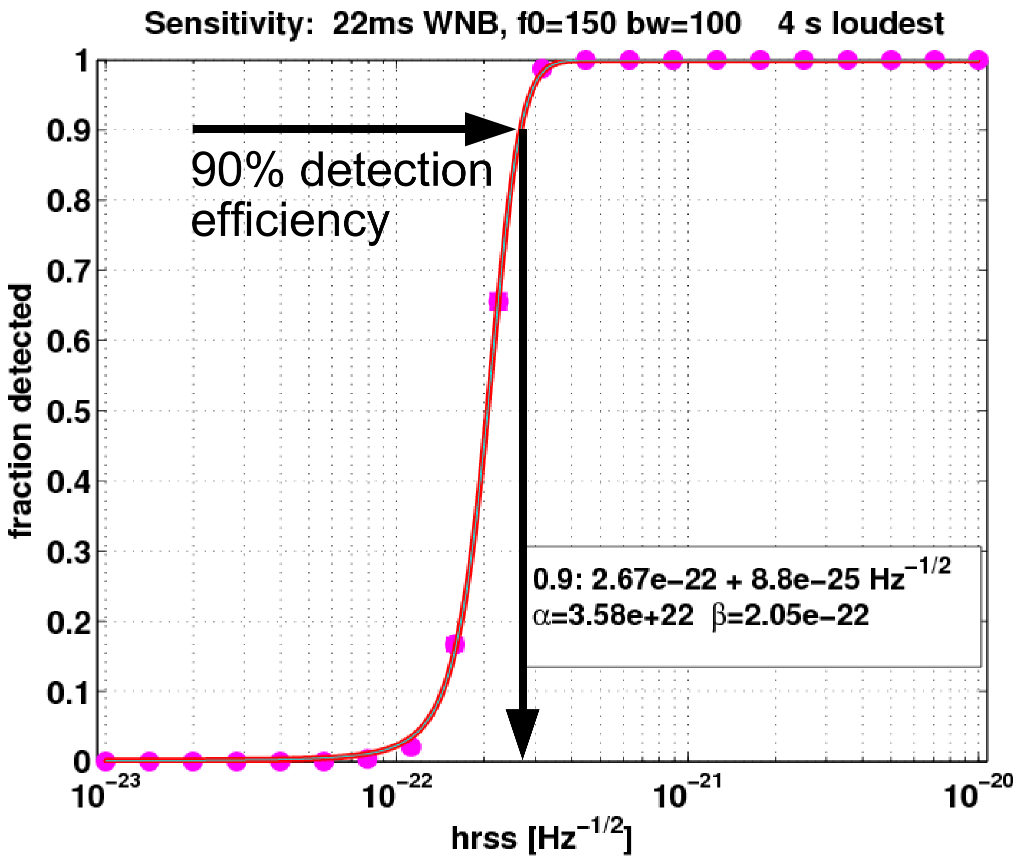
Search on-source region and record **loudest on-source event**

Inject simulations into background (vary hrss)

Search for injection within coincidence time window

- Anything louder than loudest on-source event?
- Construct efficiency curve

SAMPLE made with
SIMULATED DATA [1]



[1] Kalmus et al., Class. Quantum Grav. 24 (2007) S659–S669

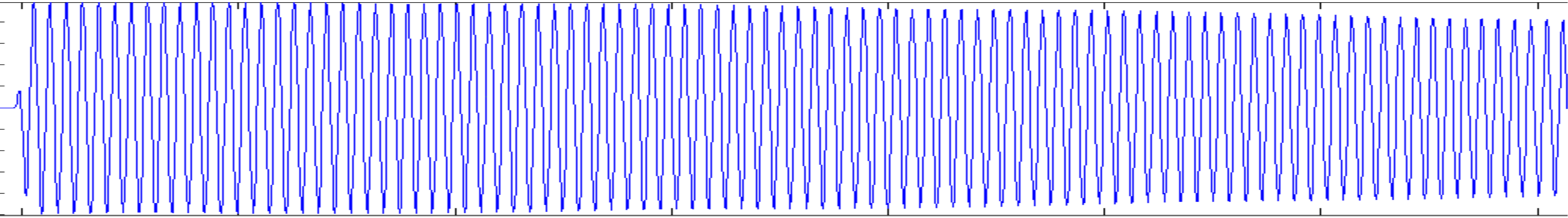
Simulations for setting upper limits: Ringdowns 1 – 3 kHz

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 equation of state [1]

Simulation tau: 200 ms

- predicted range is 140-380 ms [1]
- 200 ms template handles entire range with at most ~10% amplitude loss [2]



[1] O. Benhar, V. Ferrari, and L. Gualtieri, Phys. Rev. D 70,124015 (2004)
[2] J. D. E. Creighton, Phys. Rev. D60, 022001 (1999)

Simulations for setting upper limits: Below 1 kHz

SGR burst timescales set search time window

  5 ms – 200 ms

Band-limited to detector's sensitive regions:

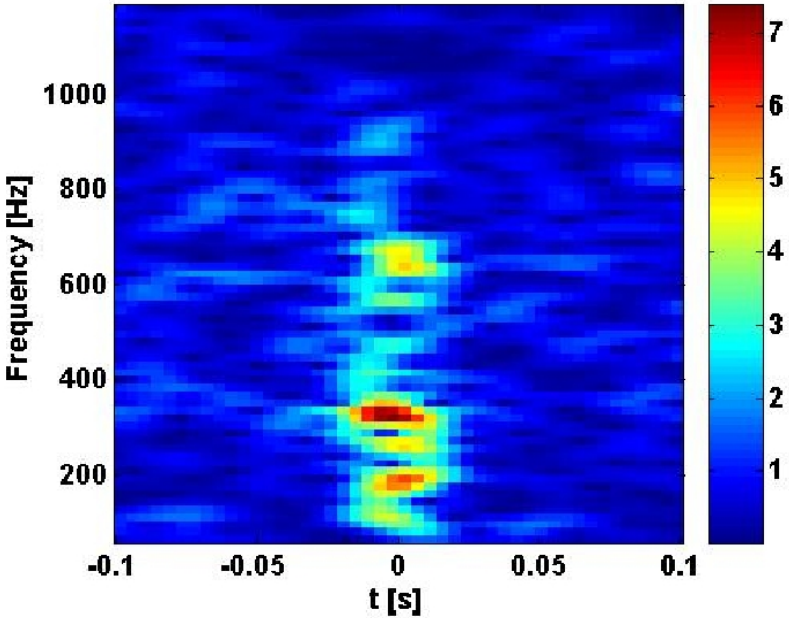
  100 – 200 Hz (small band)

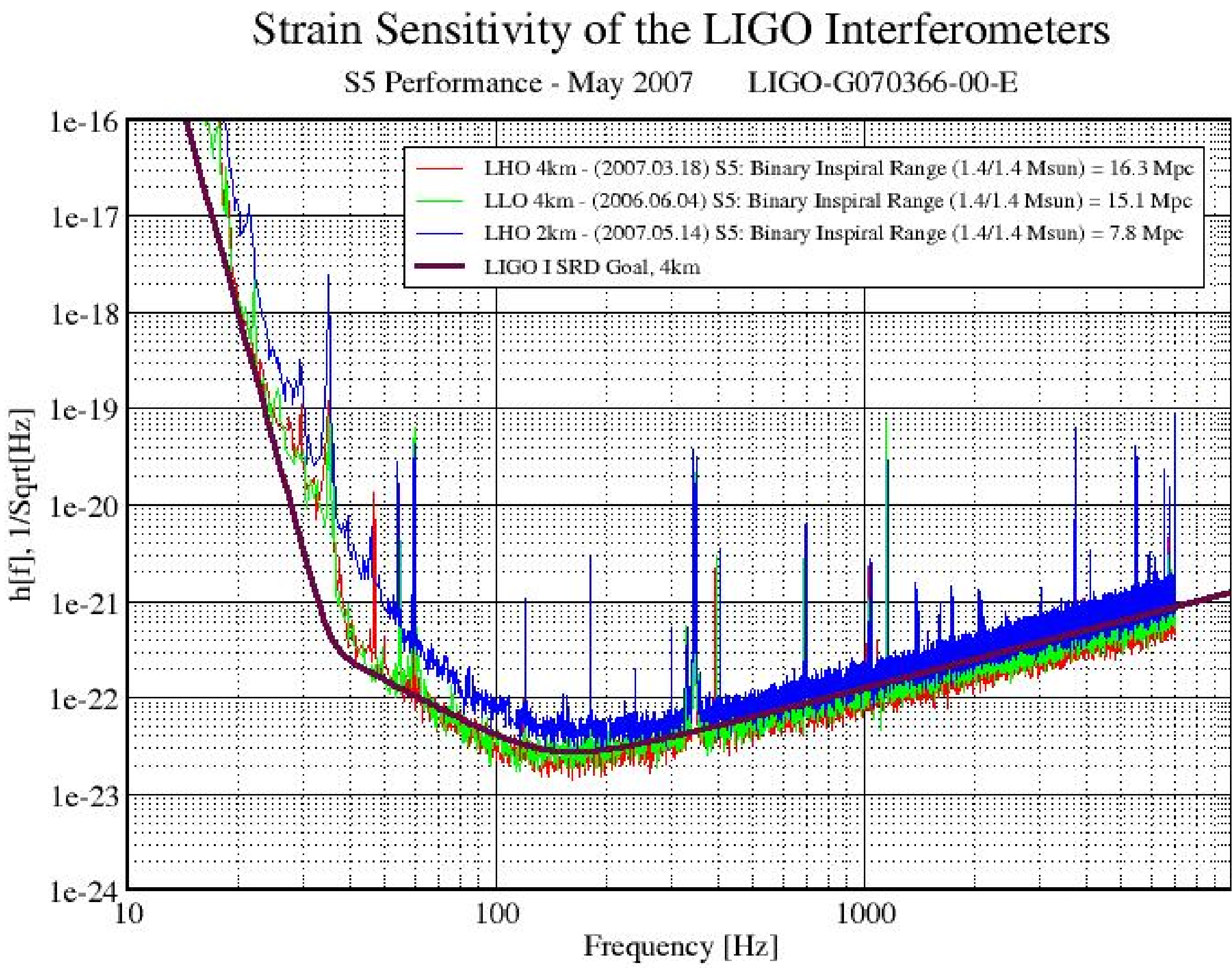
  100 – 1000 Hz (large band)

White noise burst simulations:

  11 ms and 100 ms durations

example simulation:





Flare method

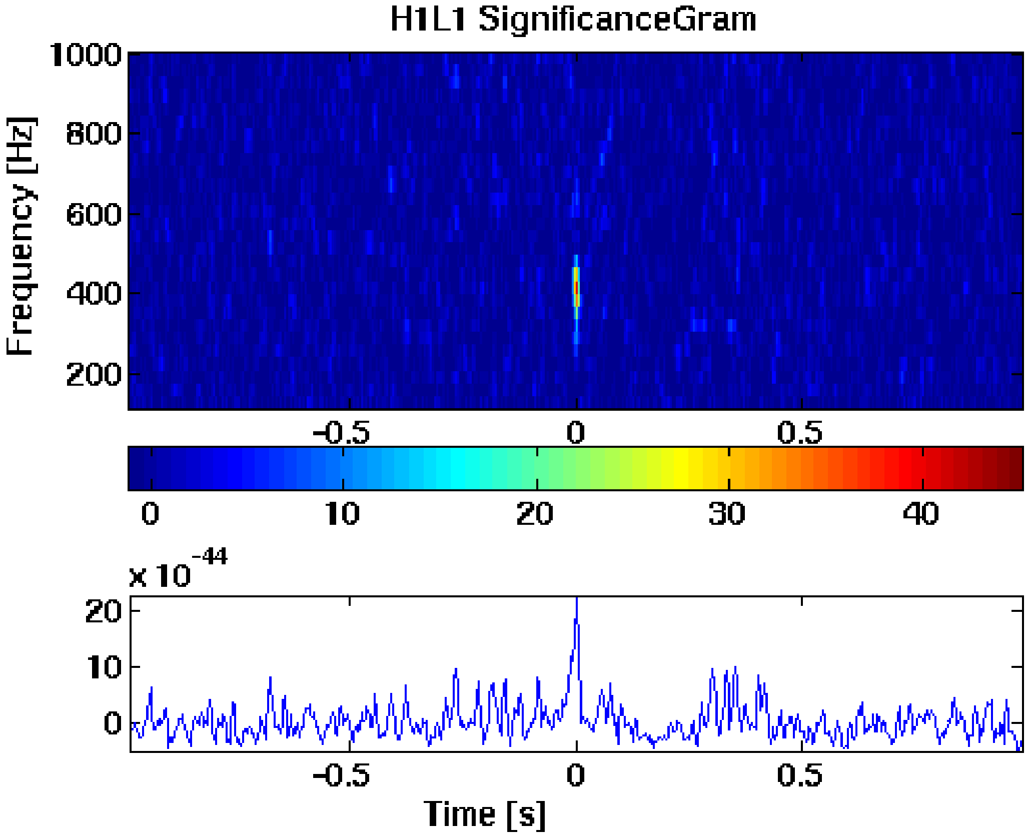
Simple but effective coherent excess power type pipeline
Single and dual detector networks
Spectrogram transformation produces a PSD or cross-PSD TF tiling
Background at each frequency used to make significance TF tiling
Clustering routine applied to pixels above significance threshold
Fully automated for multi-trigger searches

Construct cross-power matrix ***P*** from spectrogram matrices ***T***

$$\boldsymbol{P_{tf}^{H1L1} = \mathrm{Re}[T_{tf}^{H1} T_{tf}^{L1*}\, e^{-i2\pi f\, dt}]}$$

t – time index
f – frequency index
dt – H1 to L1 time-of-flight delay

sample simulation injected into noise:



Conclusion

Results are being finalized

Estimated best sensitivities, present and future

Figure of merit: $\gamma \equiv E_{EM} / E_{GW}$

For 100-200 Hz white noise burst simulations

Case 1: Another SGR 1806-20 giant flare ($E_{EM} \sim 10^{47}$ erg), near-optimal antenna

expected isotropic E_{GW} sensitivity at 10 kpc:

S5: $\sim 2 \times 10^{45}$ erg ($\gamma \sim 50$)
S6: $\sim 4 \times 10^{44}$ erg ($\gamma \sim 250$)
advLigo: $\sim 2 \times 10^{43}$ erg ($\gamma \sim 5000$)

Case 2: Typical giant flare ($E_{EM} \sim 10^{45}$ erg) with rms antenna ~ 0.5

expected isotropic E_{GW} sensitivity at 10 kpc:

S5: $\sim 1 \times 10^{46}$ erg ($\gamma \sim 0.1$)
S6: $\sim 2 \times 10^{45}$ erg ($\gamma \sim 0.5$)
advLigo: $\sim 1 \times 10^{44}$ erg ($\gamma \sim 10$)