Results of the LIGO-TAMA S2/DT8 Joint Bursts Search

Patrick Sutton

LIGO Laboratory, Caltech, for the

LIGO-TAMA Joint Working Group

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Outline

- Background
- LIGO-TAMA Network
- Analysis Overview
- Analysis Results
- Remaining Tasks and Outlook

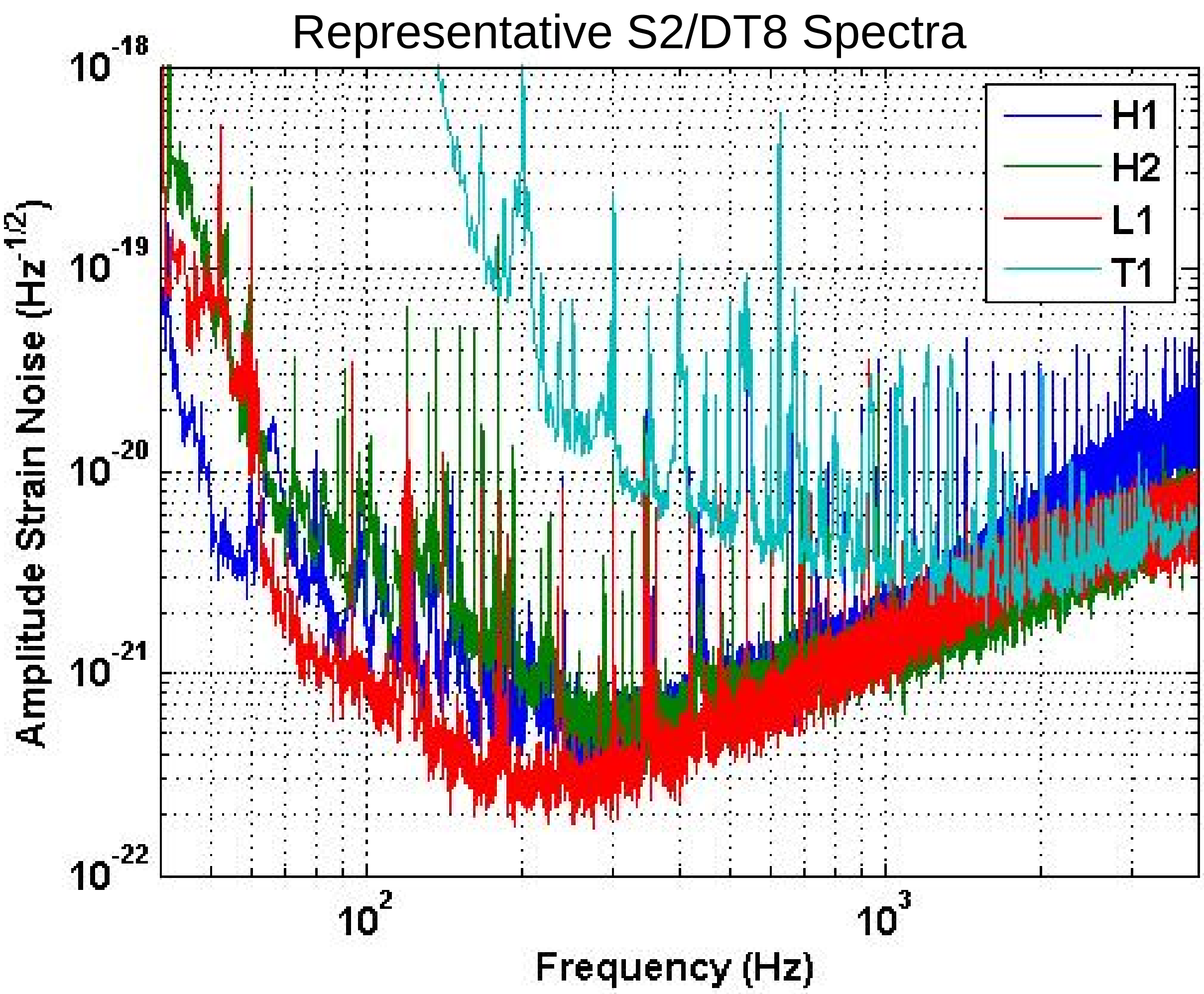
LIGO-TAMA Joint Search

- GWDAW 7, 2002: LIGO & TAMA sign MOU for joint analysis of S1/DT6 or S2/DT8 data for gravitational-wave transients.
  - » Seek optimal ways to combine LIGO and TAMA for best science.
  - » Develop infrastructure for collaboration.
- Post-S2: Began joint bursts search in S2/DT8 data, focusing on high frequencies (700-2000Hz).
  - » Complementary to LIGO-only S2 search: 100-1100Hz
  - » Inspiral & GRB 030329 analyses also in progress.

Network Searches

- Advantages & disadvantages depend on how analysis is performed. For a straightforward coincidence search, these include:
- Pros:
  - » Reduction in false alarm rate due to extra coincidence (~1/century)
  - » Increase in total usable observation time
  - » Extract sky direction, polarization information (3+ sites)
- Cons:
  - » Sensitivity limited by weaker instruments, misalignments.
  - » Technical & logistic challenges: different data quality and characterization issues, different trigger generation, long-distance coordination.

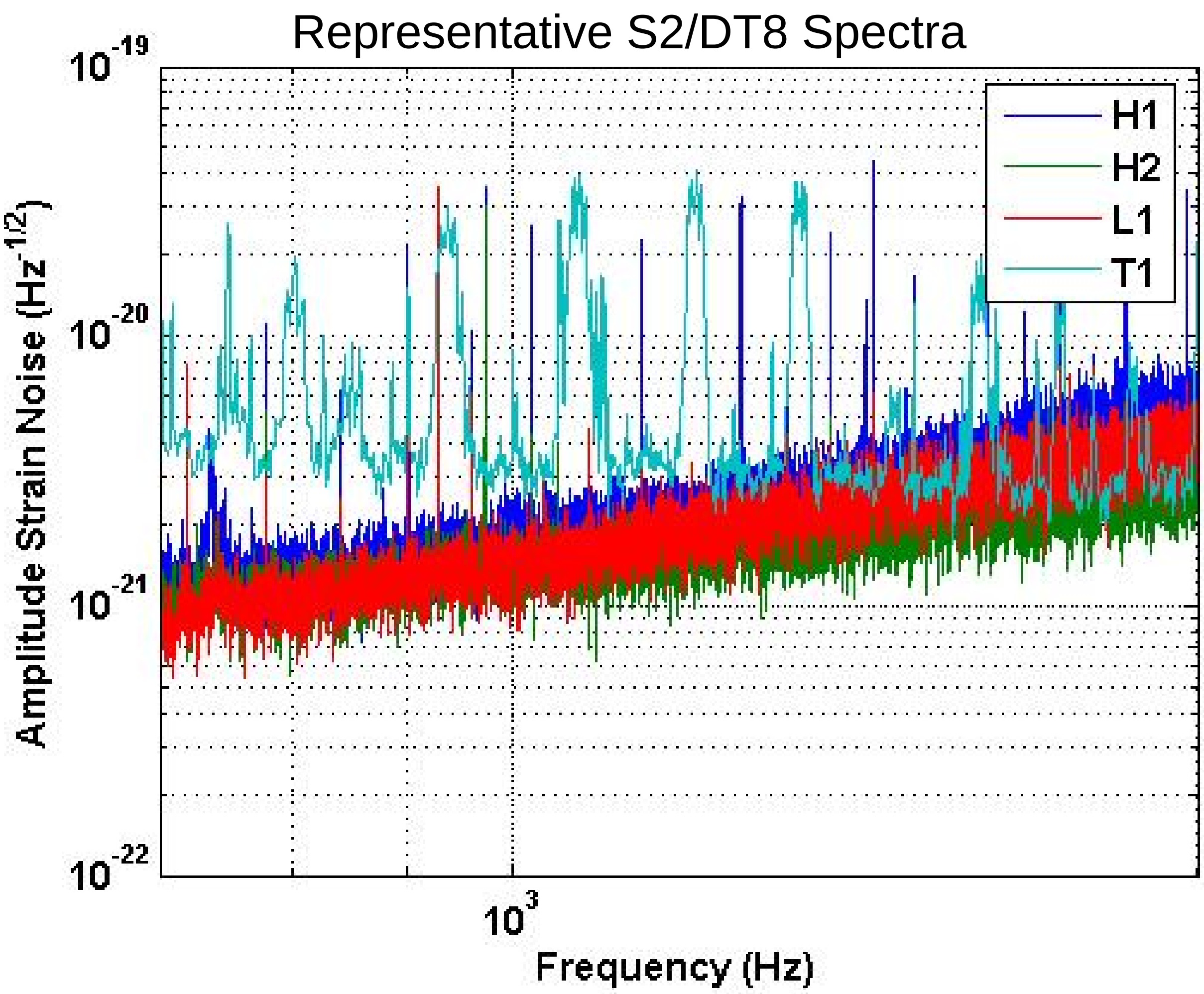
LIGO-TAMA Network



Best *joint* sensitivity near minimum of noise envelope

Focus on [700,2000]Hz

LIGO-TAMA Network



Best *joint* sensitivity near minimum of noise envelope

Focus on [700,2000]Hz

Near 700Hz: expect sensitivity limited by TAMA

Near 2000Hz: expect similar sensitivities

S2/DT8 Data Sets

H1	74%	1040hr
H2	58%	818hr
L1	37%	523hr
T1	81%	1150hr

→

H1-H2-L1-T1	18%	250hr
H1-H2-L1-**n**T1	4%	62hr
H1-H2-**n**L1-T1	23%	325hr
total	45%	637hr

nL1 ≡ L1 not operating, **n**T1 ≡ T1 not operating

- LIGO-TAMA has *double* the total usable data set of LIGO alone
  - » Better chance of "getting lucky" in a search
  - » Cut rate upper limits in half
  - » Cost: some loss in efficiency (minor effect)
- Response: Analyze all H1-H2-(L1 or T1) data
  - » H1-L1-T1, H2-L1-T1: small amount of data, much higher false rate. Ignore.

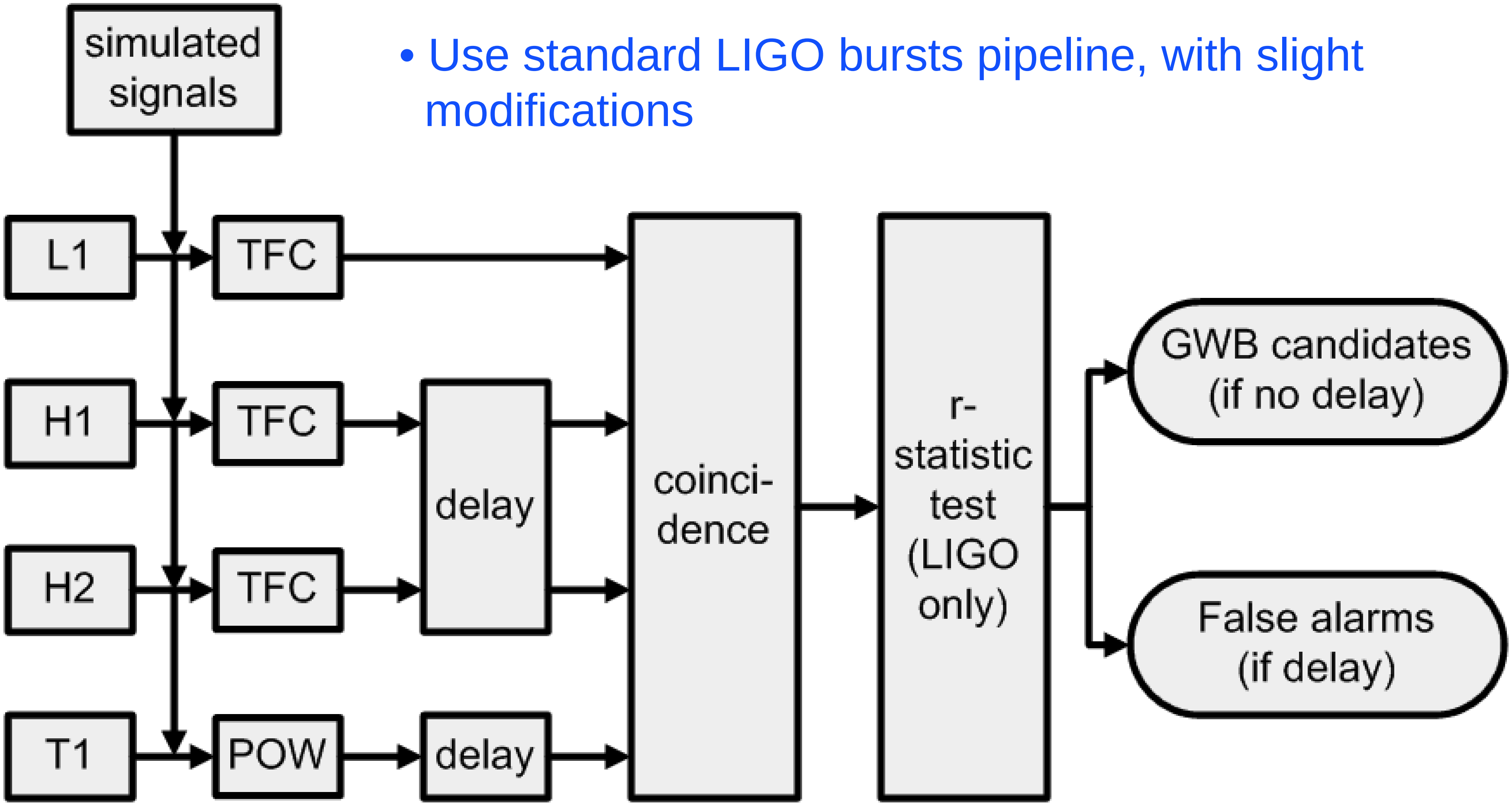
Analysis Procedure

Follow basic format of LIGO-only bursts search:

- Event Generation by LIGO and TAMA (independently):
  - » LIGO: TFClusters+BurstDSO
  - » TAMA: Excess Power
- Coincidence & Coherence:
  - » Temporal coincidence in all operating detectors
  - » R-statistic among LIGO triggers to reduce false rate
  - » Background estimation from time lags
- Efficiencies:
  - » Measure using coordinated signal injections
- Scientific results:
  - » Upper limit or confidence interval on number of detected events, rate versus strength exclusion plots. (Use Feldman-Cousins.)

Analysis Pipeline

- Use standard LIGO bursts pipeline, with slight modifications



Analysis: Novel Bits

- 3 independent data sets:
  - » Must derive single upper limit from 3 independent experiments.
- No bulk sharing of data; only *triggers* exchanged:
  - » Compare LIGO-TFClusters triggers to TAMA-Power triggers
  - » No r-statistic test with TAMA
- TAMA-LIGO 4X search has several interesting features:
  - » Extra time lags allow much more accurate background estimates
    - – LIGO 2-site network = 47 lags in (-115s,+115s)
    - – LIGO-TAMA 3-site network = 47^2 = 2209 lags in (-115s,+115s).
  - » *Not yet explored:* Extra non-aligned site with long baseline: exploit for sky direction? polarization information?

LIGO Event Generation

- Data conditioning with high-pass, linear-predictor error filters.
- TFClusters+BurstDSO algorithm:
  » Divide into overlapping segments (8ms).
  » FFT, construct spectrogram, normalize by average noise level in each frequency bin, set fixed fraction of loudest pixels as significant.
  » Trigger on clusters of black pixels (2+)
  » Central time, duration, frequency, bandwith, SNR (not used) estimated by BurstDSO; keep only triggers overlapping [700,2000]Hz.

TAMA Event Generation

- Data conditioning with line-removal filter.
- Excess-Power algorithm:
  - » Divide into overlapping segments (12.8ms).
  - » FFT, sum total power in a fixed set of frequency bins (which follow the noise floor) in the range [230, 2500]Hz, normalize average noise level.
  - » A trigger SNR>3 (threshold increased in post-processing).
  - » Central time, duration defined by highest SNR time and the duration above threshold.
- Vetoes:
  - » light intensity glitches in auxiliary channel
  - » “Rayleigh-statistic” Gaussianity test

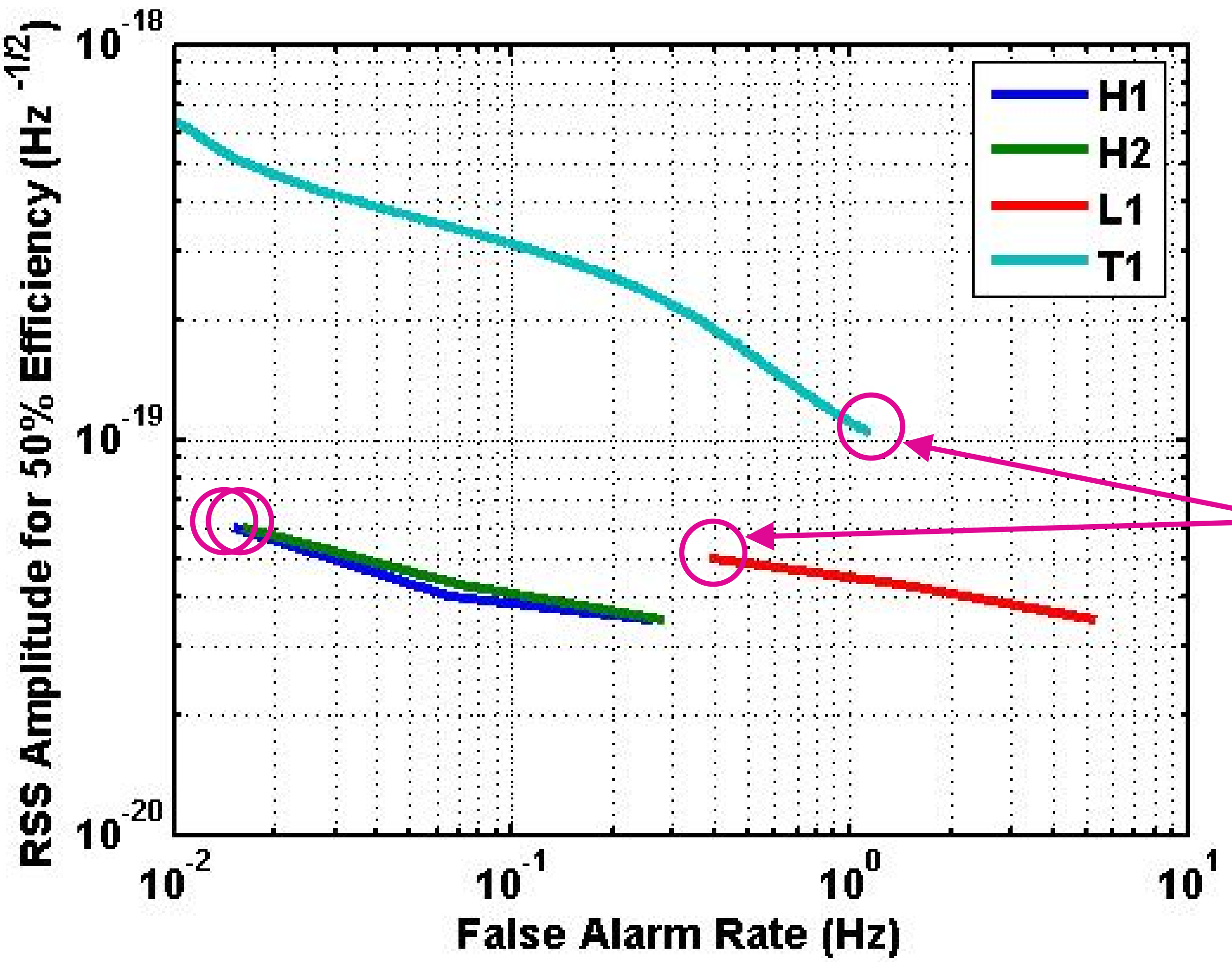
Simulations

- One set of MDC frames has been exchanged: “SG13”
  - » sine-Gaussians
  - » Q = 8.9
  - » f_0 = {700, 849, 1053, 1304, 1615, 2000}Hz
  - » isotropic sky distribution
  - » random linear polarization
  - » total ~16800 injections, distributed over LIGO 3X times (H1-H2-L1-T1 and H1-H2-L1-nT1)

Tuning Philosophy

- Use single tuning for all three data sets.
- Tune for best efficiency at each false rate.
  - » single-IFO: use to fix TFClusters parameters
  - » multi-IFO: select TFClusters & Power thresholds to match efficiencies
- Select multi-ETG rate & r-statistic threshold for << 1 event from background.
  - » beta = 3 (efficiencies not affected)

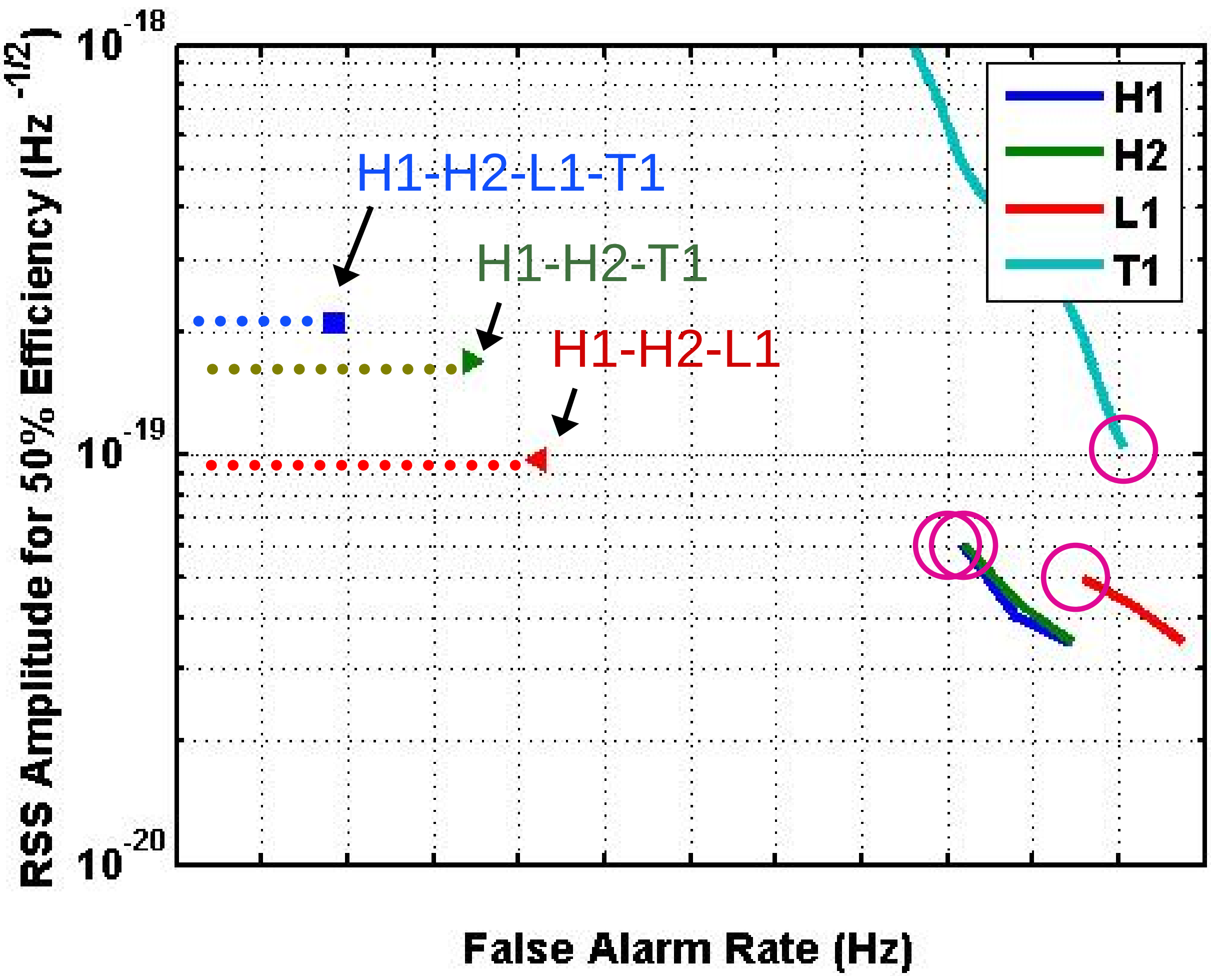
Efficiency vs False Rate



From SG13 simulations

Chosen single-IFO operating points

Efficiency vs False Rate



From SG13 simulations

Effective coincidence windows:

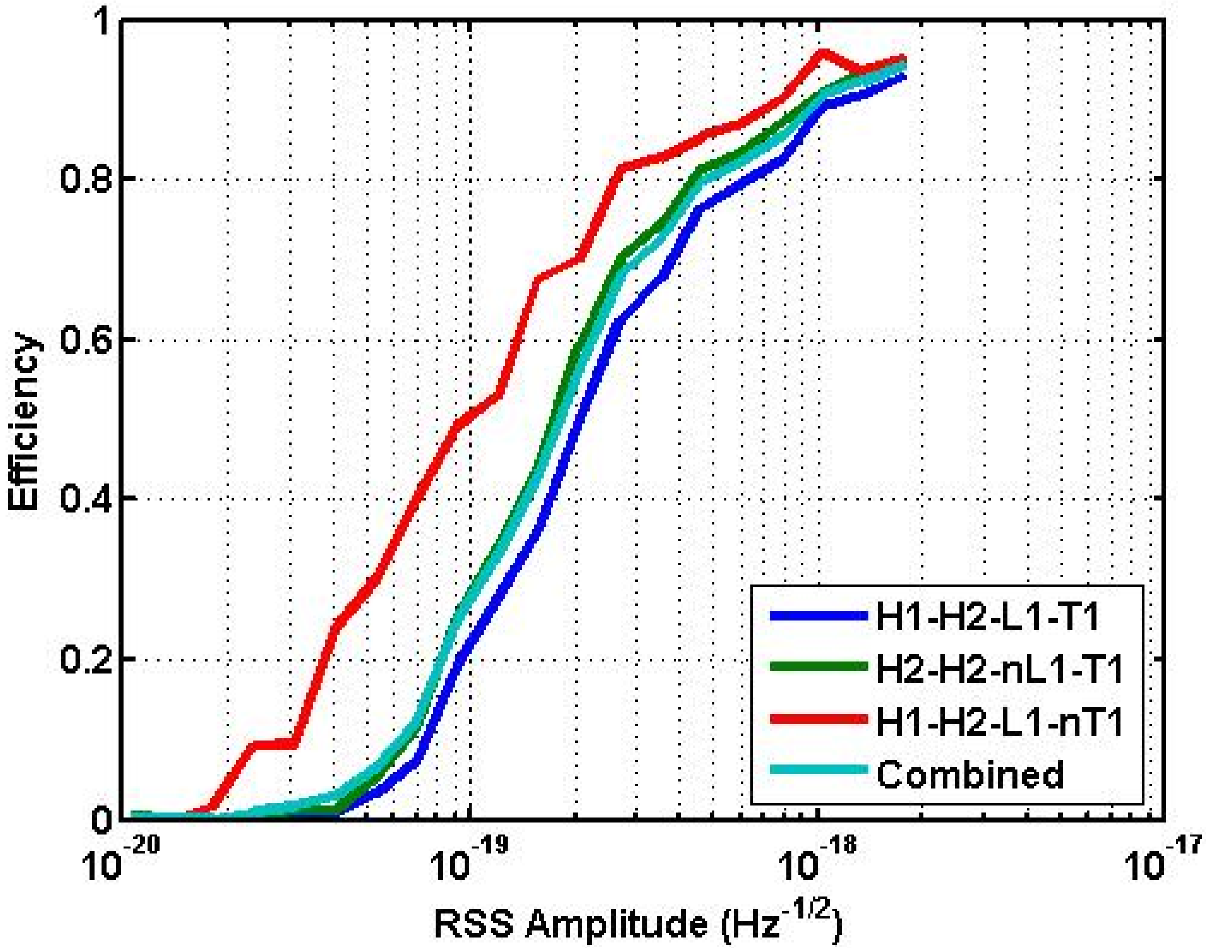
20ms (LIGO-LIGO)
43ms (LIGO-TAMA)

Network characteristics (rates are upper limits)

Full Data Set Results

- Full data set box has been opened and (almost) final upper limits have been calculated.
  - » No surviving coincidences (after r-statistic) for any of the network combinations.
  - » Rate upper limit of 0.13/day.
  - » $h_{rss}^{50\%} = 2\times10^{-19}\,Hz^{-1/2}$ averaged over networks, analysis band.

Network Efficiency

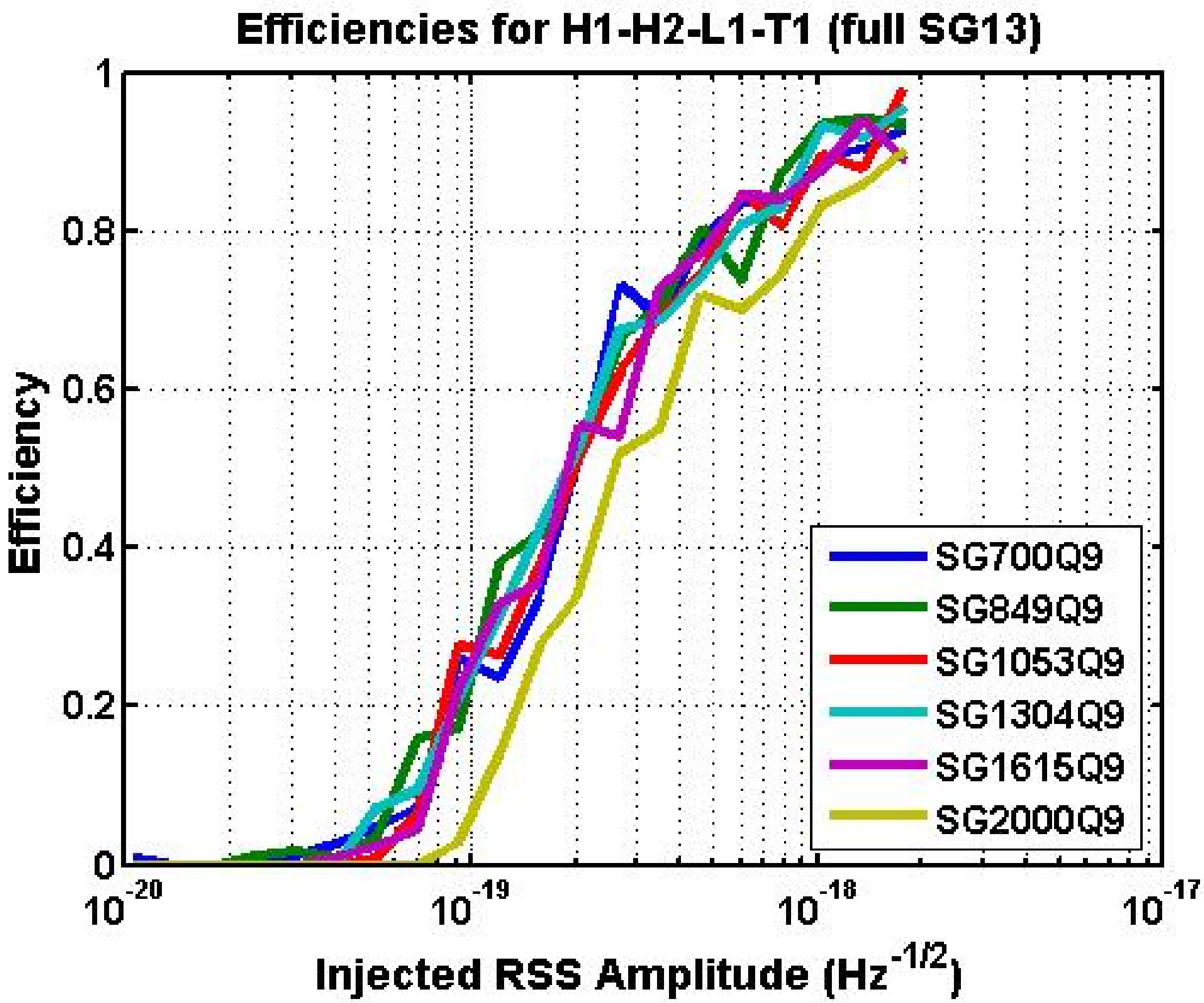


SG13 simulations

(Q=8.9 SG over [700,2000]Hz, with sky & polarization averaging)

Different network combinations have similar efficiency (factor ~2 in 50% point).

Network Efficiency, by f_0



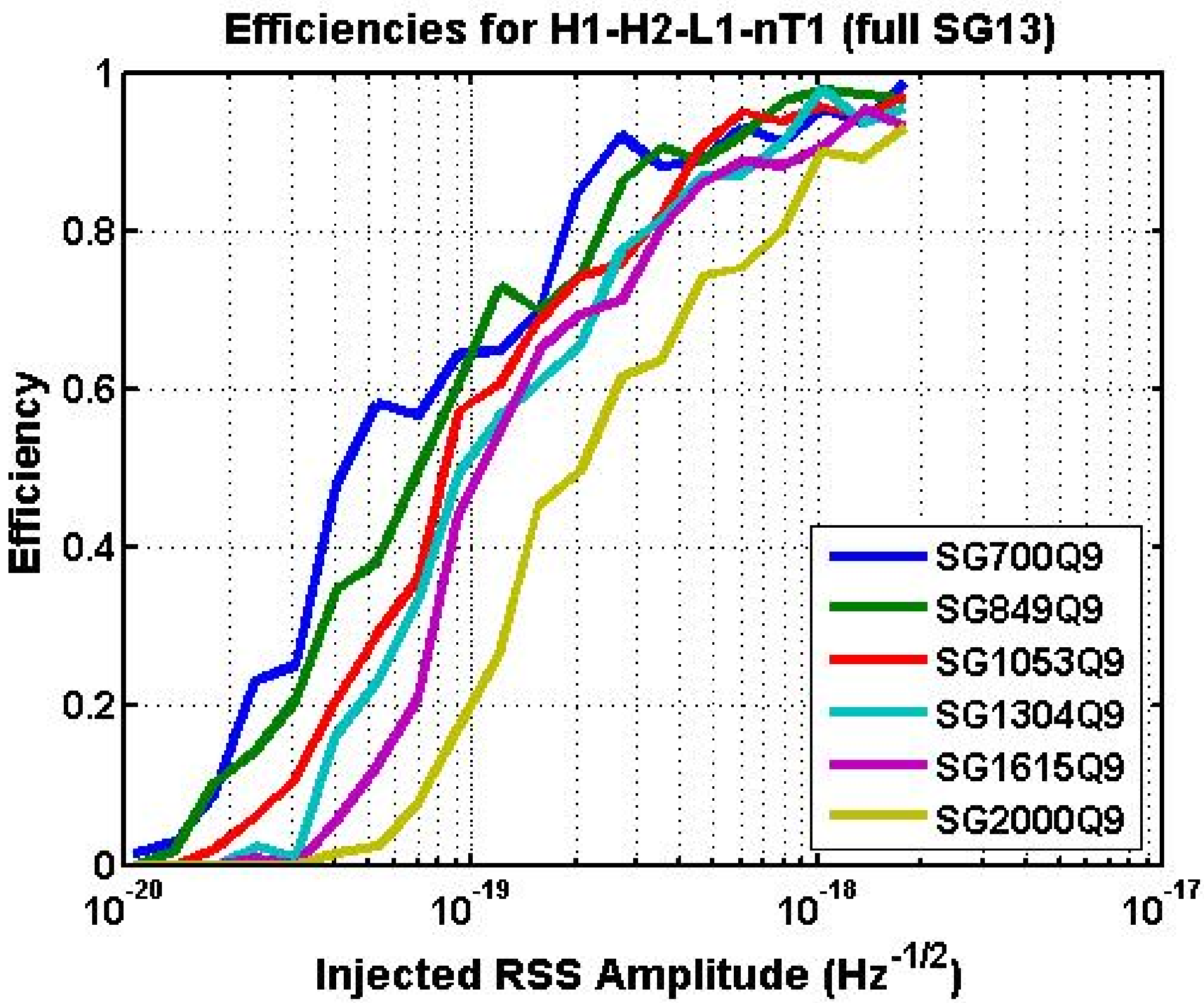
4X detection

SG13 simulations

separately by central frequency

All about the same ($h^{50\%}$ ~ 50 x noise, as expected).

Network Efficiency, by f_0



3X detection (no T1)

SG13 simulations

separately by central frequency

Better at lower frequencies – TAMA limits sensitivity there.

Upper Limits

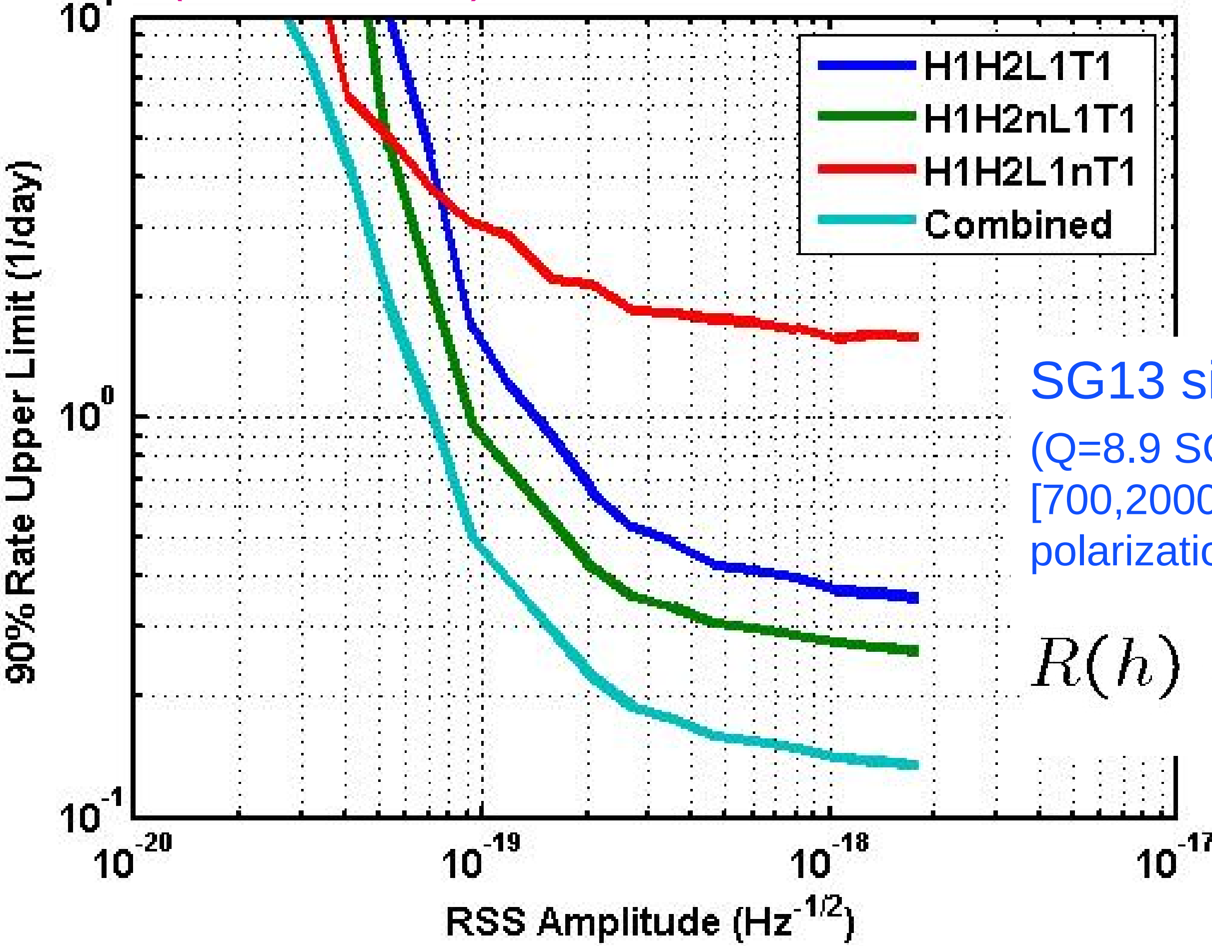
Full data set, including N before/after the R-Statistic:

Network	T (Ms)	N	R_{bck} (nHz)	N_{bck}	$R_{90\%}$(1/day)	$h_{50\%}$ ($Hz^{-1/2}$)
H1-H2-L1-T1	0.64*	0/0	<0.75	<5e-4	0.33	2.1×10^{-19}
H1-H2-**n**L1-T1	0.84*	3/0	<27	<0.023	0.25	1.7×10^{-19}
H1-H2-L1-**n**T1	0.14	0/0	<165	<0.023	2.41	0.97×10^{-19}
Combined**	1.6	3/0	~0	~0	0.13	1.8×10^{-19}

*TAMA livetimes to be finalized.
**Treating all 3 data sets as one experiment (all have N_{bck}~0).

R vs h Upper Limits

(PRELIMINARY)

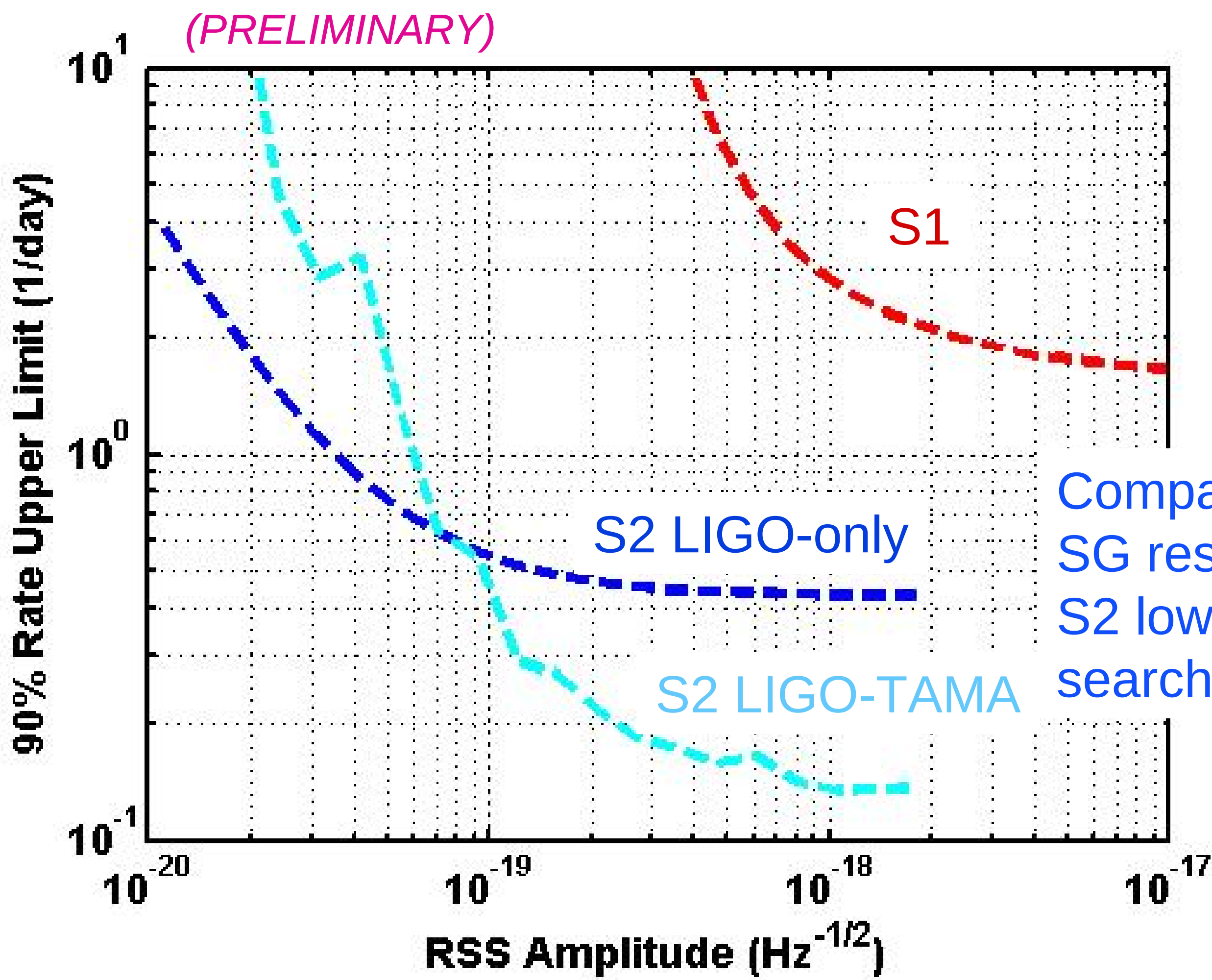


SG13 simulations

(Q=8.9 SG over [700,2000]Hz, with sky & polarization averaging)

$$R(h) = \frac{N}{\epsilon(h)T}$$

R vs h Upper Limits



Compare to 849Hz SG results from S1, S2 low-frequency searches.

Summary & Outlook

- TAMA-LIGO joint search for GWBs in S2 is in final stages.
  - » High-frequency search complementary to LIGO-only search at low frequencies.
- Two main parts:
  - » 4X: very low false rate (~few/century)
  - » 3X: lots of additional observation time
- No GWB candidates survived pipeline.
  - » Rate upper limit of 0.13/day.
  - » $h_{rss}^{50\%} = 2\times10^{-19}\mathrm{Hz}^{-1/2}$ averaged over networks, analysis band.

Summary & Outlook

- Remaining issues:
  - » Extra data to be analysed: TAMA has provided ~10% more triggers, observation time from end of DT8 (missed in exchange due to script bug).
  - » Livetime to be finalized (account for TAMA veto deadtime of few %)
  - » Include calibration uncertainty in efficiencies.
  - » Expect change in upper limits <10%.
  - » Review
- Paper draft in preparation.
  - » Preliminary draft circulated to burst group, circulate to LSC in December
  - » Hope to present results at GWDAW.
- S3?
  - » Exploring value of joint S3 search with LIGO, TAMA, GEO representatives.