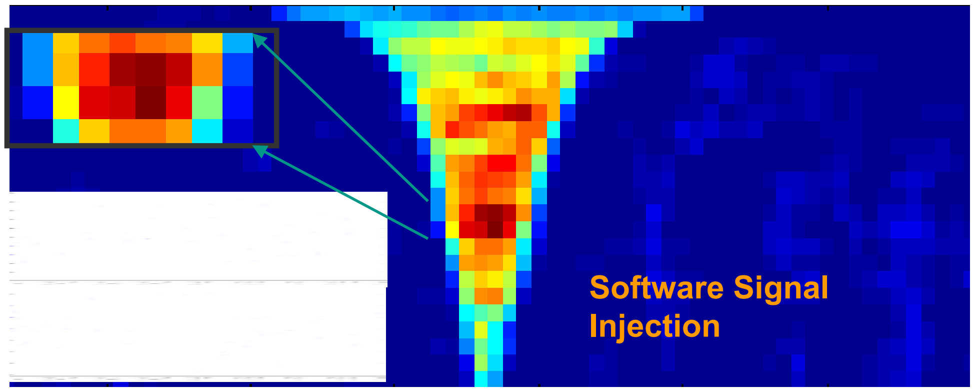
Experimental Upper Limit from LIGO on the Gravitational Waves from GRB030329



Stan Whitcomb

For the LIGO Scientific Collaboration

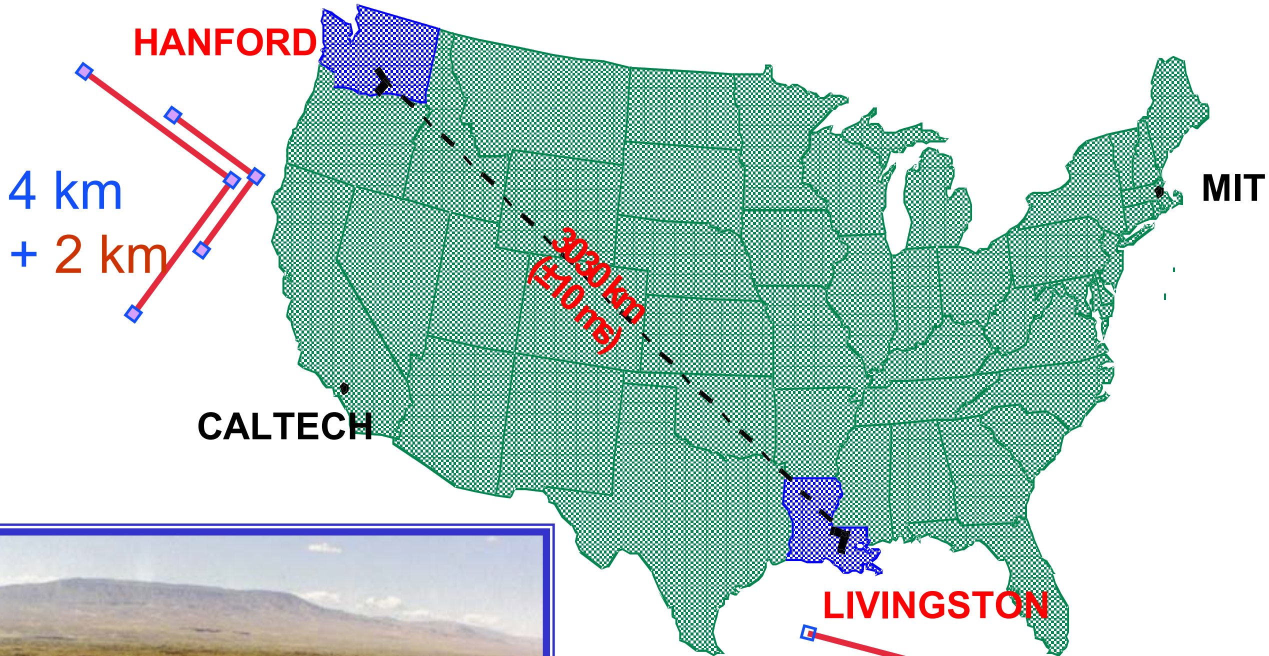
Informal Lunch Seminar

MIT

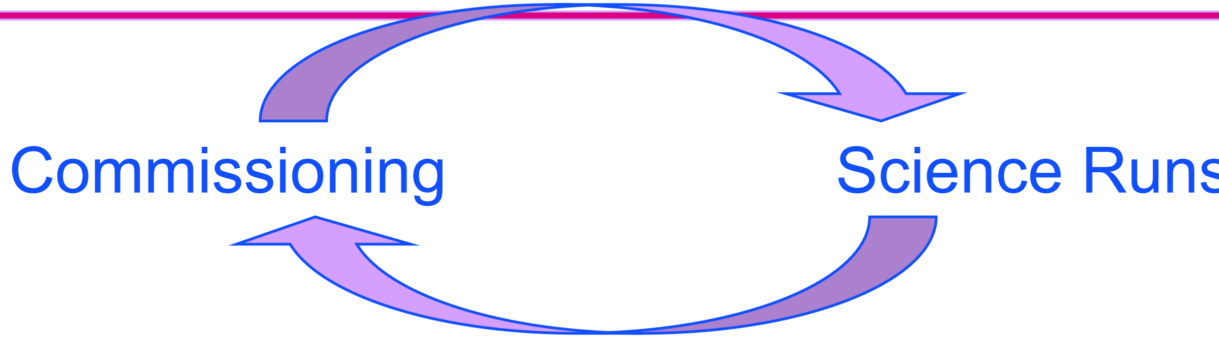
30 January 2004

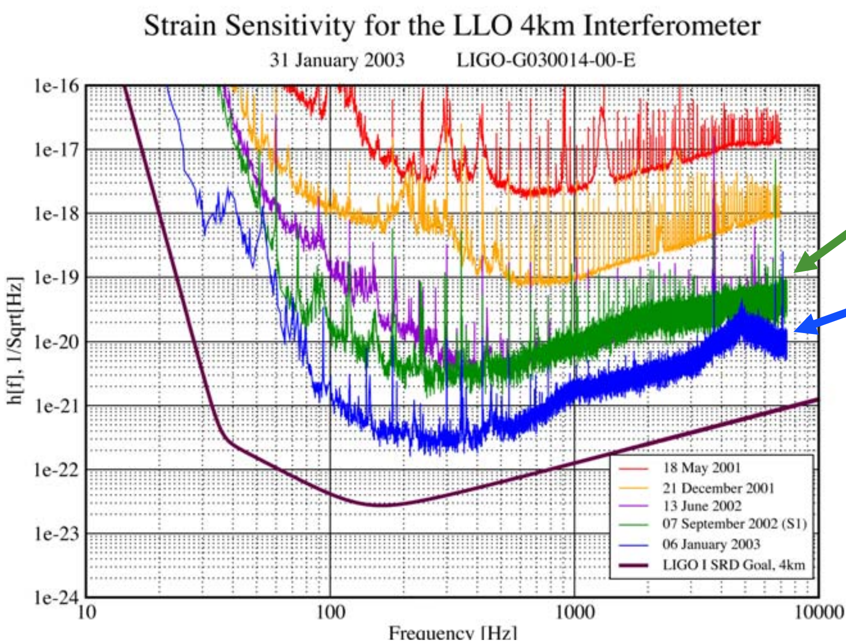
Special thanks to Szabi Marka

LIGO Observatories



Transition to Full Operation





S1 (papers "in press")

17 Days (Aug-Sep 2002)

S2 (this talk)

59 Days (Feb- Apr 2003)

S3 (even better)

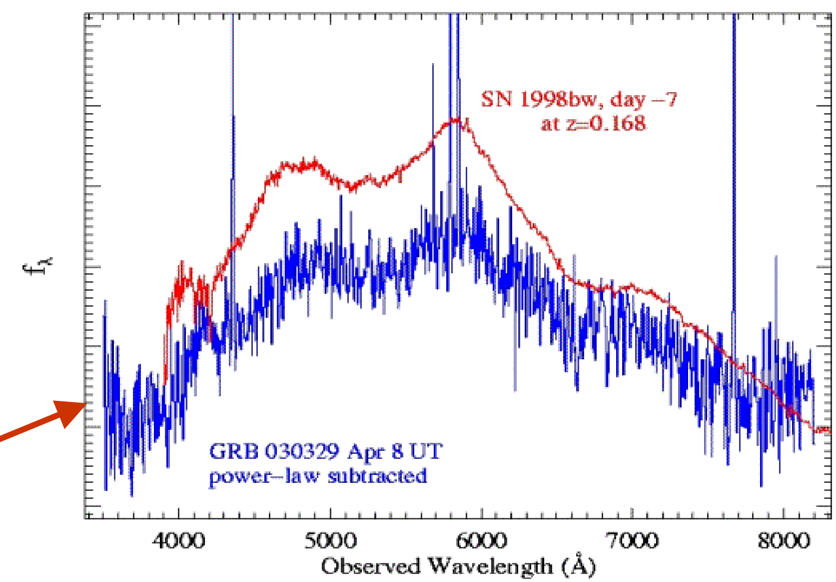
70 Days (Oct 03 – Jan 04)

GRBs during S2

GRB	GPS time	Locked IFO	LIGO segment	Location error
030217	729485155.00	H2/L1	27	well-defined
030218	729603771.00	H1/H2/L1/TA	39	annulus
030220	729792777.00	H1/TA	39	annulus
030223	730028719.00	H1/H2/L1/TA	60	annulus
030225	730220586.00	H2/TA	70	annulus
030226	730266404.99	H1/H2/L1	68	well-defined
030227	730370549.25	H1/H2/TA	89	well-defined
030228	730499219.00	H1/H2/TA	107	annulus
030301	730585653.00	H1/H2	119	annulus
030304	730856078.00	L1/TA	189	annulus
030306	730957115.00	H2/TA	156	well-defined
030307	731082733.00	H1/H2/TA	170	annulus
030317	731919546.00	H1/L1	276	annulus
030320a	732190313.00	H1/H2/L1/TA	236	well-defined
030320b	732221370.00	H1/H2/TA	226	annulus
030323a	732444157.00	H1/H2/L1/TA	267	well-defined
030323b	732491830.60	H1/H2/L1/TA	273	well-defined
030324	732510775.80	H1/H2	249	well-defined
030325	732636923.00	H1/H2/L1/TA	294	well-defined
030326	732710634.00	H1/H2/L1/TA	304	well-defined
030328	732885671.34	H2/TA	295	well-defined
030329a	732973047.67	H1/H2/TA	292	well-defined
030329b	732987260.35	H1/H2/TA	294	well-defined
030331	733124333.82	H1/L1	428	well-defined
030403	733376279.00	H1/L1(6s)	455	annulus
030405	733544261.00	H1/H2/L1/TA	387	well-defined
030406	733704140.00	H1/L1/TA	487	well-defined
030410	734009035.00	H1/H2/TA	385	annulus
030413	734254490.00	H2/L1/TA	494	well-defined
030414	734363320.00	H1/H2/TA	411	well-defined

Supernova Spectrum Emergence

GRB 030329 is now also SN2003dh



T. Matheson (CfA), GCN 2120

Both Hanford detectors operating for GRB030329

Signal region and GRB030329 trigger

Relative delay between gravity wave and GRB predicted to be small

- **Signal region to cover most predictions**

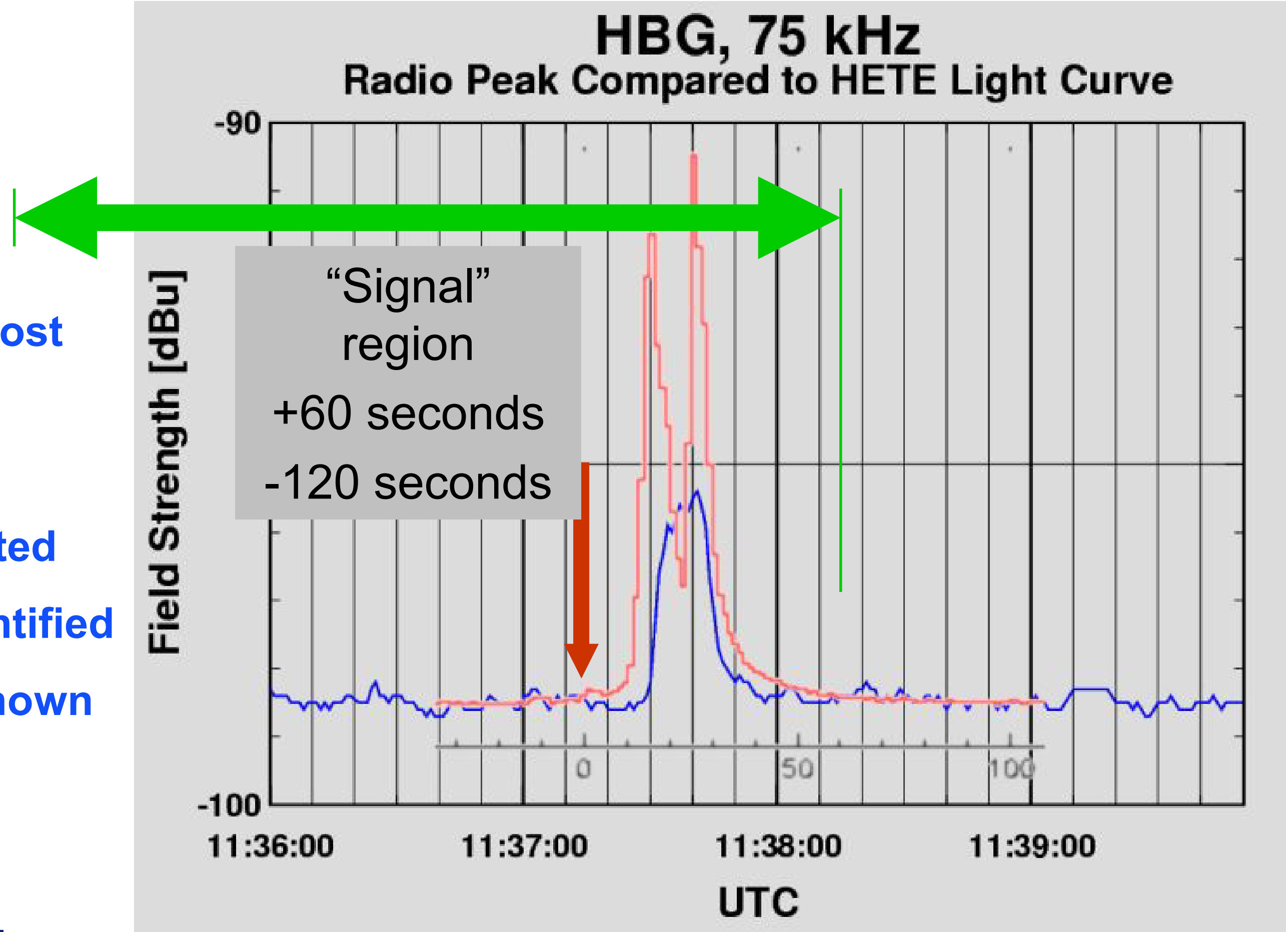
Known direction

- **Optical counterpart located**
- **LIGO antenna factor identified**
- **LIGO arrival times are known**

Source distance is known

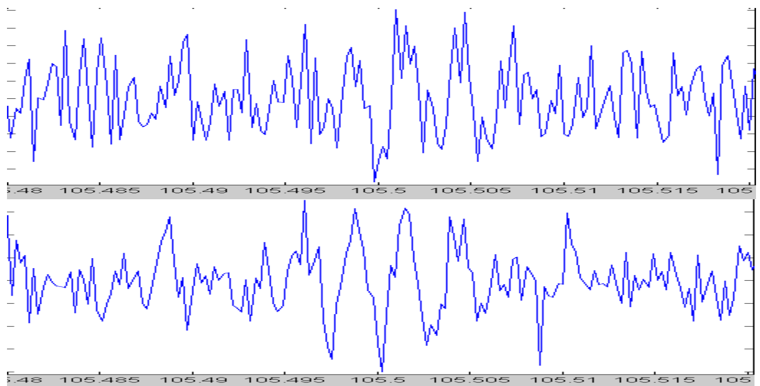
- **z=0.1685 (d~800Mpc)**

Unknown waveform/duration



http://www.mpe.mpg.de/~jcg/grb030329.html

Correlation Analysis



$$s_1(t) = h(t - t_1) + n_1(t)$$

$$s_2(t) = h(t - t_2) + n_2(t)$$

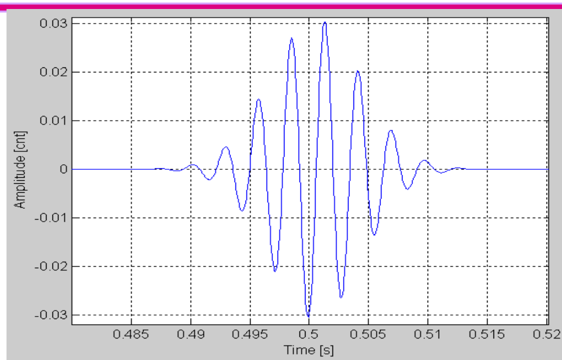
$$C(t, t_w, t_{off}) = \int_{t - t_w/2}^{t + t_w/2} s_1(t') s_2(t' + t_{off}) dt'$$

$$\approx \int_{t_w} h^2(t) dt + \int_{t_w} n_1(t) n_2(t) dt$$

h_{rss}^2

< > = 0

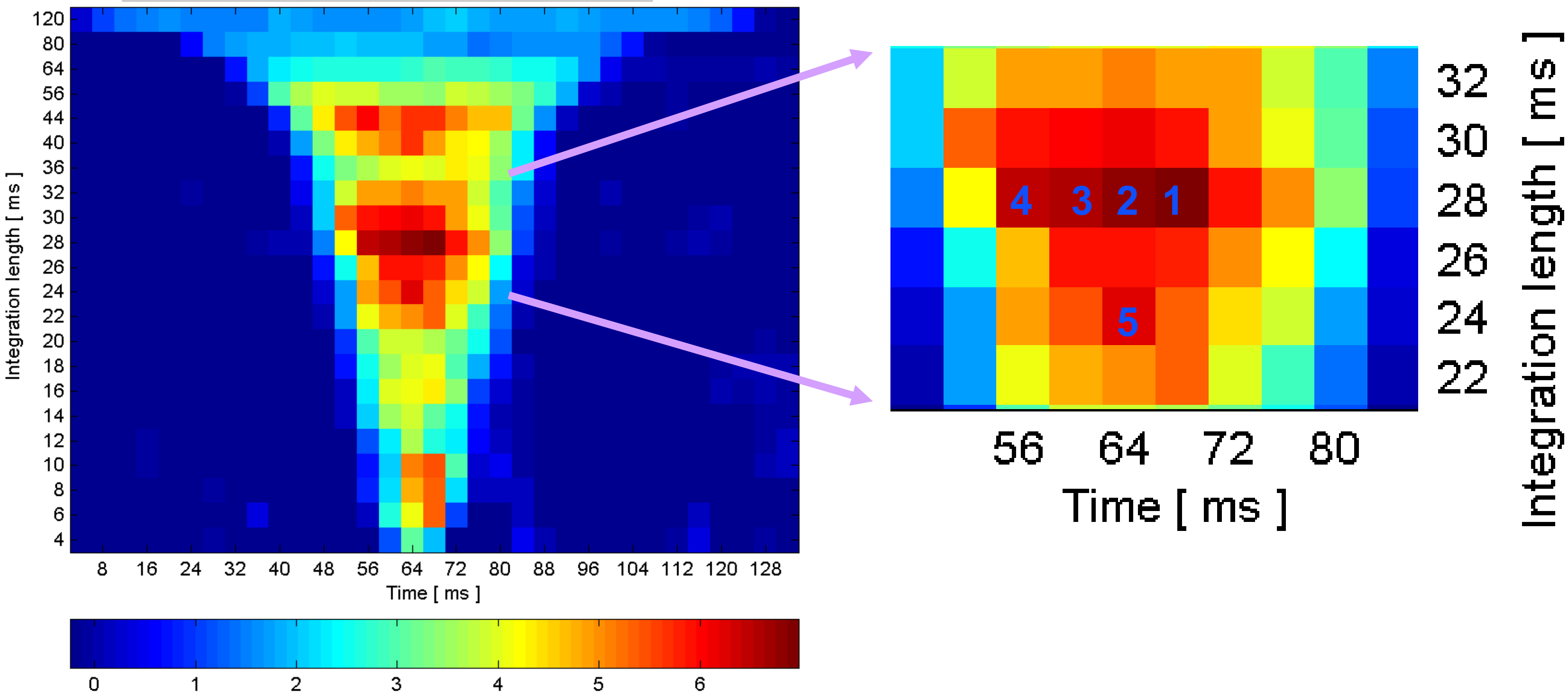
Event Identification - Simulated Signal



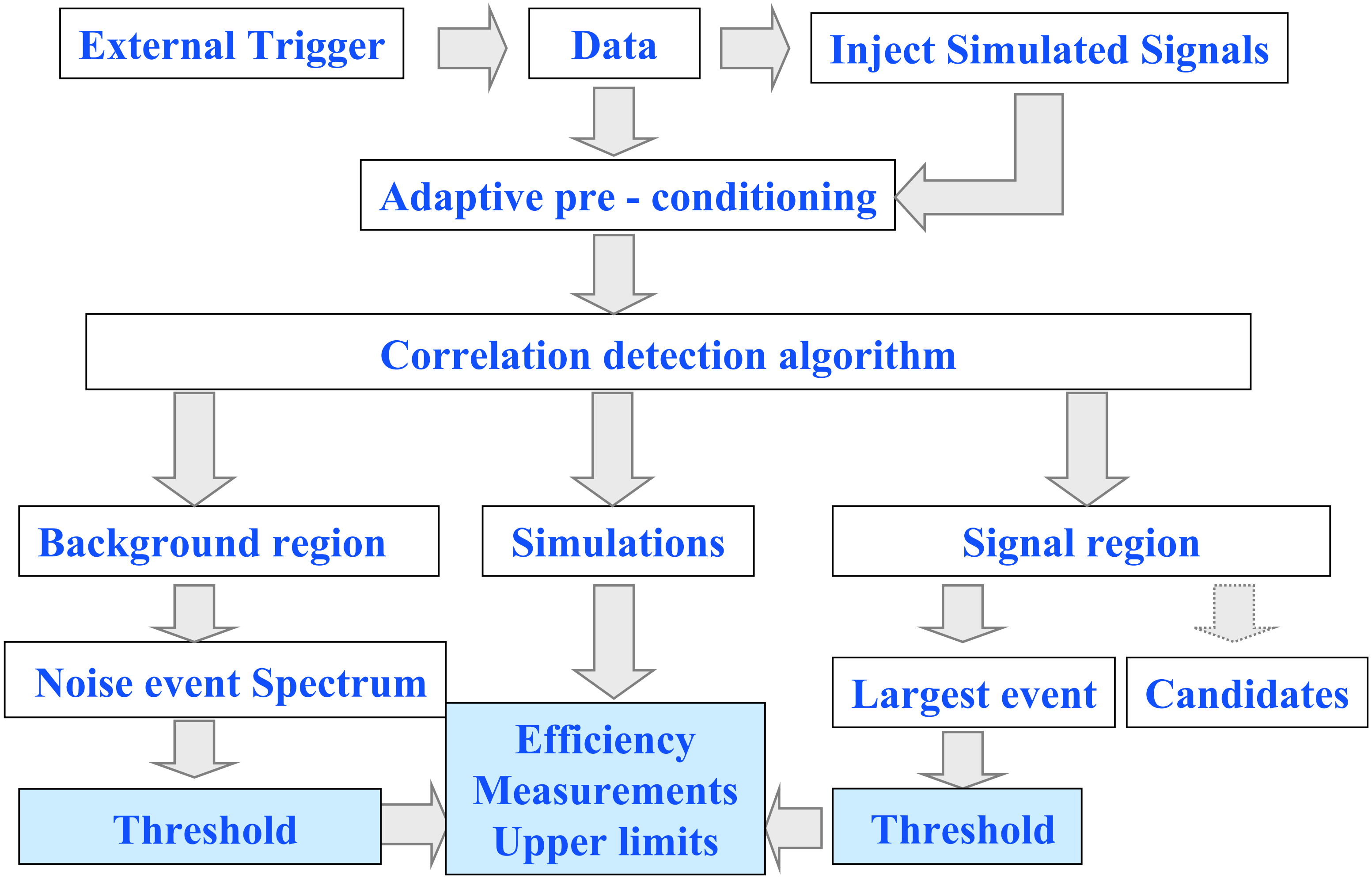
Color coding: “Number of variances above mean”

<u>Event strength</u> [ES] calculation:

Average value of the “optimal” pixels

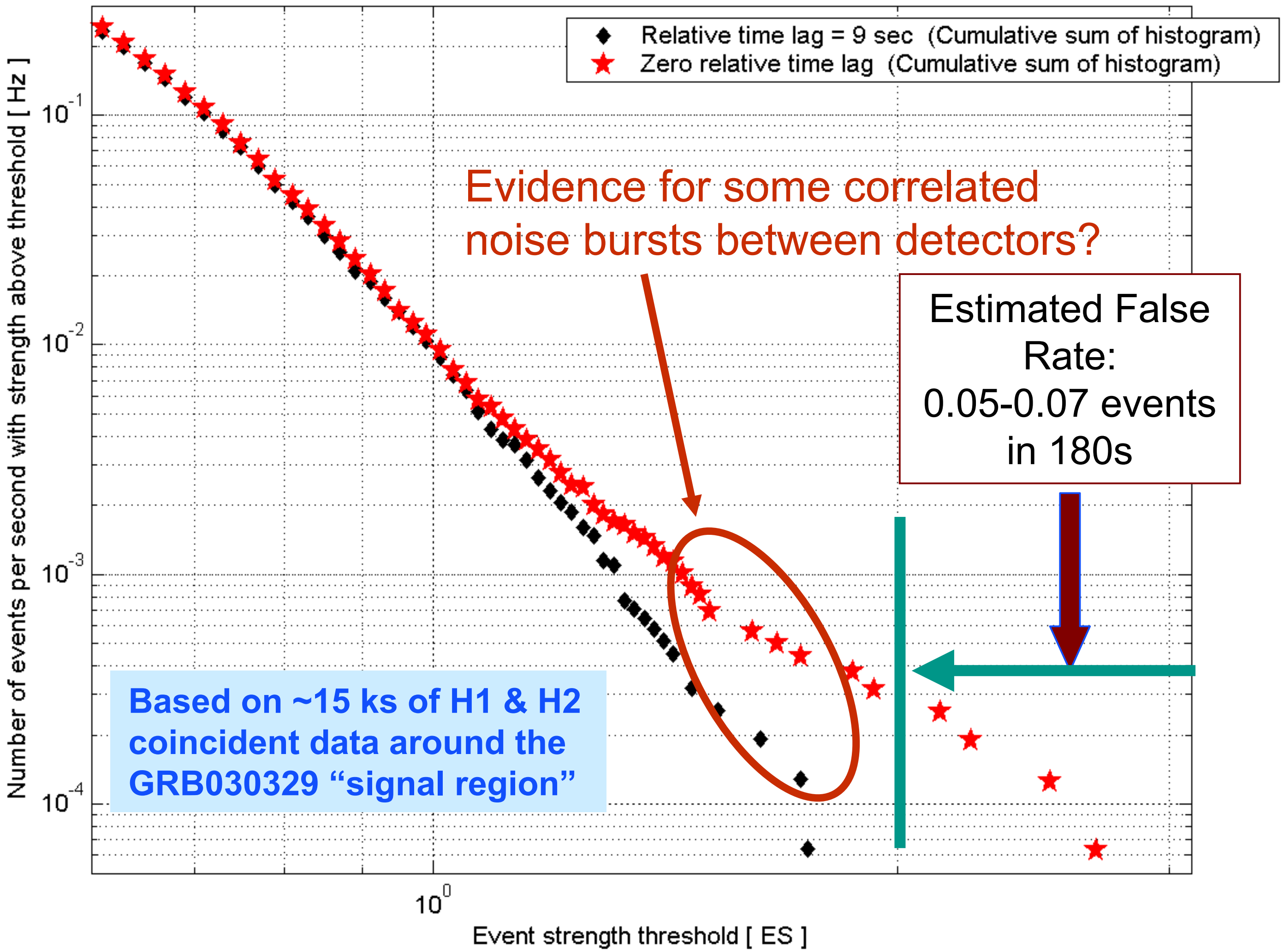


Analysis Flow Chart

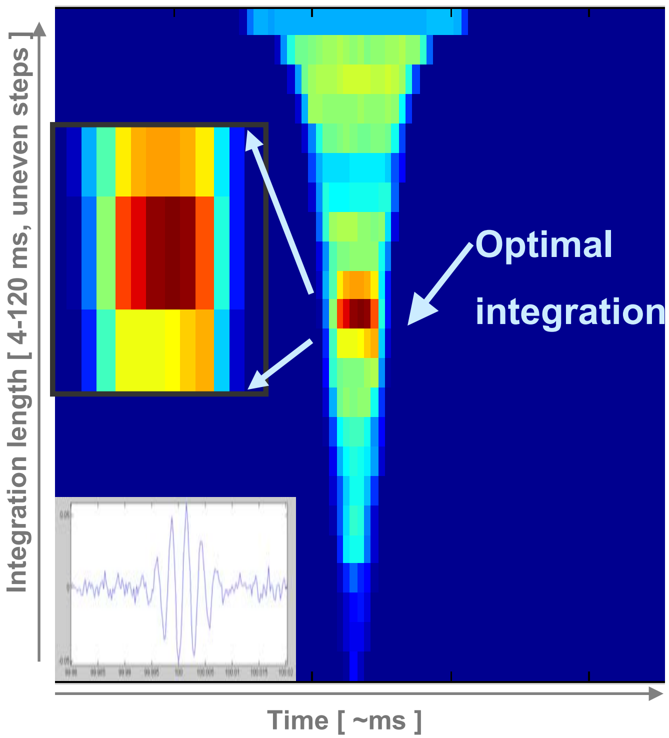


Spectrum of Noise Events

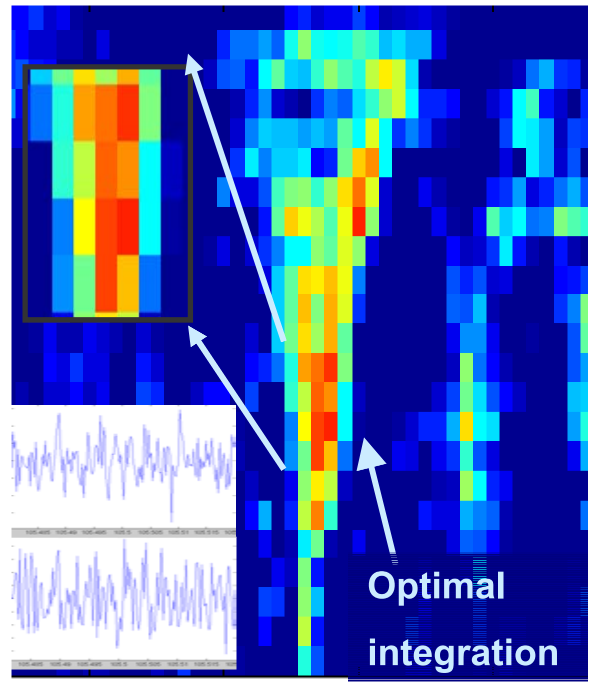
Note: Preliminary !



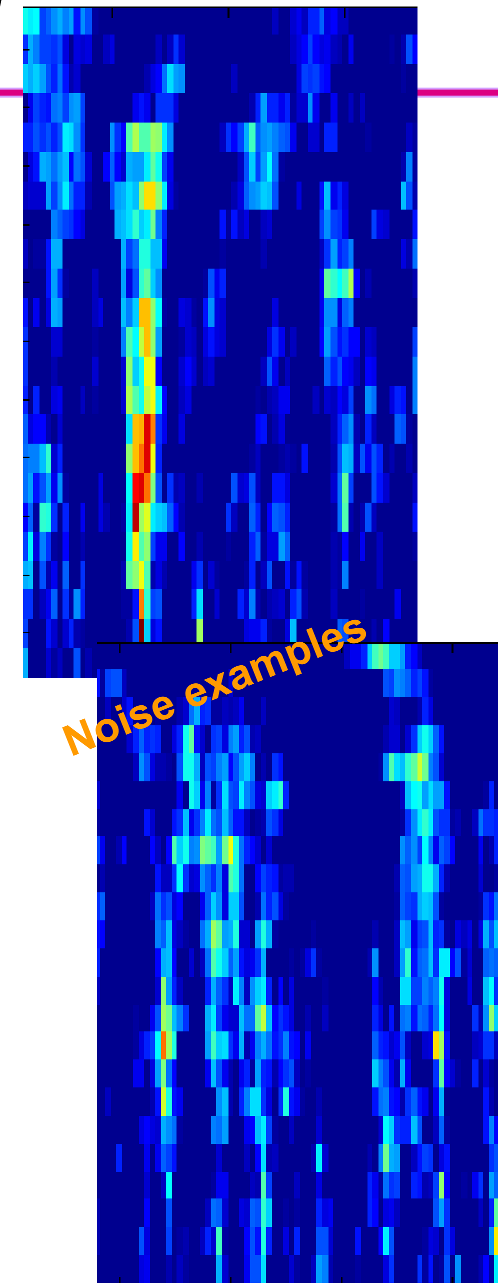
Sensitivity Determination



"Huge" Sine-Gaussian
F = 361Hz, Q = 8.9
h_{RSS} ~ 6x10^{-20} [1/√Hz]

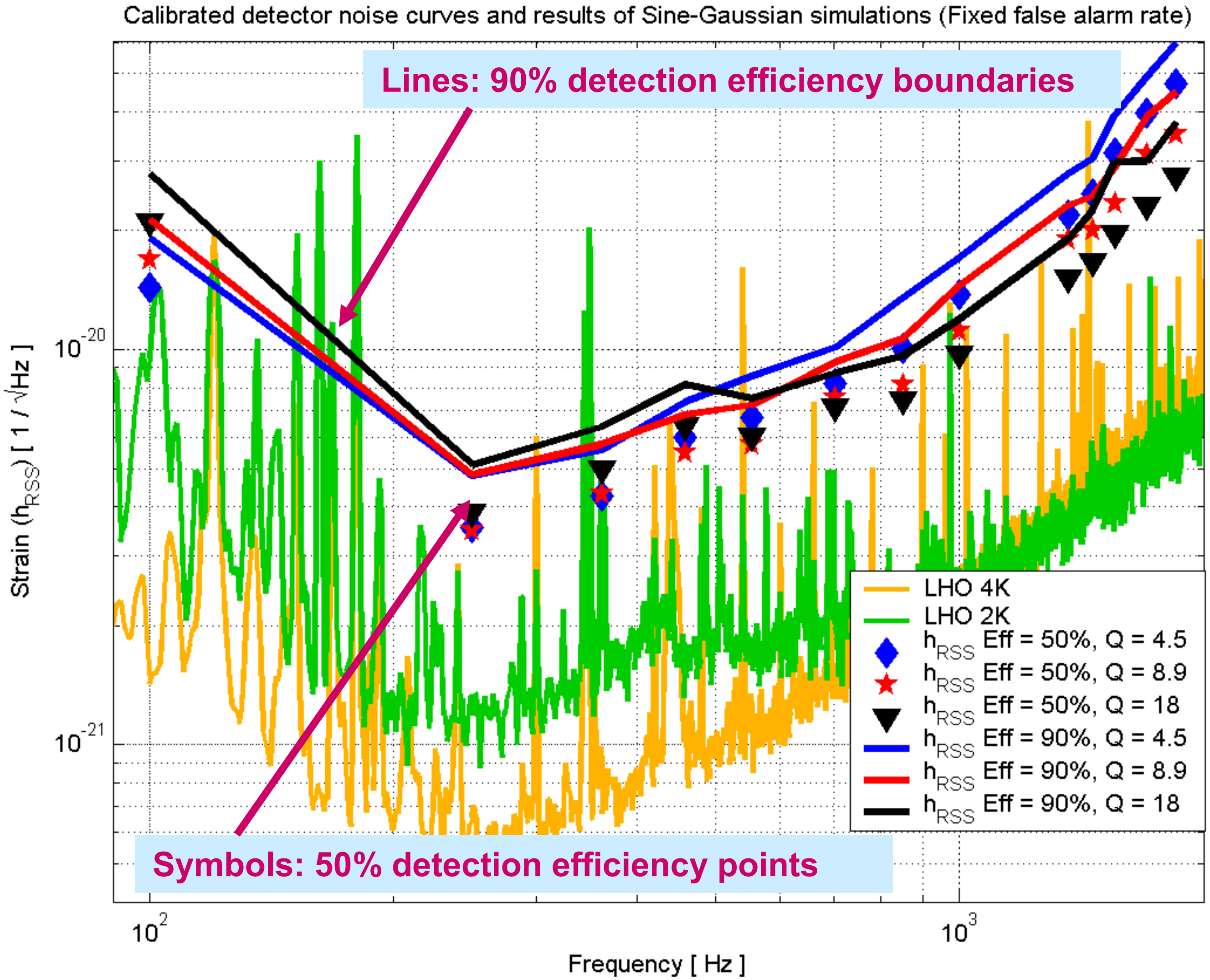


"Small" Sine-Gaussian
F = 361Hz, Q = 8.9
h_{RSS} ~ 3x10^{-21} [1/√ Hz]
(~ detection threshold)



Detection Efficiency at Fixed False Alarm Rate

Note: Preliminary !

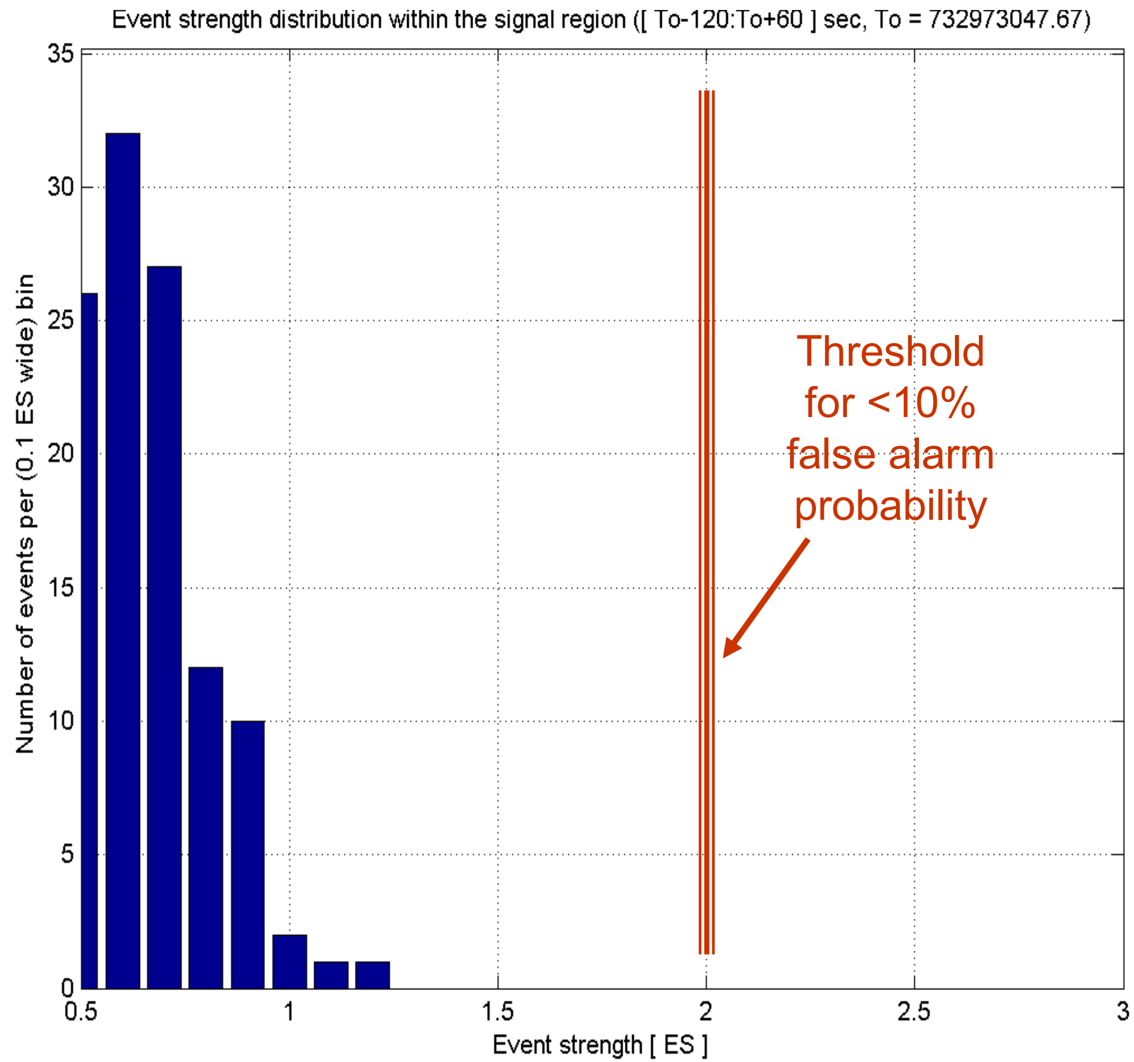


- Calibration known within ~10%
- Detection efficiencies obtained for threshold corresponding to ~4 x 10^{-4} Hz false alarm rate (<10% probability of noise event in 180 sec)
- H1/H2 noise curves reflect levels around GRB030329

Events Within the Signal Region

Note: Preliminary !

- **The signal region seems to be "relatively quiet" when compared to the neighboring regions**
- **No event was detected with strength above the pre-determined threshold**
- **It is an upper limit result**



Observed Limit on h_{rss} Relates to GW Energy

$$P_{GW} \propto \left| \frac{dh(t)}{dt} \right|^2$$

For an observation (or limit) made at a luminosity distance *d* from a source

$$E_{GW} = \left(\frac{2\pi^2 c^3}{G} \right) d^2 \int_0^\infty f^2 \left| \tilde{h}(f) \right|^2 df$$

$$\approx \left(\frac{2\pi^2 c^3}{G} \right) d^2 f_c^2 \int_0^\infty \left| \tilde{h}(f) \right|^2 df$$

h_{rss}^2

LIGO

Example: Estimating E_{GW} for GRB030329

Note: Preliminary !

H1-H2 only

Antenna attenuation factor ~0.37 (assuming optimal polarization)

$z = 0.1685 \Rightarrow d \approx 800\text{Mpc}$

For narrowband GWs near minimum of noise curve (simulated with Q≈9 250 Hz sine-Gaussian), obtain 90% efficiency

$$h_{RSS} \lesssim 5 \times 10^{-21} \, [1/\sqrt{\text{Hz}}]$$

$$\Rightarrow E_{GW} \lesssim 125 \, M_{\odot} \, (1 / 0.37) \approx 340 \, M_{\odot}$$

Summary and Prospects for Future Searches

- Executed a sensitive, cross-correlation based search for gravitational wave bursts around GRB030329
- Sensitivity (depending on frequency)
  h_{RSS} < few x 10^{-21} [1/√Hz]
  - » Current limit of some hundreds of $M_{\odot}$ in GWs
  - » Detector improvement: both detectors, factor of 10 – 30 (in h_{rss}) between S2 and final sensitivity (depending on frequency…)
    ⇒ improvement of 100 – 300 in E_{GW}
  - » Beaming factor: estimate for every GRB detected, 100 to 500 "missed" -- reasonable for one year of observation might give 10 times closer event (cf. SN1998bw at ~ 40 Mpc)
    ⇒ another factor of 100 in E_{GW}
  - » More detectors, better location in antenna pattern, better discrimination against noise events….
  - » very realistic chance to set a <u>sub-solar mass limit</u> in the near future