Search for a Gravitational-Wave Burst Associated with GRB 070201 using LIGO Data

Isabel Leonor
University of Oregon

For the LIGO Scientific Collaboration
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Outline of burst search

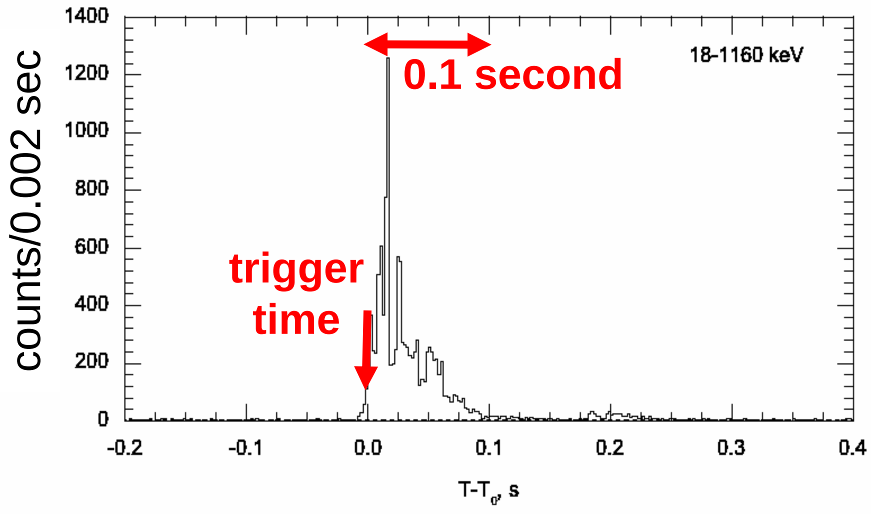
- search for unmodelled, short-duration gravitational-wave burst (GWB) coincident with GRB 070201
- search 180 seconds of LIGO data surrounding trigger time of GRB 070201 (on-source segment)
- use crosscorrelation of two interferometers (IFOs) to search for associated GW signal

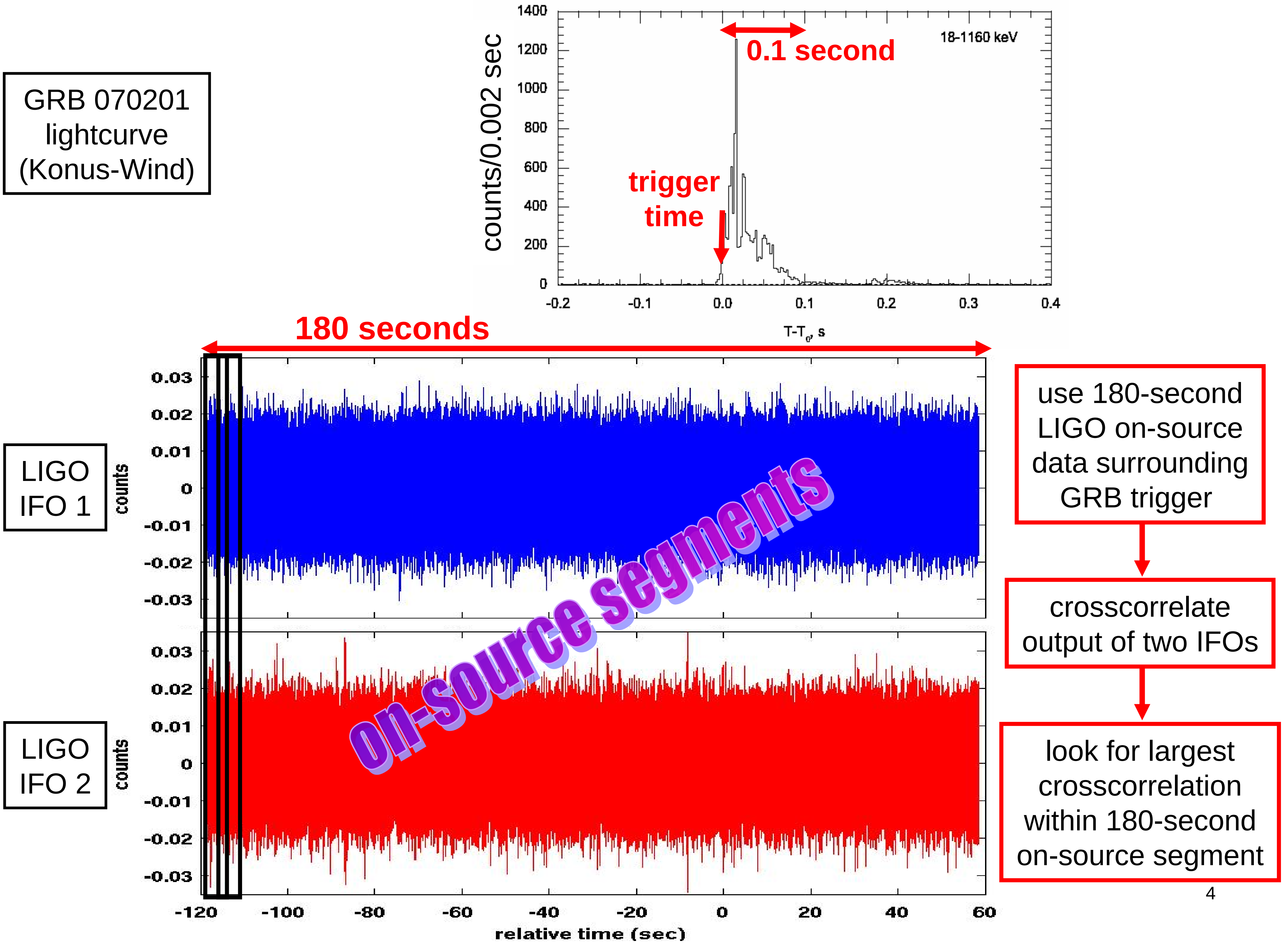
$$crosscorr = \frac{\sum_i x_i y_i}{\sqrt{\sum_j x_j^2}\sqrt{\sum_k y_k^2}}$$

correlated signal in two IFOs
➔ large crosscorr

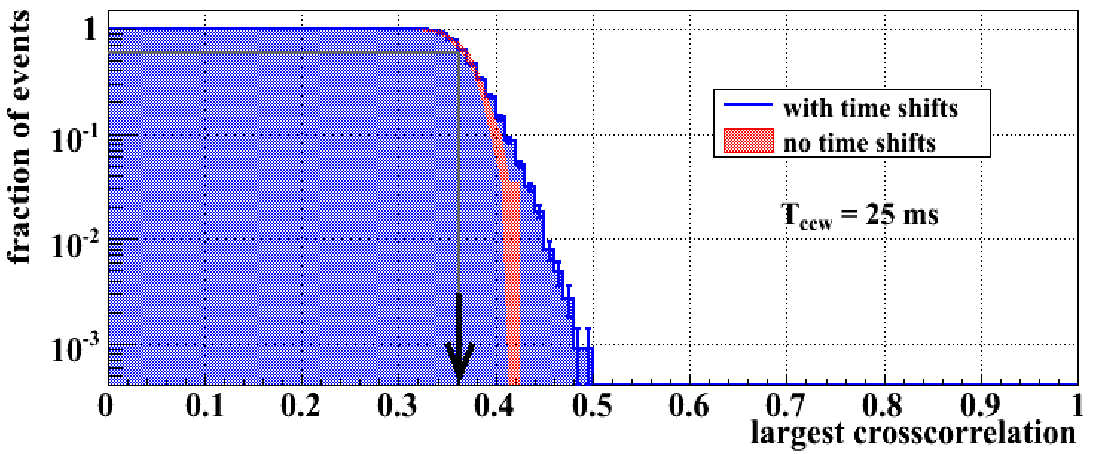
- use crosscorrelation lengths of 25 ms and 100 ms to target short-duration GW bursts of durations ~1 ms to ~100 ms
- use bandwidth of 40 Hz to 2000 Hz

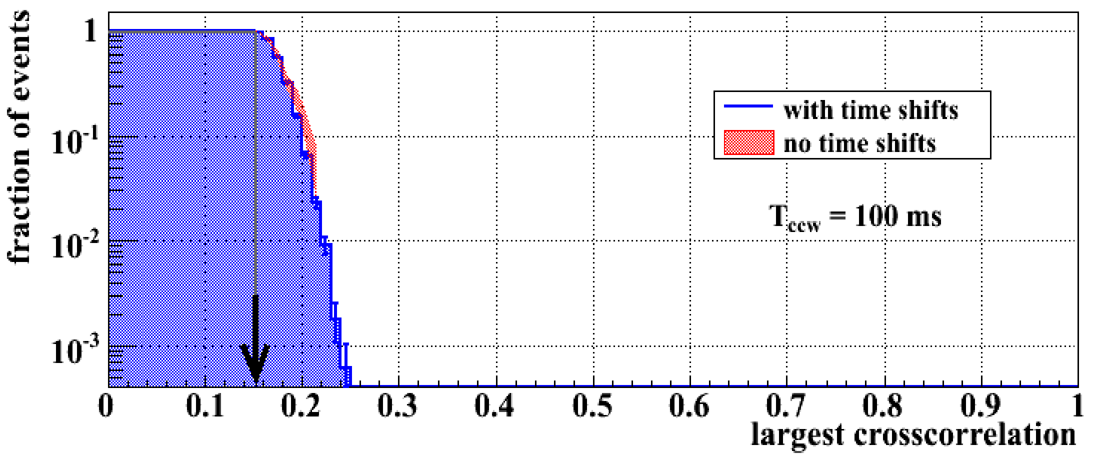
GRB 070201
lightcurve
(Konus-Wind)




GRB 070201
lightcurve
(Konus-Wind)
counts/0.002 sec
1400
1200
1000
800
600
400
200
0
0.1 second
18-1160 keV
trigger
time
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
T-T0, s
180 seconds
LIGO
IFO 1
counts
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
LIGO
IFO 2
on-source segments
-120
-100
-80
-60
-40
-20
0
20
40
60
relative time (sec)
use 180-second
LIGO on-source
data surrounding
GRB trigger
crosscorrelate
output of two IFOs
look for largest
crosscorrelation
within 180-second
on-source segment

Burst search results: probability of largest on-source crosscorrelation





- applied search to off-source segments
- used three hours of off-source data surrounding on-source segment to estimate background distribution of largest crosscorrelation
- false alarm probability of on-source largest crosscorrelation is estimated using this distribution:

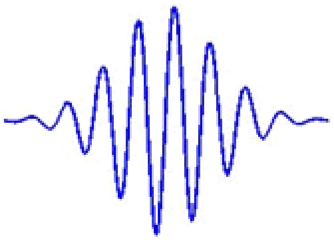
p = 0.58 for 25-ms cc
p = 0.96 for 100-ms cc

→consistent with null hypothesis

Estimating $\mathbf{h_{rss}}$ sensitivity using sine-gaussian waveforms

$$h_{\rm rss} = \sqrt{\int \left(| h_{+}(t) |^2 + | h_{\times}(t) |^2 \right) dt}$$

take into account antenna factor and interferometer response



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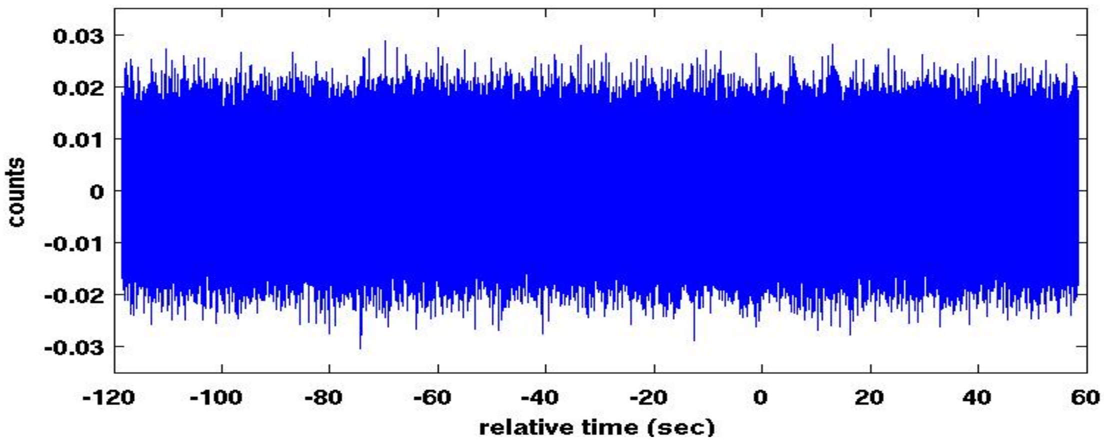
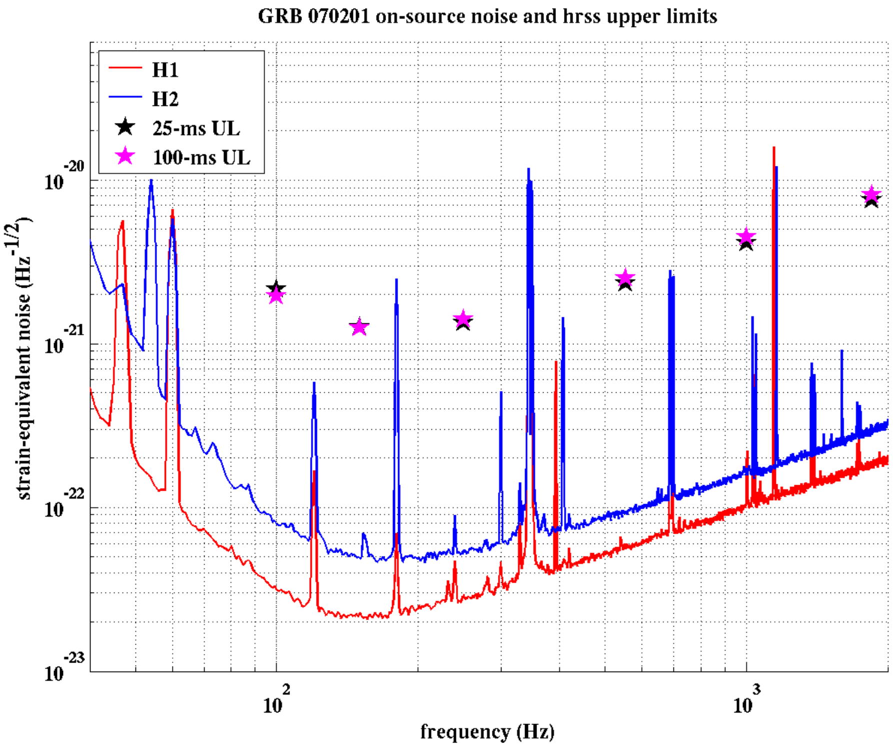


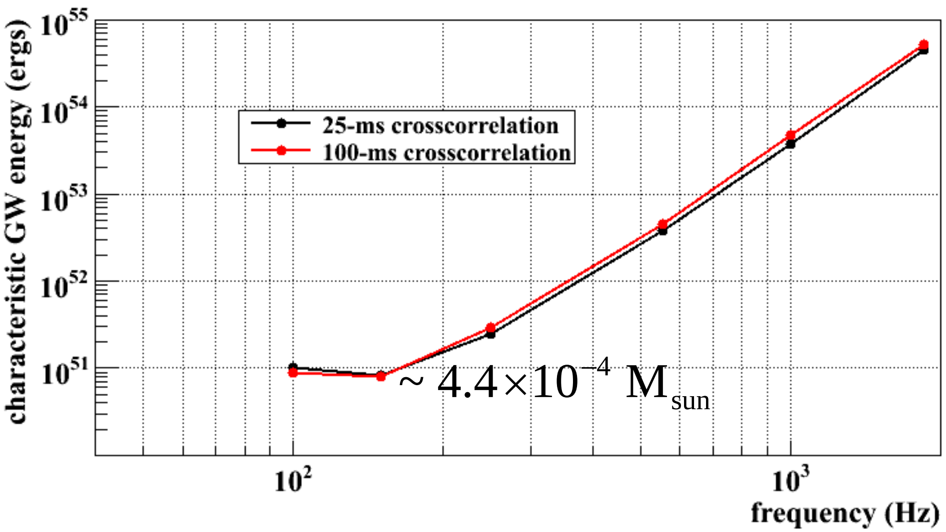
- GW waveforms not known
- inject simulated sine-gaussians into data to estimate search sensitivity
- use circular polarization
- take into account antenna response of interferometers
- measure crosscorrelation with injected signal in data

90% confidence upper limits on hrss: Q = 8.9, circularly polarized sine-gaussians



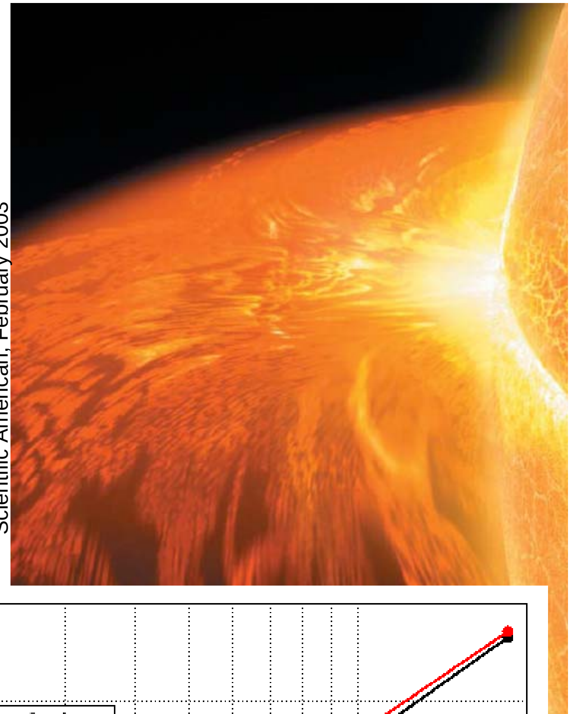
Corresponding GW energy, assuming isotropic emission, with source at D = 770 kpc:

$$E_{\mathrm{GW}} \approx \frac{\pi^2 c^3}{G} D^2 f_0^2 h_{\mathrm{rss}}^2$$

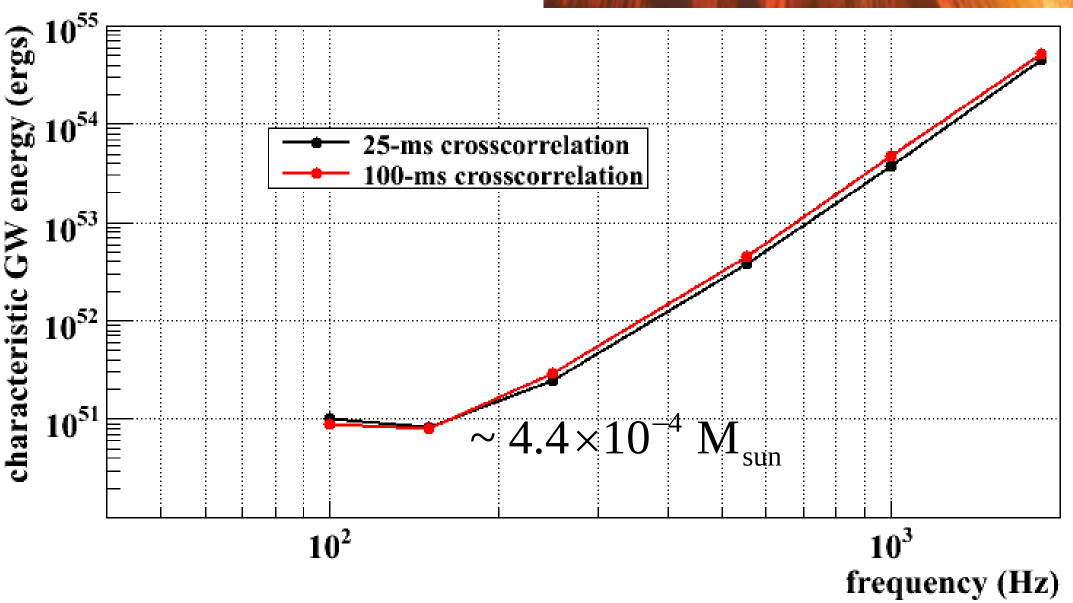


Implication for soft gamma repeater (SGR) model in M31

SGR: highly magnetized neutron star; can emit giant flares (rare) (arXiv:0712.1502)



Scientific American, February 2003



- giant flare from SGR: one hypothesized explanation for 070201 burst
- energy release in gamma rays consistent with SGR model
- measured gamma-ray fluence = 2 x 10^{-5} ergs/cm^{2} (Konus-Wind)
- corresponding energy release in gamma-rays at M31,

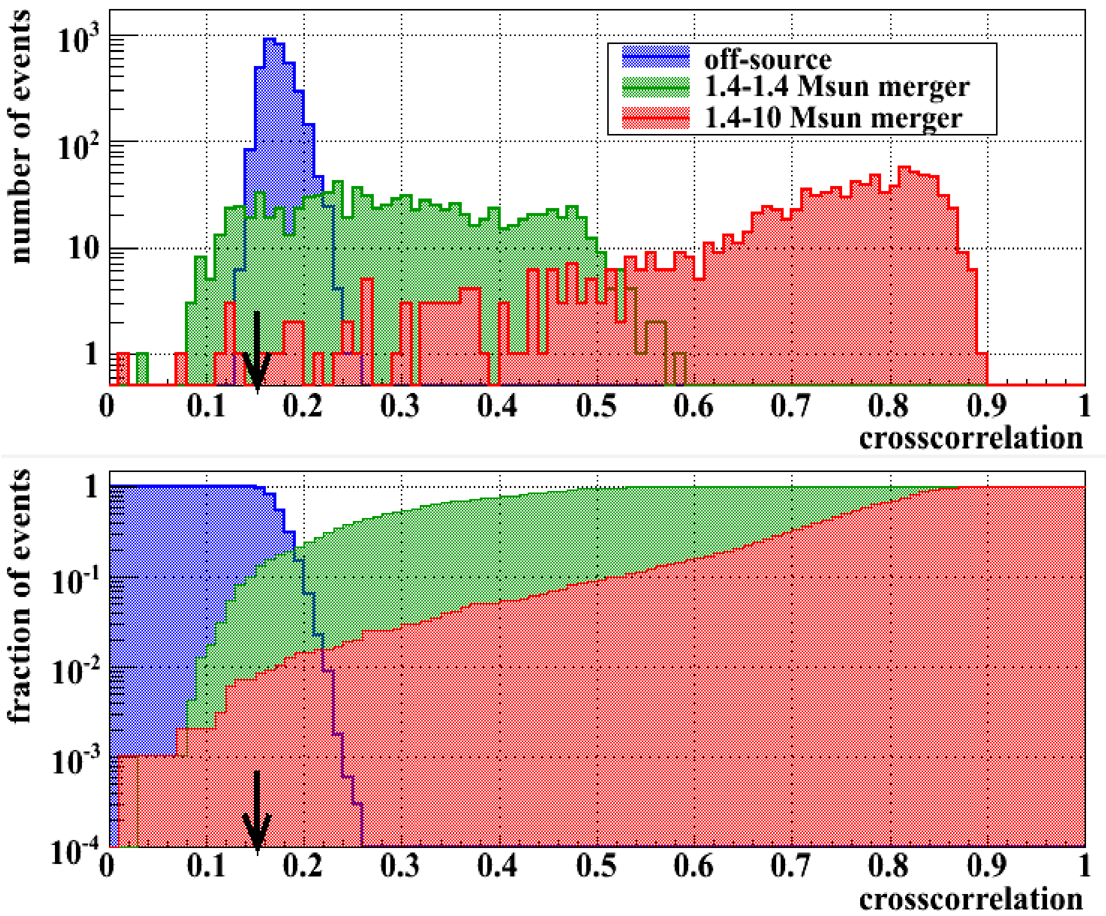
$$E_{\gamma,\mathrm{iso}} = \phi \times 4\pi D^2 \approx 10^{45}\ \mathrm{ergs}$$

➔ orders of magnitude smaller than LIGO limit on energy release in GW for GRB 070201

- SGR models predict energy release in GW to be no more than ~10^{46} ergs

LIGO limits on GW energy release from GRB 070201 do not exclude an SGR model in M31

Efficiency of burst search for simulated inspiral signals at M31 (100-ms search)



- injected into on-source segment simulated NS-NS inspirals (1.4-1.4 Msun), and NS-BH inspirals (1.4-10 Msun)
- inclination angles of binary plane were isotropically distributed
- simulations did not include merger phase of coalescence
- measured fraction of events which had crosscorrelations larger than the on-source largest crosscorrelation
- **at 90% confidence,**

efficiency > 0.878, 1.4-1.4 Msun
efficiency > 0.989, 1.4-10 Msun

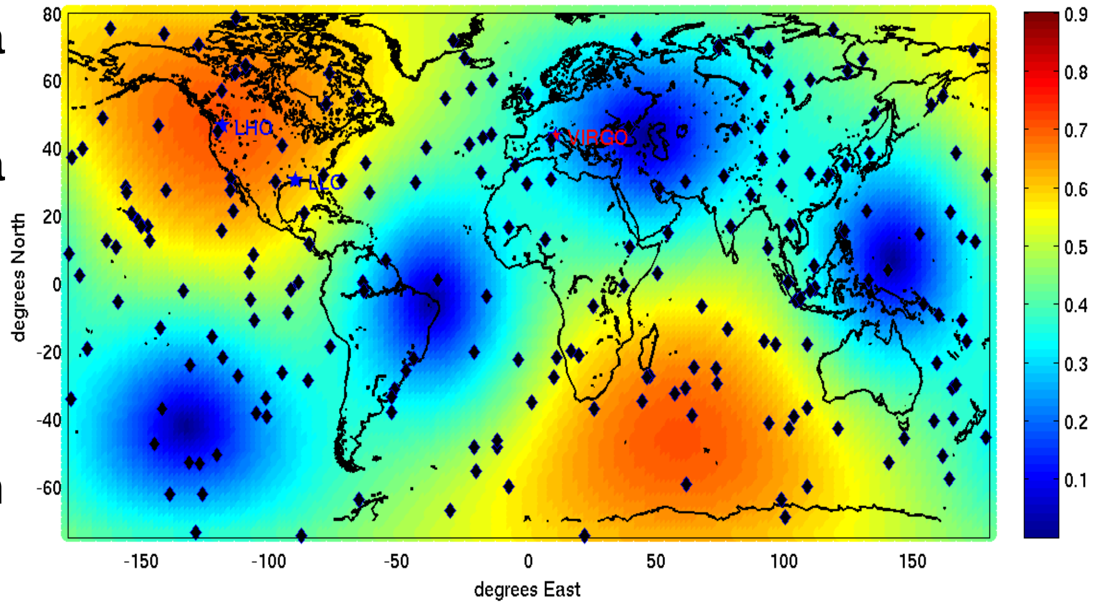
These results give an independent way to reject hypothesis of a compact binary progenitor in M31

The GRB sample for the LIGO S5 run

- **213 GRB triggers from November 4, 2005 to September 30, 2007**
  - **~70% with double-IFO coincidence LIGO data**
  - **~40% with triple-IFO coincidence LIGO data**
  - **~25% with redshift**
  - **~10% short-duration GRBs**
  - **all but a handful have have accurate position information**
- **analysis is ongoing using both burst search and inspiral search algorithms**

GRB triggers were mostly from Swift; some were from IPN, INTEGRAL, HETE-2

Polarization-averaged LHO antenna factor F_{ave}



search sensitivity also depends on GRB position

Summary

- results of GW burst search in 180-second on-source segment for GRB 070201 are consistent with null hypothesis
- we have set 90% confidence upper limits on hrss using circularly polarized Q=8.9 sine-gaussians
  - corresponding limits on isotropic energy emission in GW do not exclude an SGR model in M31
- we have measured the efficiency of the burst search to simulated inspiral waveforms using a threshold set at the largest on-source crosscorrelation
  - results give an independent way to reject hypothesis of a compact binary progenitor in M31
- analysis is ongoing to search for gravitational waves associated with sample of 213 GRB triggers contemporaneous with LIGO S5 run