Search for gravitational-wave burst (GWB) counterparts to gamma-ray bursts (GRB) using data from the fifth LIGO science run and the first Virgo science run

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LIGO-G0900392-v2

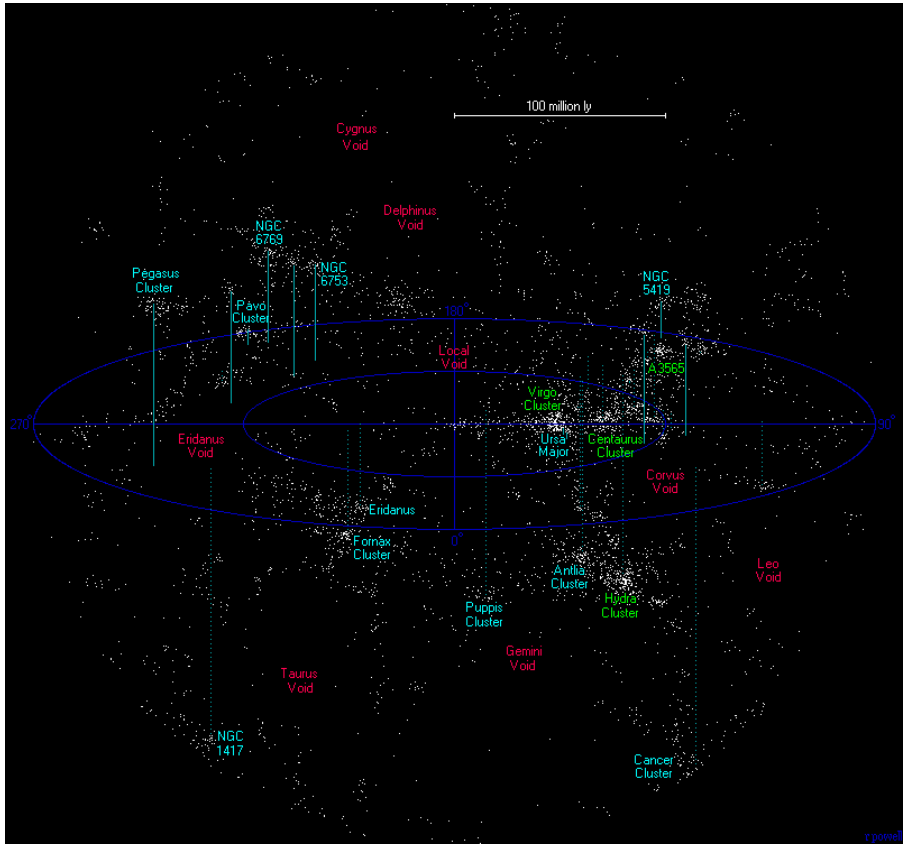
GRB-GWB triggered burst search with LIGO-Virgo

- GRBs are at cosmological distances (z ~ 1)
  - short GRBs nearer
- volume of sensitivity depends on strain amplitude sensitivity of interferometers

$$V \propto D_{\text{reach}}^3 \propto h_{\text{IFO}}^{-1/3}$$

- special GRBs, e.g. GRB 070201
- LIGO-Virgo S5/VSR1 run
  - 2 years total run time; ~200 GRB triggers, mostly from Swift
- enhanced LIGO-Virgo
  - GRB triggers mostly from Fermi+Swift; factor of 3 increase in trigger rate

initial LIGO-Virgo: D ~ 50 Mpc
thousands of large galaxies,
hundreds of galaxy groups



Source: www.atlasoftheuniverse.com

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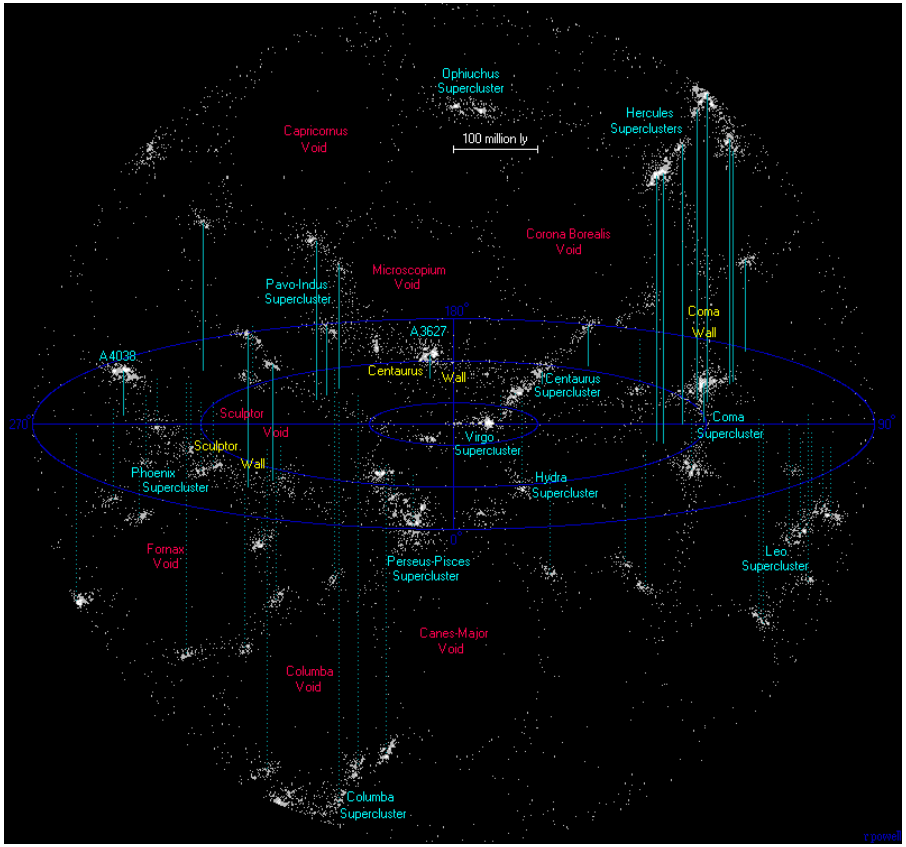
enhanced LIGO-Virgo: D ~ 100 Mpc
several hundred thousand large galaxies, dozens of galaxy clusters



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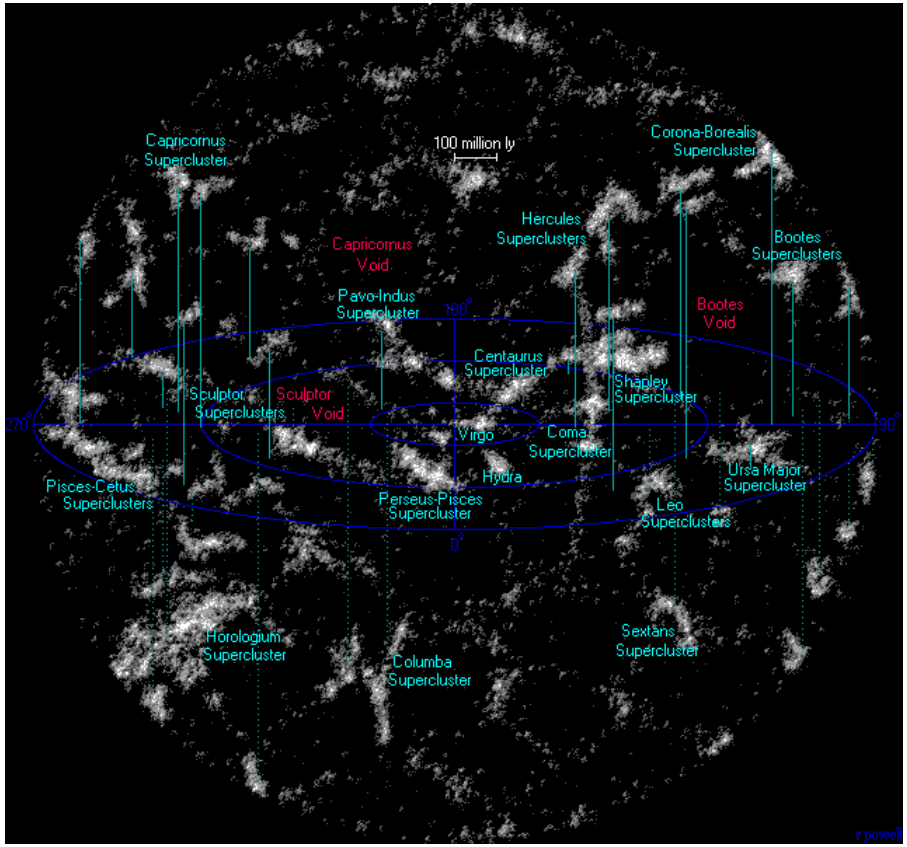
advanced LIGO-Virgo: D ~ 500 Mpc
millions of large galaxies,
hundreds of superclusters



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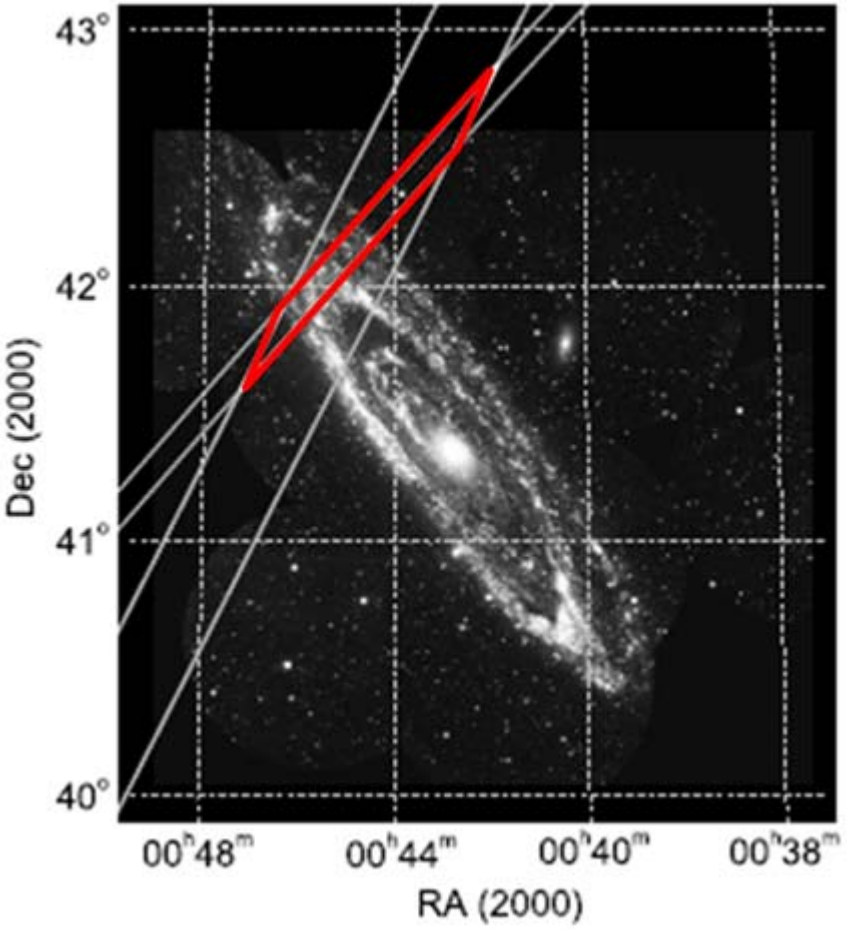
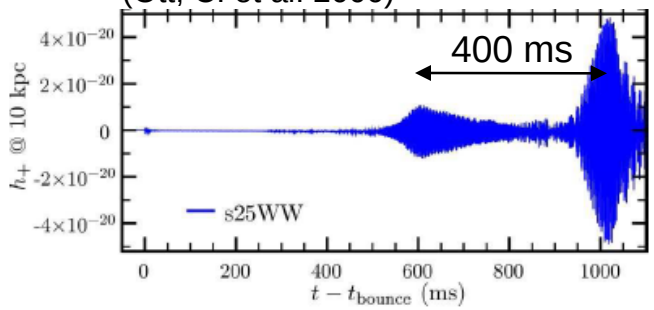
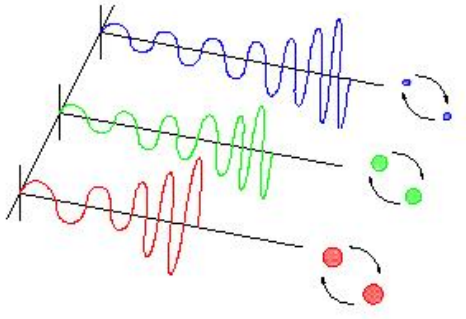
(arXiv:0712.1502)
GRB 070201 error box overlapped spiral arm of Andromeda galaxy



Methods of searching for gravitational-wave (GW) counterparts to GRBs

(Ott, C. et al. 2006)





Search for GW burst signals

- model-independent
- cross-correlate different data streams; fully coherent network search
- target GW burst signals less than ~few seconds
- used to search for GW counterpart to long and short GRBs

Search for GW inspiral signals

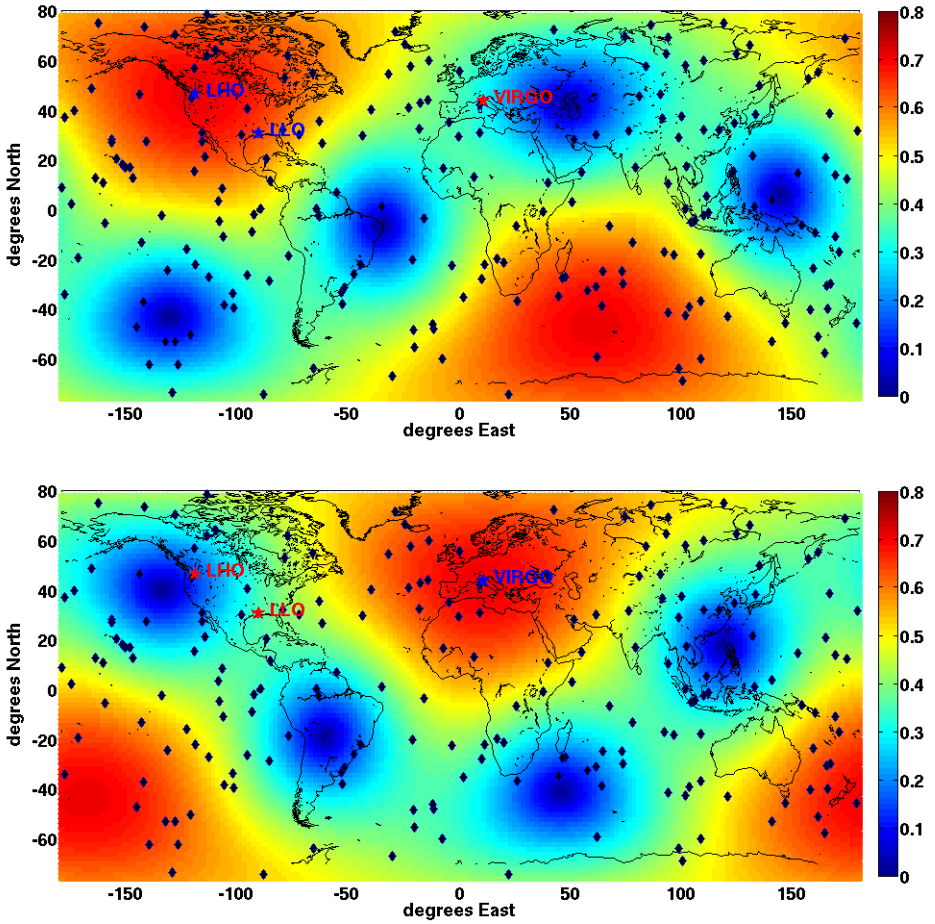
- makes use of inspiral templates
- cross-correlate data stream with inspiral templates
- target GW inspiral signals from coalescing masses in the range $1\ M_\odot < m_1 < 3\ M_\odot$, $1\ M_\odot < m_2 < 40\ M_\odot$
- used to search for GW counterpart to short GRBs

The GRB sample for the LIGO S5/VSR1 run

- **212 GRB triggers** from Nov. 4, 2005 to Oct. 1, 2007
  - **~70%** with double-IFO coincidence LIGO data
  - **~45%** with triple-IFO coincidence LIGO data
  - **~15%** short-duration GRBs
  - **~25%** with redshift
  - **~20%** fall in joint LIGO-Virgo times
  - all but a handful have have accurate position information

burst analysis has been completed; paper due out soon

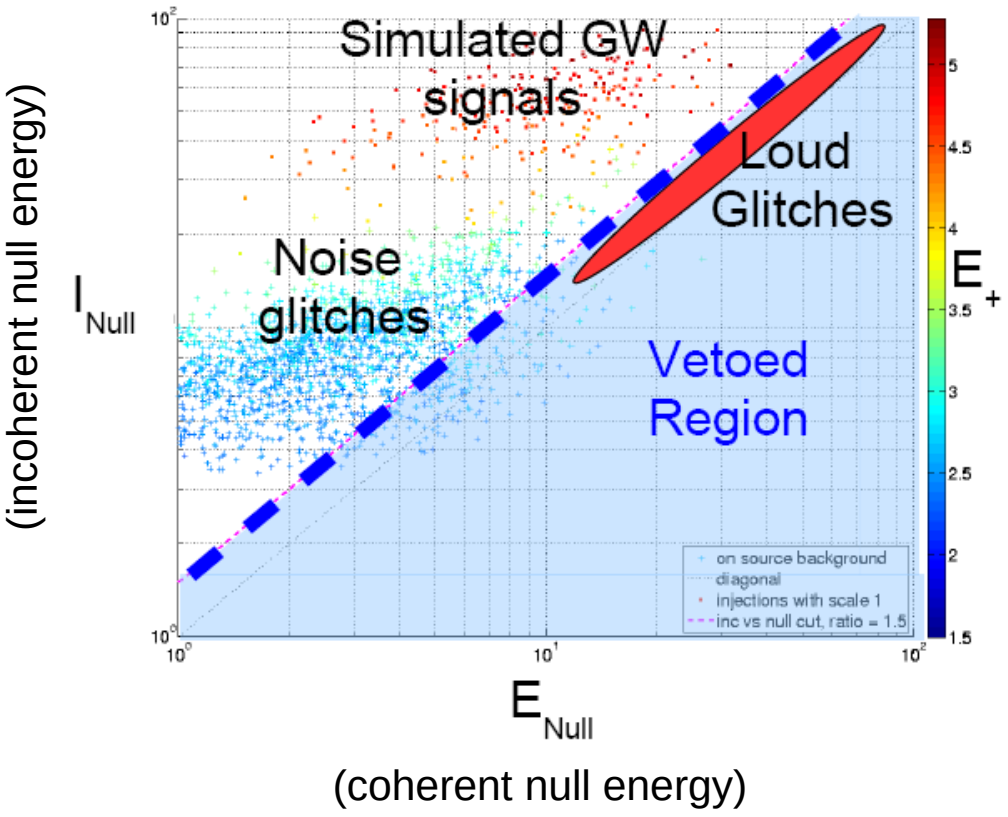
GRB triggers were mostly from Swift; some were from IPN3, INTEGRAL, HETE-2



LIGO Hanford average antenna factor

Virgo average antenna factor

Current burst search algorithm: fully coherent network search



- takes into account different antenna responses of detectors to source at a given sky location
- coherently adds multiple data streams from a network of interferometers to maximize SNR
- reconstructs h_+ and h_X components of signal
- null stream can be used for consistency tests, i.e. better background rejection

S5/VSR1 GRB-GWB burst search sensitivity

- assuming energy emitted in GW

$$E_{\rm GW} = 0.1\, M_{\rm sun}, \quad f_0 = 150 \text{ Hz}$$

$$\Rightarrow D \sim 50 \left(\frac{E_{\rm GW}}{0.1\, M_{\rm sun}} \right)^{1/2} \text{ Mpc}$$

- estimated GWB detection rate

(best estimates; unknown uncertainties; takes into account satellite detector efficiencies)

$$R_{\rm GW} \sim \rho_{\rm GRB} \left(\tfrac{4}{3} \pi D^3 \right)$$

long GRBs:

$$\rho_{\rm GRB} \sim 0.5 \text{ Gpc}^{-3} \text{ yr}^{-1}$$

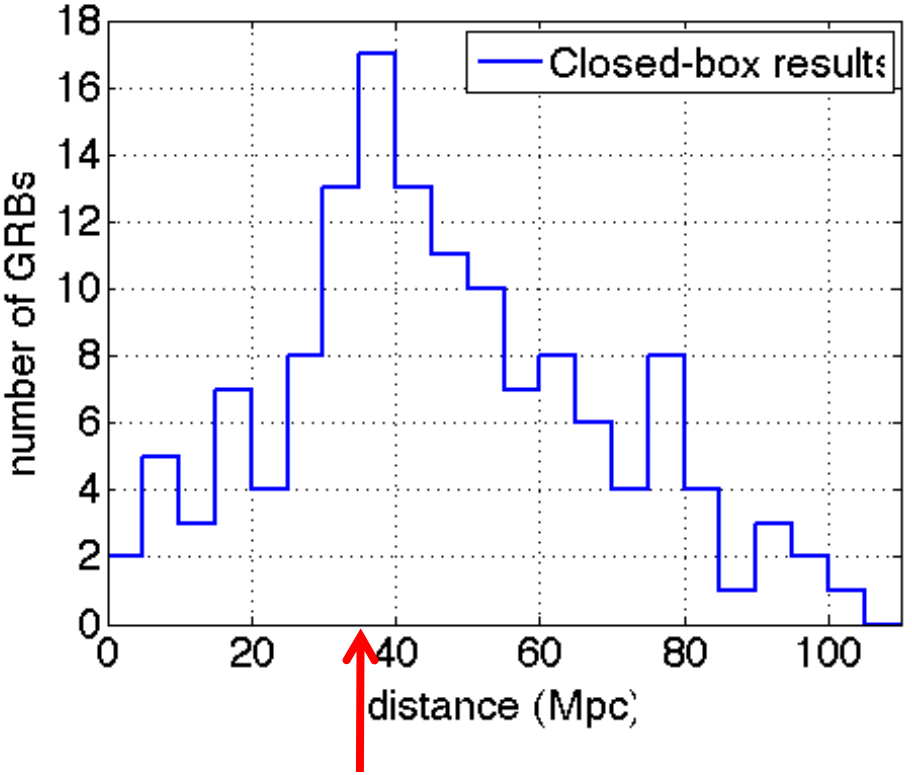
$$R_{\rm GW} \sim 5 \times 10^{-5} \text{ yr}^{-1}$$

short GRBs:

$$\rho_{\rm GRB} \sim [8-30] \text{ Gpc}^{-3} \text{ yr}^{-1}$$

$$R_{\rm GW} \sim [0.5-2] \times 10^{-3} \text{ yr}^{-1}$$

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

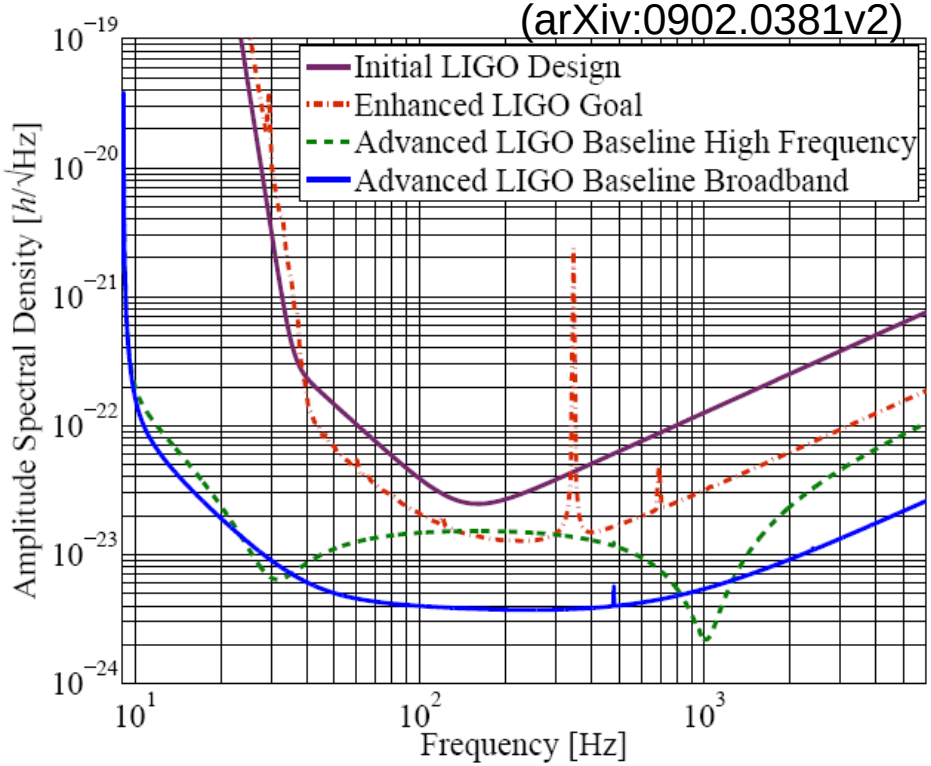


GRB 980425/SN 1998bw
at 36 Mpc

Prospects for enhanced LIGO-Virgo and advanced LIGO-Virgo

(arXiv:0902.0381v2)

- enhanced LIGO-Virgo (S6/VSR2 run)
  - factor of 2 increase in amplitude sensitivity vs. initial LIGO-Virgo
  - will commence summer of 2009
- advanced LIGO-Virgo
  - factor of 10 increase in sensitivity vs. initial LIGO-Virgo

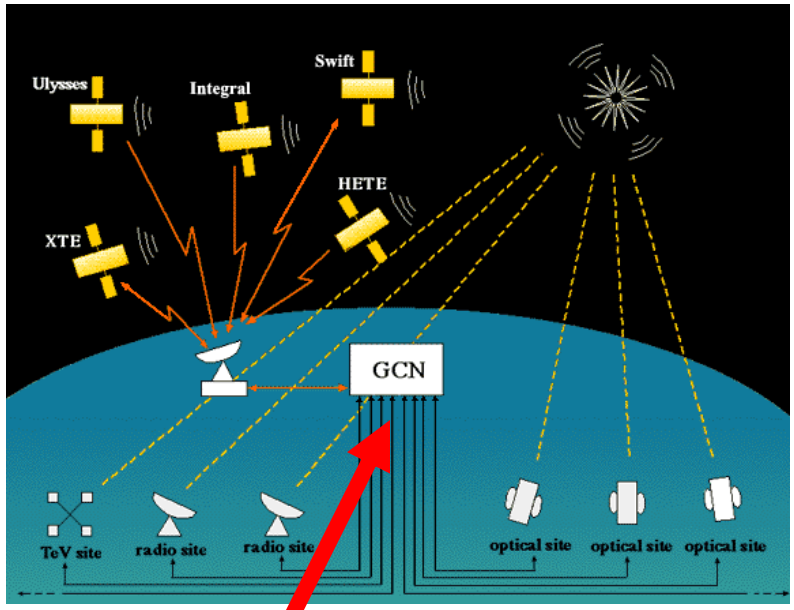


$$E_{\rm GW} = 0.1\, M_{\rm sun}\,, \quad f_0 = 150 \text{ Hz}$$

Detector	Estimated distance reach	Estimated detection rate (yr^{-1})	
		Long GRBs	Short GRBs
Enhanced LIGO-Virgo (S6/VSR2)	~ 100 Mpc	~ 0.0021	$\sim 0.03 - 0.13$
Advanced LIGO-Virgo	~ 500 Mpc	~ 0.26	$\sim 4 - 16$

S6/VSR2 low-latency GRB-GWB triggered burst search

- plan to have analysis results within a few hours of GRB trigger
- availability of results within ~hours means we can contribute in timely manner to discussion of interesting GRBs
- for interesting GRBs, disseminate results to science community within ~week
- expect GRB trigger rate of ~1 per day (high-confidence GRBs)



Summary

- fully coherent LIGO-Virgo analysis for searching for GW counterparts to GRBs is in place and working very well
- S5/VSR1 GRB-GWB search paper under review and will be out soon
- anticipating enhanced LIGO-Virgo S6/VSR2 run
  - factor of ~2 increase in amplitude sensitivity (~8 increase in volume sensitivity)
  - GRB trigger rate of ~1 per day from Fermi+Swift+other satellites
  - low-latency search (results ~hours after GRB trigger)