A proposal for gravitational wave-neutrino joint search for core-collapse supernovae

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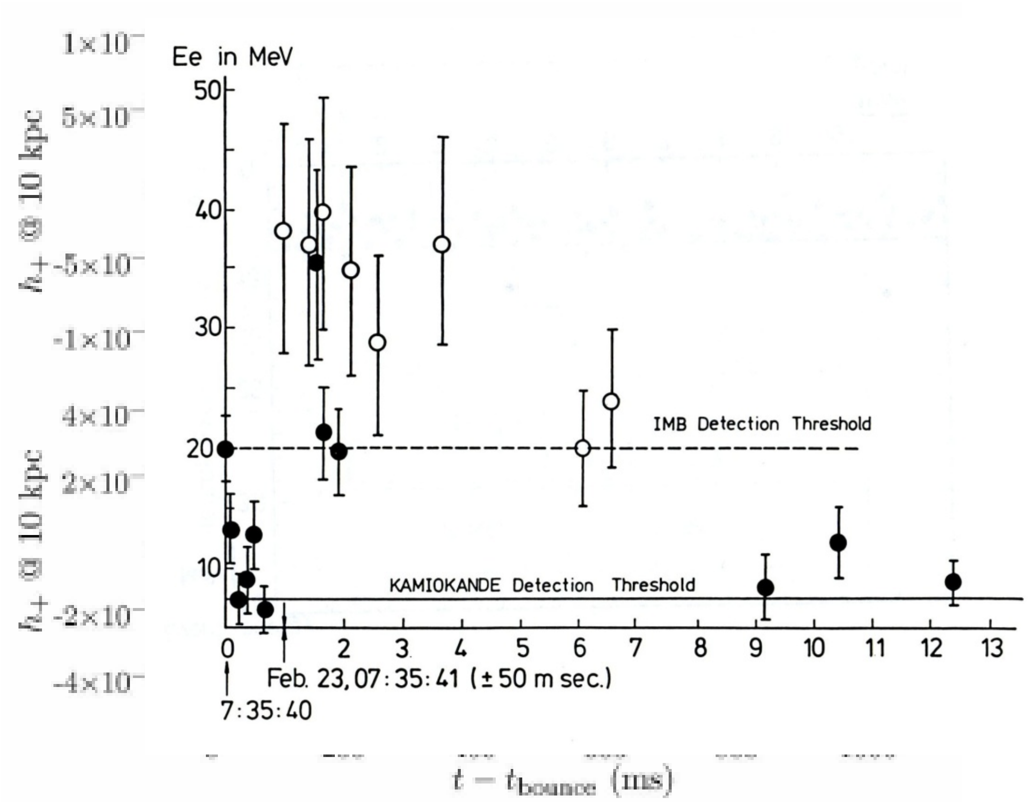
Observing the Universe



Koshiba, M. et al. 1988,
in “SN 1987A in the LMC”

Ott, Burrows, Lessart, Livne, 2006

- Electromagnetic waves
- Particles: neutrinos, cosmic rays
- Gravitational waves

Core-collapse GW emission and rates

- Several mechanisms may give rise to gravitational wave (GW) emission from core-collapse supernovae (see review by Ott in CQG2009, also astro-ph/0809.0695)
  - » Rotating collapse and bounce E_{gw} ($M_{solar}c^2$) 5×10^{-10} -- 5×10^{-8}
  - » Post-bounce convection and Stationary Accretion Shock Instability (SASI) E_{gw} ($M_{solar}c^2$) 1×10^{-12} – 5×10^{-9}
  - » Rotational instability E_{gw} ($M_{solar}c^2$) 1×10^{-8} – 1×10^{-7}
  - » PNS core oscillations and dynamical rotational instabilities E_{gw} ($M_{solar}c^2$) 1×10^{-8} -- 8×10^{-5}
- Huge variations in predictions exist, significant uncertainties and unknowns acknowledged by the simulation community → modeling can not be the final word in gravitational wave yield from core-collapse → a measurement is needed
- Event rates also subject to uncertainties → supernovae may be optically silent (due to extinction or because of weak or no explosion)
- Yield in gravitational waves and rate of such events most likely to be pessimistic → we ought to look for what nature may have out there for us!

Current searches and their reach

- GW detectors performed all-sky, all-time searches primarily offline until now. Online searches are expected to be implemented with the next science run of LIGO-Virgo .
- Search sensitivity expressed in terms of energy going into gravitational waves at the source (which in turn is limited by the strain sensitivity at the detectors):

$$E_{\mathrm{GW}} = \frac{r^2 c^3}{4G} (2\pi f_0)^2 h_{\mathrm{rss}}^2$$

  Assume for a sine-Gaussian-like signal, 153 Hz, Q=8.9, h_{rss} at 50% efficiency is 6.5×10^{-22} $Hz^{-1/2}$

  » 2×10^{-8} $M_{\odot}$ emitted at 10 kpc

  » 0.05 $M_{\odot}$ emitted at Virgo Cluster

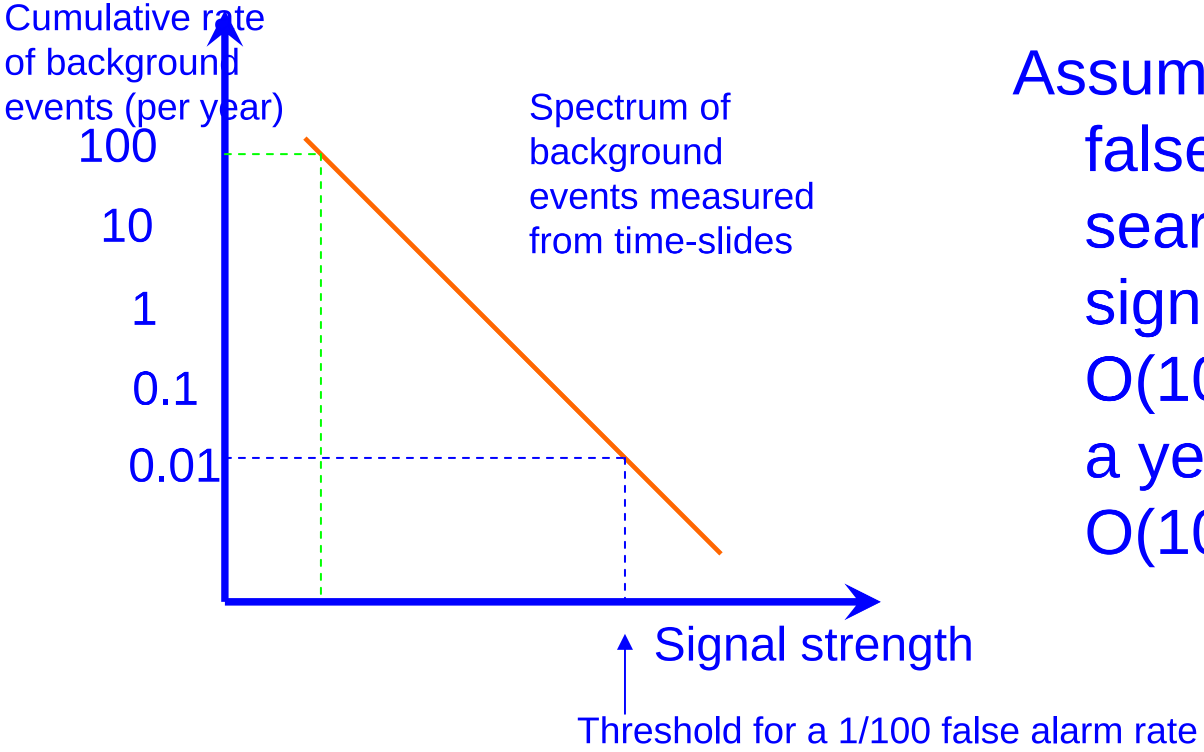
- SNEWS online alerts provide good coverage to nearby core-collapse supernovae by analyzing data jointly from the several neutrino detectors with ~Galactic sensitivity that are now online

What can gravitational wave and neutrino detectors do for each other?

- So far, LIGO and Virgo are recipients of SNEWS “gold” alerts → a near real-time analysis of GW data is initiated upon receipt of such an alert using the time stamp and potentially the direction provided by the neutrino detector network
- Move towards collaborative efforts
  - » Establish communication among projects -- facilitate the use of expertise knowledge in the best possible way of analyzing each experiment's data around the time of a SNEWS alert
  - » Define analysis parameters jointly
  - » How we can improve the sensitivity of the search?
  - » How can we improve the livetime coverage and detection confidence of the combined GW-neutrino network?
- Bring LIGO-Virgo into SNEWS?

Joint offline searches

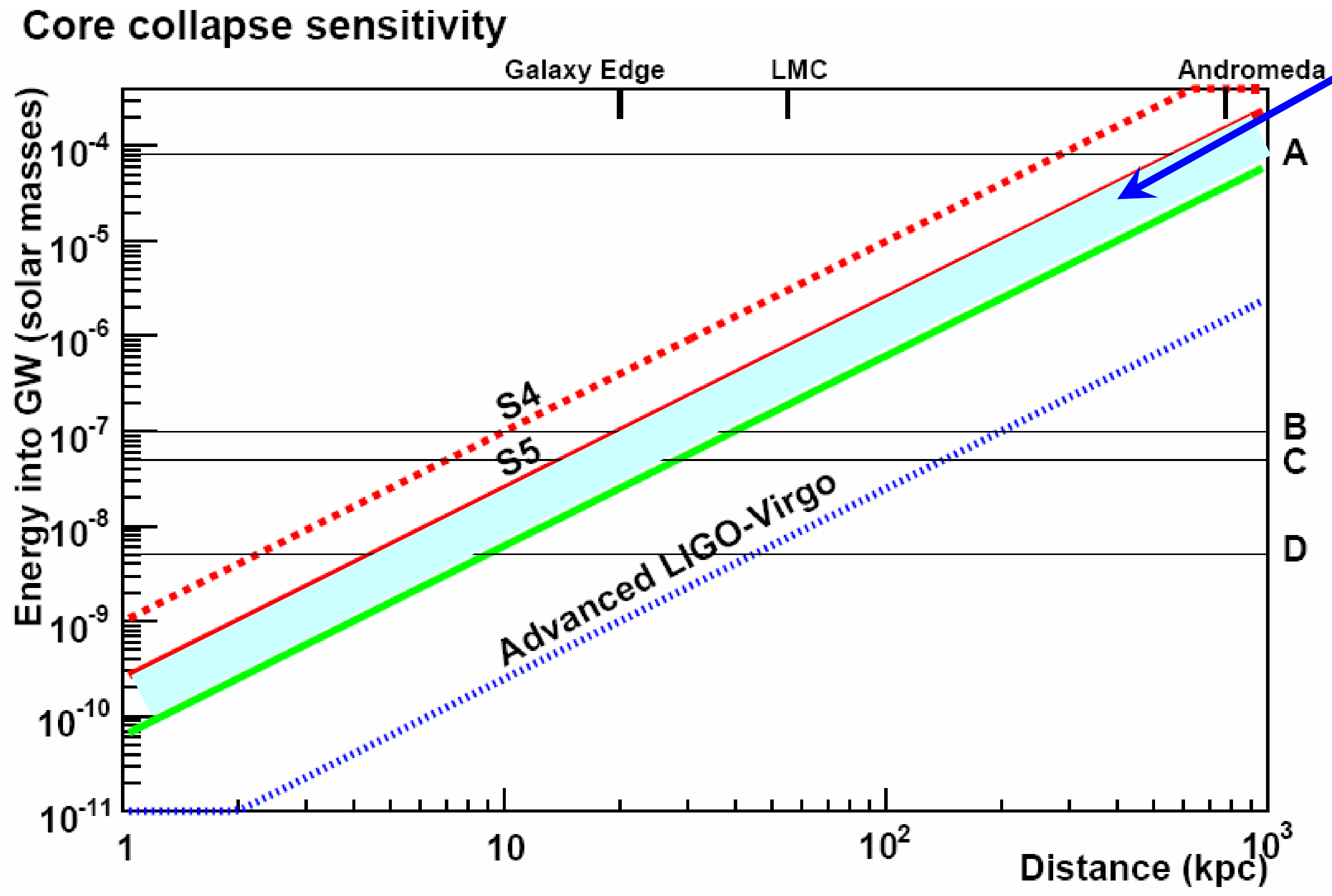
Additional coincidence test (GW for the neutrino network, neutrino trigger for the GW network) allows the operation of each component of the network at a lower threshold so that to ultimately detect with confidence weaker events



Assuming a target of a 1/100 false alarm, a triggered search looking for a GW signature within O(1s) of O(1000) neutrino events in a year can afford over an O(100) GW events

Science reach and null results

- GW detector sensitivity fixes the E_{gw}/D^2 a search may reach under some assumption of signal morphology → line in the log-log plot: all combinations of energy-distance above and to the left can be probed (and excluded if null result) in a search
- We expect the lowering of the threshold the joint analysis allows to provide a factor of 2 strain sensitivity improvement, factor of 4 in energy going into GW reach

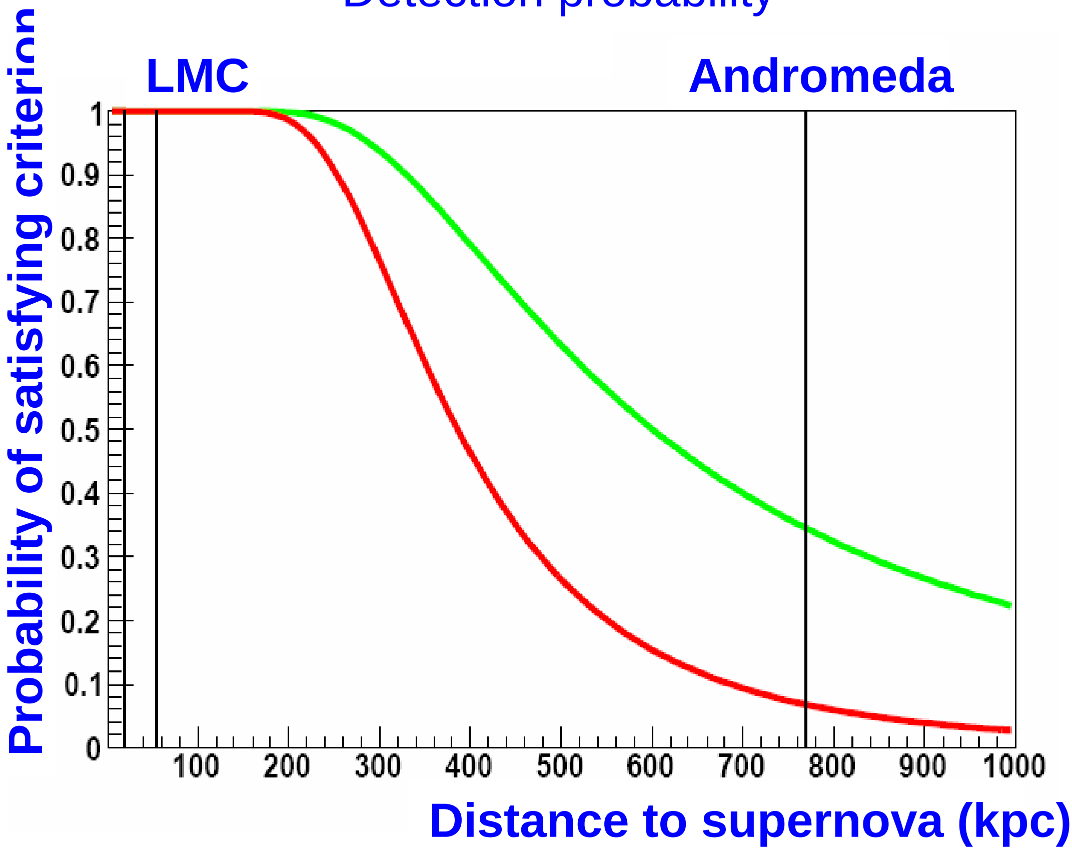


Colored lines reflect search ability to constrain models under the assumption of SG153Hz/Q=9 signal morphology and corresponding search sensitivity. This will be about a factor 50 worse at 550Hz and a factor 500 worse at 1kHz

Joint search could benefit neutrino search as well

- criterion for neutrino search can be relaxed
- example: for Super-K distant SN search, criterion is at least 2 neutrino events per 20 seconds and high energy threshold of 17 MeV
- if coincidence with GW signal is required, then criterion can be relaxed to a single neutrino event; odds will increase that distant core-collapse will satisfy this criterion
- energy threshold could also be lowered

Detection probability



Summary

- Neutrino and gravitational wave detectors are or will soon be online waiting for the next nearby supernova
- Rates of such events and GW yield associated with them is uncertain → the scientific payoff from a direct measurement will be tremendous
- Combined GW-neutrino analyses may improve the supernova sensitivity in a significant way
- Need to build a working relationship across the communities while preparing for the next nearby supernova and as we explore methods to improve sensitivity via joint analyses
- A proposal for this effort to commence has been made to LIGO, Virgo, Super-K, LVD, Borexino – it is being examined
- Join us if you are interested!