Multimessenger Astrophysics with Gravitational Wave Detectors

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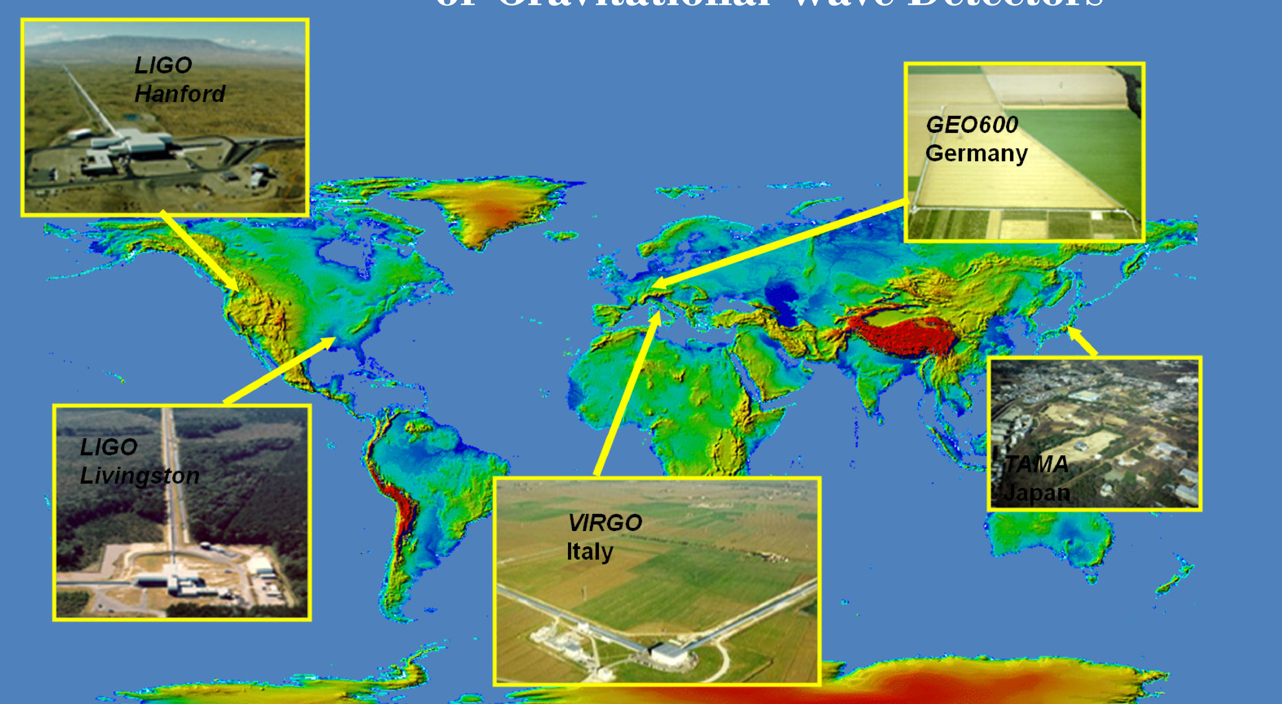
Including gravitational waves in multimessenger observations shall enable the extraction of scientific insight that was hidden from us before. Therefore, gamma-ray, X-ray, optical, radio and neutrino observations of cataclysmic cosmic events with plausible gravitational wave emission are being used or considered in combination with searches for gravitational waves. Information on the progenitor, such as trigger time, direction and expected frequency range, can additionally enhance our ability to identify gravitational wave signatures with amplitudes close to the noise floor of the detector.

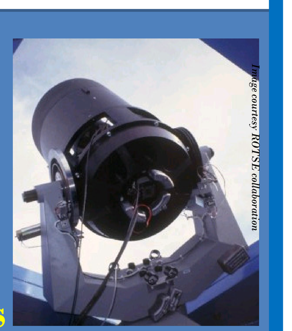
Even simple correlation in time and direction between multiple messengers that correspond to the same astrophysical event can greatly increase the confidence of a detection of GWs, and search strategies can be optimized in this respect. Furthermore, several long-term goals of GW astrophysics require detection of astrophysical events in other channels beyond GWs. For example, an association between short hard GRBs and inspiraling neutron star binaries may be confirmed in this manner. The joint detection of GWs and neutrinos together with the observation of the optical light curve from a nearby supernova would greatly enhance our understanding of supernova explosions.

The Global Network of Gravitational Wave Detectors



Two Ways for Utilization of Gravitational Waves in Multimessenger Astrophysics

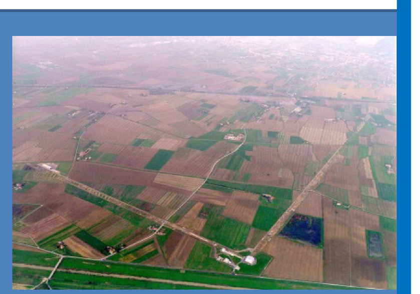
"LOOC UP" strategy:




GW → Flow of trigger information → Telescopes, Satellites or other external entities

GW detector networks are all-sky monitors, with a typical angular resolution of several degrees. Large FOV optical and infrared telescopes (e.g. ROTSE, TAROT, SkyMapper, QUEST, Palomar Transient Factory, Pi in the Sky, LONEOS) which are already in existence, or will see first light in the near future, provide very exciting prospects for such joint observations. *See poster by P. Shawhan.*

"ExtTrig" strategy:




Telescopes, Satellites or other external entities → Flow of trigger information → GW

Advantages of external triggers for GW searches

-Establish astrophysical observation based association between gravitational waves and electromagnetic/particle observations

-Correlation in time (and direction) between a GW event candidate and the astrophysical trigger event should provide confident detection of GWs

-Better background rejection, higher sensitivity to GW signals

Information from External Observations

1. **Trigger Time**
   Search within an astrophysically motivated trigger time window
   -> higher detection probability at fixed false alarm probability
   -> better limits in absence of detection
2. **Source Direction**
   Search only the relevant portion of the sky or
   Veto candidates not consistent with expected Δt
3. **Frequency Range**
   Frequency-band specific analysis of data set (e.g. SGR QPOs)
4. **Progenitor Type**
   Model dependent search can be performed, e.g.
   search for burst (long GRBs, hypernovae)
   search for CBC (short hard GRBs)

Current Status

-*No direct detection of GWs up to date.* Expected GW signal strengths are weak compared to the background noise levels of current detectors, and searches are challenged by the non-stationary/glitchy nature of the background noise.

-*Application of other messengers (mainly EM observations) in GW astronomy is ongoing.*

-Searches triggered by observations from gamma-ray and X-ray satellites were performed for long and short duration gamma ray bursts (GRB030329 and hundreds of GRBs since 2005, including GRB070201) and for Galactic soft gamma repeaters (including the 2004 hyperflare of SGR1806-20).

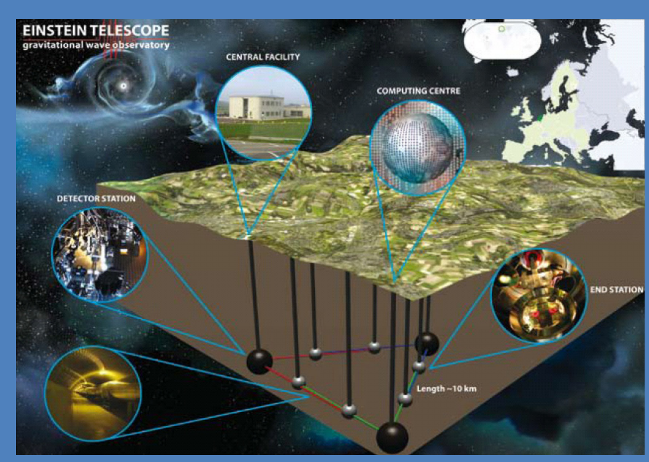
-*The LIGO and Virgo detectors have made specific scientific statements for some nearby events.* For example, constraining the source type or location of GRB070201 – a short-hard GRB event observed to come from a direction overlapping M31 (ruled out the hypothesis that this GRB was due to a binary progenitor in M31 at >99% confidence).

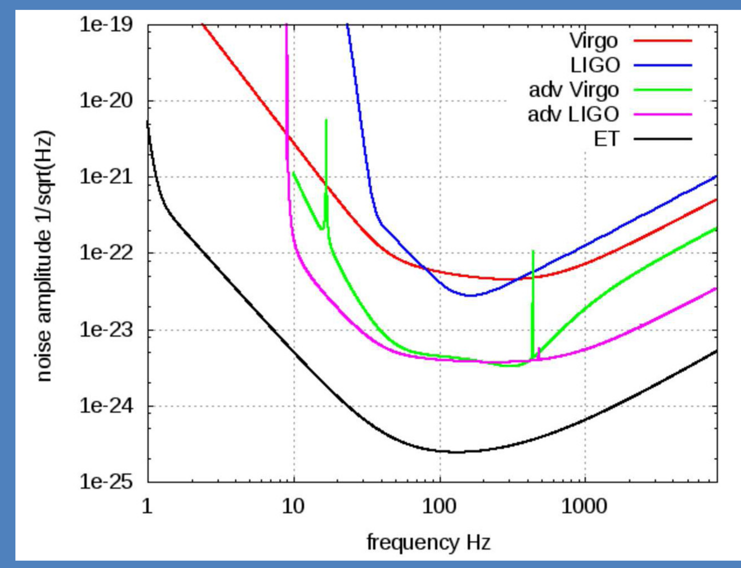
-*LOOC UP program is ongoing*: Online analyses of gravitational wave data for gravitational wave transients have been developed and triggers are being passed to large FOV EM observatories.

Of the GRB satellites, a Target of Opportunity program with SWIFT is ongoing: outstanding trigger event candidates may be passed for follow up.

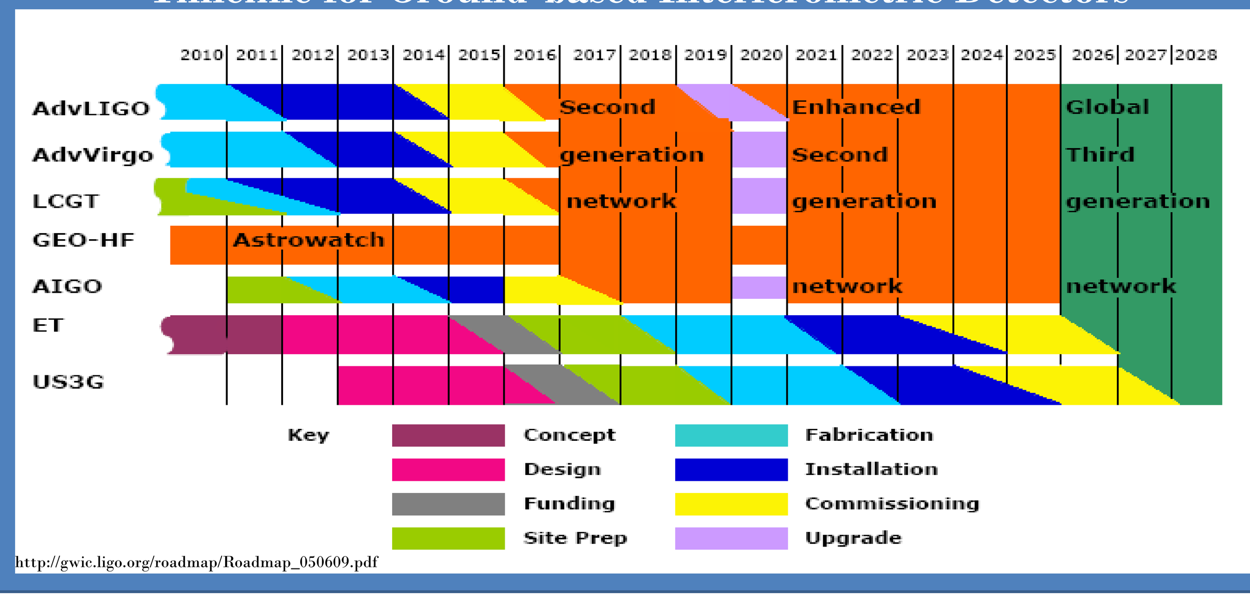
-Multimessenger observational projects are at the advanced planning stage for other electromagnetic and particle counterparts.

Design Noise Spectra of Current and Future Ground Based Gravitational Wave Detectors





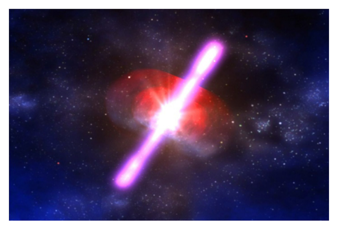
Timeline for Ground-based Interferometric Detectors



Sources

Distance sensitivity of a generic GW detector: $D_{\mathrm{L}} \simeq \sqrt{\frac{3G\,(1+z)\,E_{\mathrm{GW}}}{\pi^2 c^3\, S(f)}}\,\frac{F_{\mathrm{rms}}}{\rho_{\mathrm{det}} f} \simeq 5\,\mathrm{Gpc}\,(1+z)^{1/2}\,\frac{10}{\rho_{\mathrm{det}}}\,\frac{100\,\mathrm{Hz}}{f}\left(\frac{E_{\mathrm{GW}}}{10^{-2} M_{\odot} c^2}\right)^{1/2} \frac{2.5\times10^{-25}/\sqrt{\mathrm{Hz}}}{S(f)^{1/2}}\,F_{\mathrm{rms}}$

Gamma Ray Bursts:



-The most recent LIGO-Virgo search *(see poster by J. Kanner)* placed lower limits of »15 Mpc on the distance to the GRBs studied, assuming isotropic emission of 0.01 $M_{sun}c^2$ at the network's most sensitive frequency, 150 Hz.

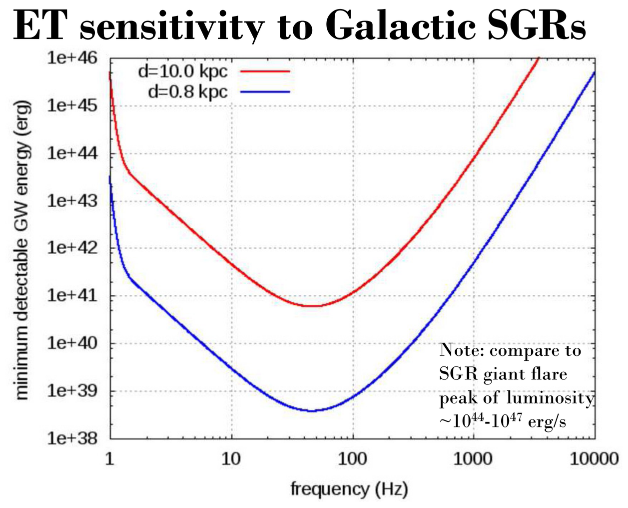
-The binary coalescence thought to be associated with *a short GRB* will produce gravitational radiation that will be detectable with the Advanced LIGO and Advanced Virgo detectors and is expected to be observable by ET to z ~ 2-4.

Soft Gamma Repeaters:

-LIGO has placed upper limits on gravitational wave emission by SGRs in the range 10^{46}-10^{50}erg, depending on frequency, and assuming a nominal source distance of 10 kpc (*see poster by P. Kalmus*). A frequency range specific search for gravitational waves associated with quasiperiodic oscillations in the tail of the SGR flare was also considered.

-The Advanced detectors turning on in five years will probe GW emission from SGRs at a 10 kpc distance to two orders of magnitude deeper.

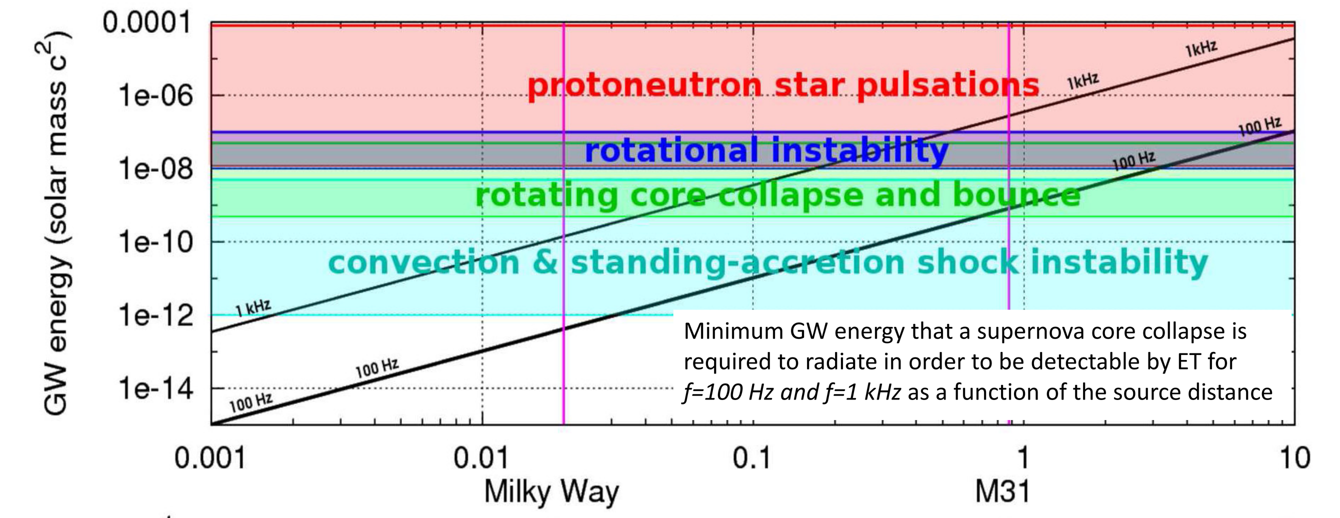
ET sensitivity to Galactic SGRs

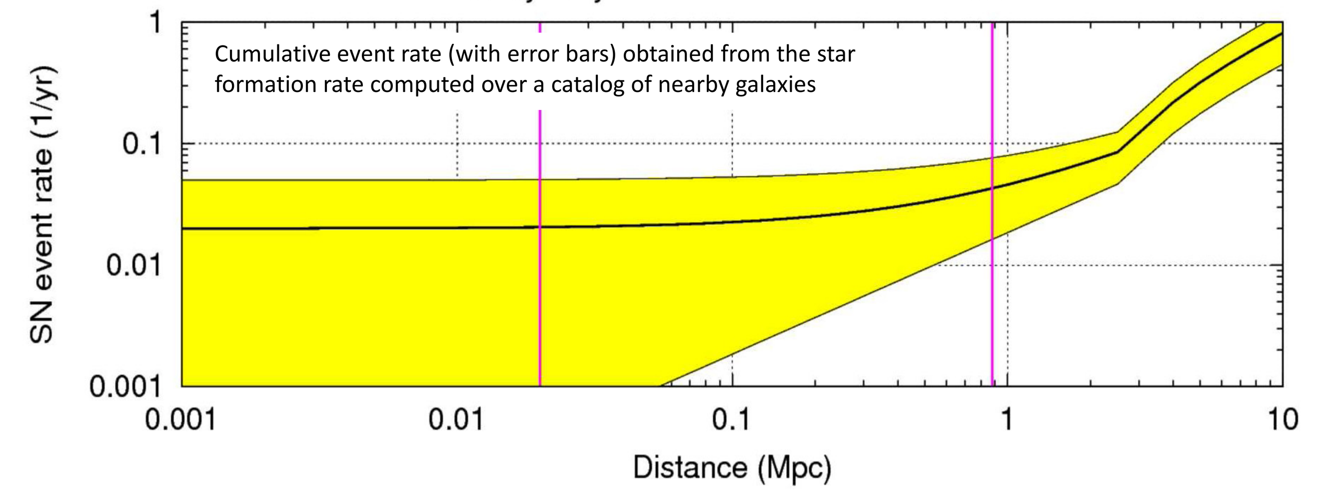


10 kpc - typical galactic distance
0.8 kpc - estimated distance to SGR 0501+4516

Optically Detected Core-Collapse Supernovae:

It is expected that the second-generation LIGO detectors will be able to detect GWs from the supernovae in the neighborhood of the Galaxy.





Some mechanisms are predicted to be sufficiently energetic to be detectable by ET at a distance of up to 10 Mpc, where the SN event rate reaches a value of order unity.

Radio Waves

Possible Source: compact binaries where one of the compact objects is a magnetar.

GW data can be used to trigger detailed follow-up radio observations by future ground-based radio telescopes, such as LOFAR and the Square Kilometer Array.

Pulsar Glitches are thought to excite quasi-normal mode oscillations in their parent neutron star, which are then damped away by gravitational wave emission. A search in LIGO data for a gravitational wave signal produced by quasi-normal mode excitation associated with a timing glitch of the Vela pulsar in August 2005 is to be published.

Low Energy Neutrinos

The reach of low-energy neutrino and GW detectors may allow coincident observation of core-collapse supernovae in the neighborhood of the Galaxy, albeit the expected event rate is low. The multimessenger approach will likely pay off during the ET era.

High Energy Neutrinos

A joint search for coincident events in high energy neutrinos and gravitational waves by ANTARES and IceCube and the LIGO-Virgo network is ongoing (*see poster by I. Bartos*) and will continue through the Advanced LIGO and Virgo era.

Reference: E. Chassande-Mottin, M. Hendry, P. J. Sutton and S. Marka, "Multimessenger astronomy with the Einstein Telescope", *submitted to GRG*

LIGO Document G0900919

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