Detecting a stochastic GW background with Einstein Telescope

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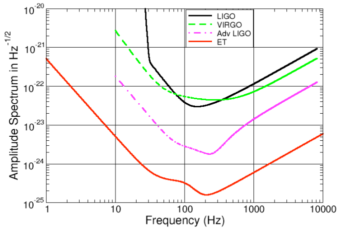
Einstein Telescope is a 3-year design study funded by EC FP7 for a third-generation terrestrial gravitational wave detector.

The goal is a GW strain sensitivity $S_n^{1/2}(f)$ two orders of magnitude better than current LIGO/VIRGO [1], increasing the detectable rate of astrophysical events by a factor 10^6 over today, and an extended frequency range down to 1-10 Hz. The sensitivity to stochastic background will be improved by over 10^4 relative to LIGO's bound

$$\Omega_{gw} < 6.9 \times 10^{-6} \text{ (95\% confidence)}$$

around 100Hz [1], and by a larger factor at lower frequencies.



The sensitivity goals will require underground cryogenic interferometers with significant advances in optical technology.

ET's basic design consists of three 60° interferometers (ifo) along the sides of an equilateral triangle. The topology is sensitive to all GW polarizations and also allows detection of stochastic background by cross-correlating pairs of ifo outputs.

Sources of stochastic GW

Stochastic GW background may arise from quantum or classical field dynamics in the very early Universe, from evolution of topological defects after inflation, or from the superposition of many astrophysical sources such as neutron stars. Gravitational waves propagate from the earliest moments in cosmological history with practically no absorption or distortion and can be a major inde-pendent probe of cosmology and fundamental physics.

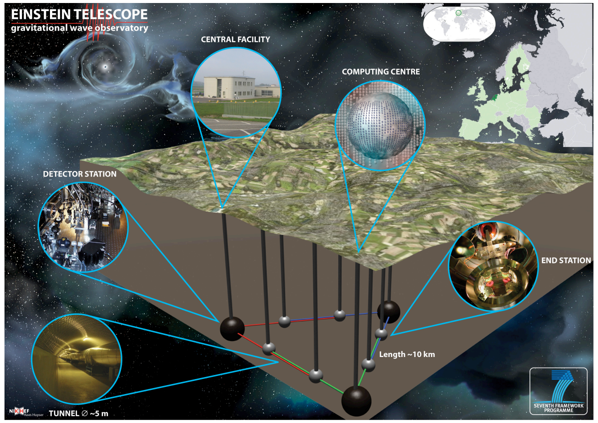
The stochastic GW energy density is related to the rms strain spectral density S_{gw} via

$$\Omega_{\rm gw}(f) \equiv \frac{1}{\rho_c}\frac{d\rho_{\rm gw}}{d\ln f} = \frac{4\pi^2}{3H_0^2} f^3 S_{\rm gw}(f)$$

Broad-band sources

Both inflation and cosmic string evolution give rise to ``flat'' spectra (the GW power in each e-fold of frequency is nearly constant). Inflationary GW are known to be too weak for ground-based detectors to probe given CMB bounds [2].

Cosmic strings give rise to an amplitude Ω_{gw} that depends on the string tension $G\mu$ (currently limited to a few x 10^{-7} from cosmological observations [3]) and other theoretical parameters as [4]:



Artist's impression of Einstein Telescope

$$\Omega_{gw}(f) \sim 10^{-8}(G\mu/10^{-9})^{1/2} p^{-1} (0.2\Gamma\alpha)^{1/2}$$

A factor 10^2 in detector strain sensitivity gains us 10^8 in $G\mu\alpha$.

Peaked sources

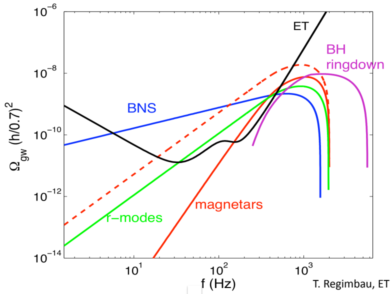
An event localized in cosmic time will produce a stochastic GW spectrum with a peak at frequency [5]

$$f_{\rm peak} = f_* \frac{a_*}{a_0} \approx (6\times 10^{-8}\,{\rm Hz}) \frac{f_*}{H_*} \frac{T_*}{1\,{\rm GeV}} \left(\frac{g_*}{100}\right)$$

where f_*, a_*, H_*, T_* refer to the epoch of GW production. Possible sources include (p)reheating [6], bubble colllisions and turbulence in first-order phase transitions [7] and decay of SUSY flat directions [8].

Astrophysical sources

The superposition of a large number of unresolved astrophysical GW sources also creates a stochastic background, which can probe the properties of compact objects (neutron stars and black holes) and their evolution with redshift [9]. We show an estimate of the signals from various sources:



T. Regimbau, ET Vision Document

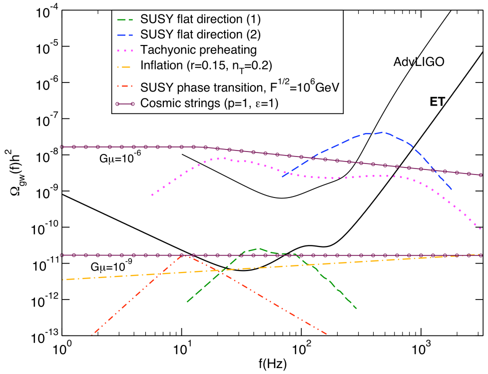
As shown, astrophysical backgrounds may easily be visible and/or mask the cosmological signal, although there are large theoretical and observational uncertainties in their expected amplitude.

Detection

For the correlation of two detectors with noise spectral density $S_n(f)$ the minimum detectable background at given S/N is

$$\Omega_{\rm gw,min}(f) \sim \frac{4\pi^2}{3H_0^2} \frac{f^3 S_n(f)}{(2T\Delta f)^{1/2}} \frac{S/N}{F_{12}\gamma(f)}$$

for an observing time t and frequency band Δf. The overlap reduction function $F_{12}\gamma(f)$ depends on detector geometry and separation.



Estimated sensitivity of ET to possible cosmological sources of stochastic GW:
correlation of two co-located 60° ifos, signal-to-noise ratio 2.56, observing time 1 year

ET has the potential to detect primordial GW backgrounds from many models of new physics in cosmology. Models with `flat' spectra may be confirmed or ruled out by the presence or absence of PGW.

For a `peaked' spectrum new physics may be detected and the model parameters (temperature, mass scale) could be determined and compared to results from particle physics and cosmology.

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ET website www.et-gw.eu
WG4 workarea https://workarea.et-gw.eu/et/WG4-Astrophysics
ET Science Team https://workarea.et-gw.eu/et/Science_Team
ET Vision Document: in preparation.