Probing cosmology & fundamental physics with Einstein Telescope

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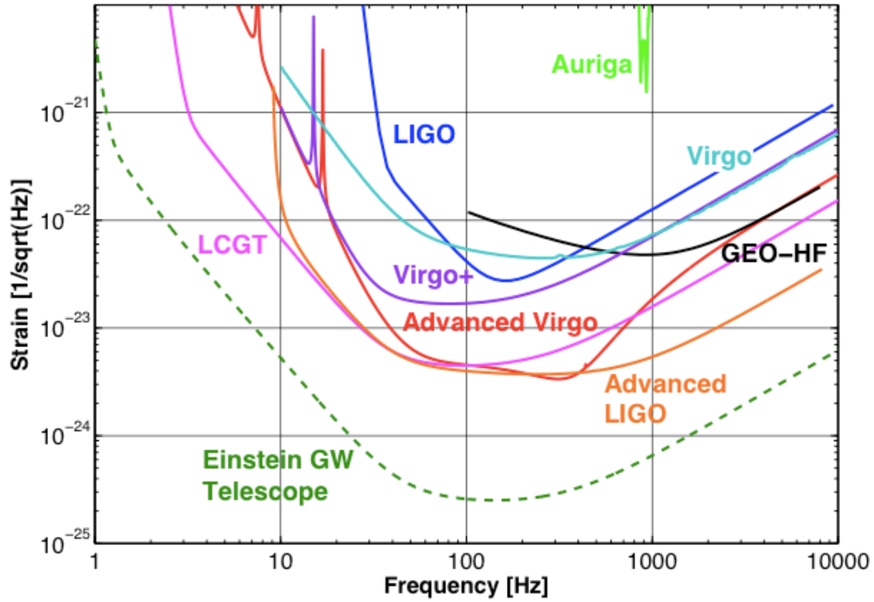
Advanced GW detectors and beyond

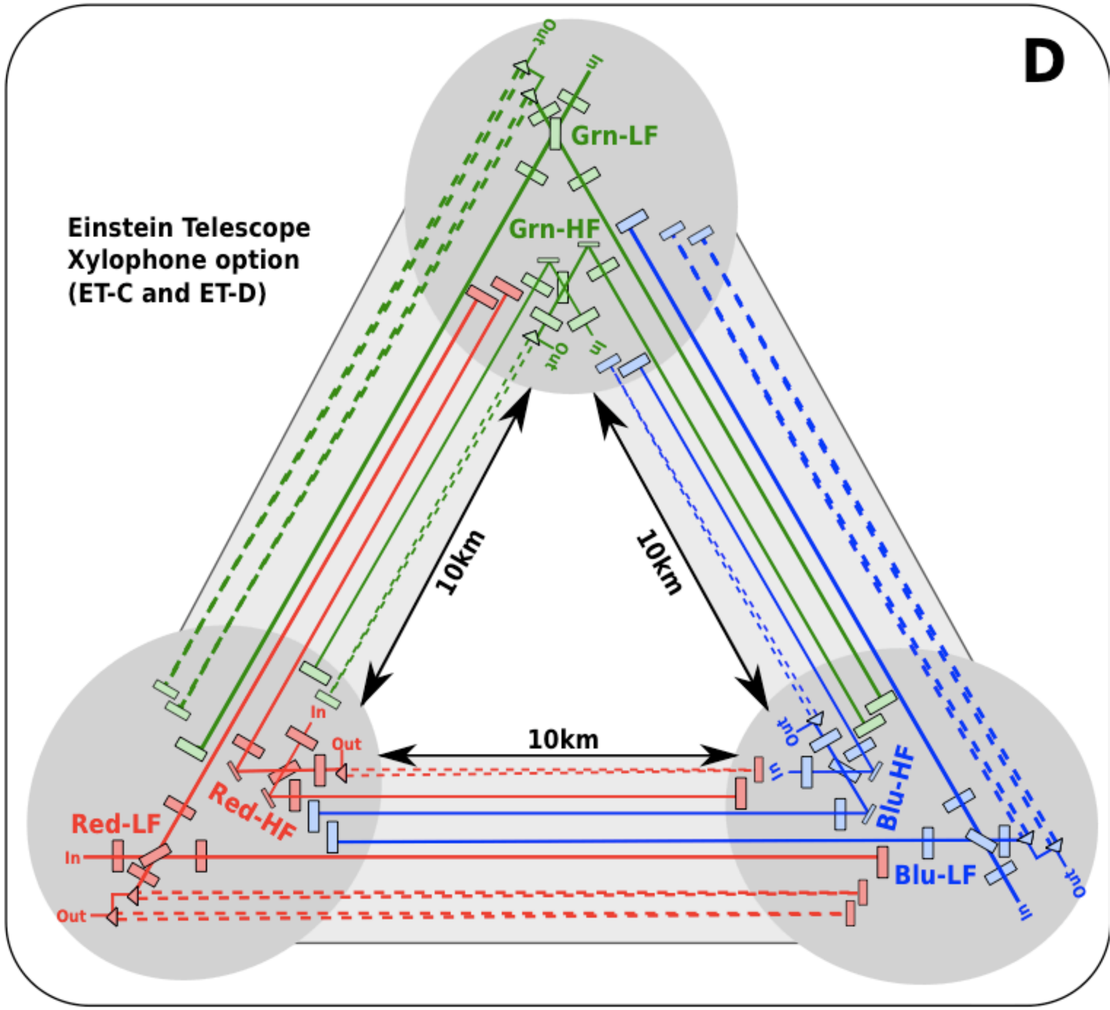
- Advanced era: 2015+
  - First direct GW detections
  - Characterize source populations
  - Compact binary inspiral, burst-like, continuous-wave, stochastic



- Large uncertainty in source strength / rates
  - CBC rates from ~1/yr ('low') to ~10^3/yr ('high')
- Many questions will remain after detection
  - Fundamental physics, cosmology, detailed astrophysics of sources …

Einstein Telescope

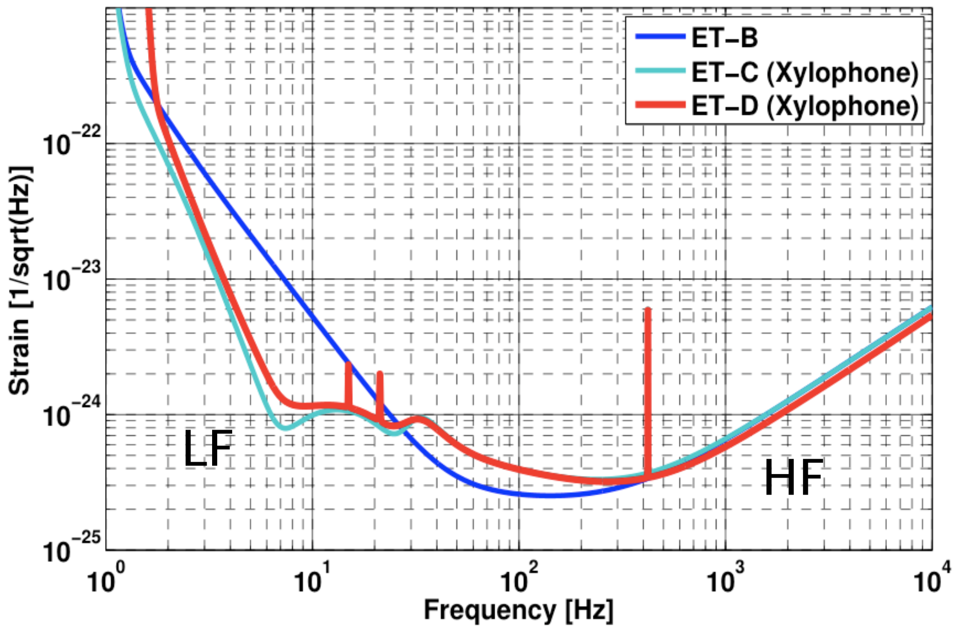
- Planned 3rd–generation GW observatory
- Conceptual Design Study completed in 2011
- Goal : improve on Advanced detector sensitivity by ~ factor 10
- Equilateral △ : most cost–effective way to see both GW polarizations
- Underground : reduce low–frequency noises



http://www.et-gw.eu/etdsdocument

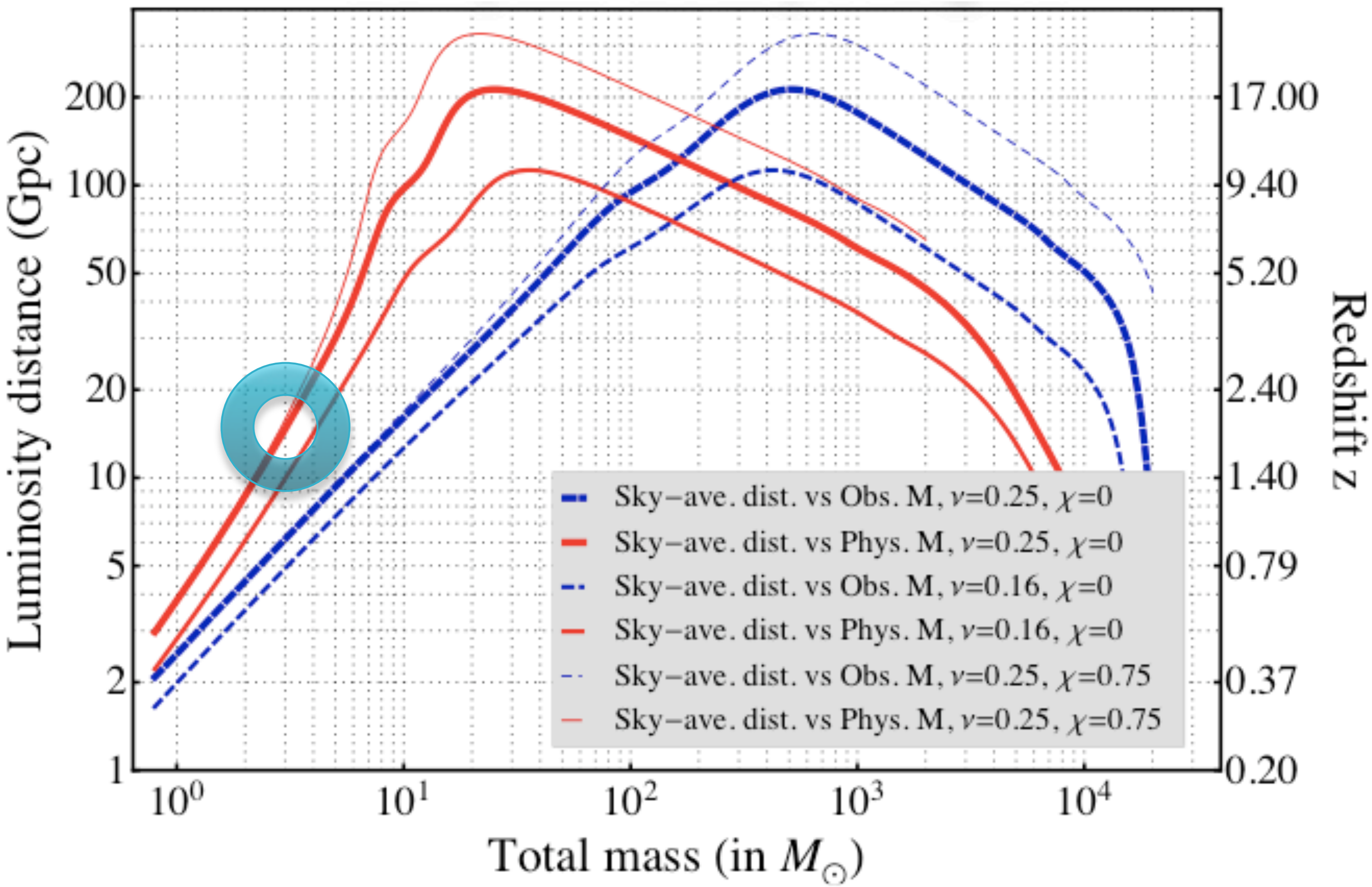
Projected ET sensitivity curves

- "Xylophone" idea: separate HF and LF interferometers



- HF: high power, room temperature
  - 3 MW arm cavity power
- LF: low power, cryogenic
  - Silicon mirrors, mass ~ 200kg, cooled to 10K

ET reach for binary sources



- Binary Neutron Star: total mass 2.5-3 $M_\odot$

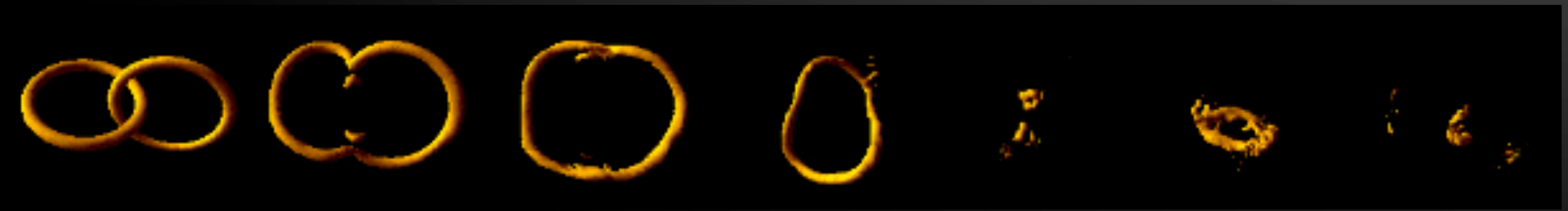
Seen out to $z \approx 2$

ET science in one slide

1. Fundamental physics & gravity
   - Graviton mass, Brans–Dicke parameter, deviations from PN phasing, no-hair property
   - Masses and EoS of compact stars
2. Astrophysics
   - Pulsar glitches, neutron star instabilities
   - GRB progenitors
   - Core-collapse SN
3. Cosmology
   - Hubble constant & expansion history of Universe
   - Evolution of binary merger rate
   - IMBH
   - GW background from early Universe

Stochastic GW backgrounds at ET

» Fundamental Physics in the Early Universe



Cosmic string evolution: Battye & Shellard

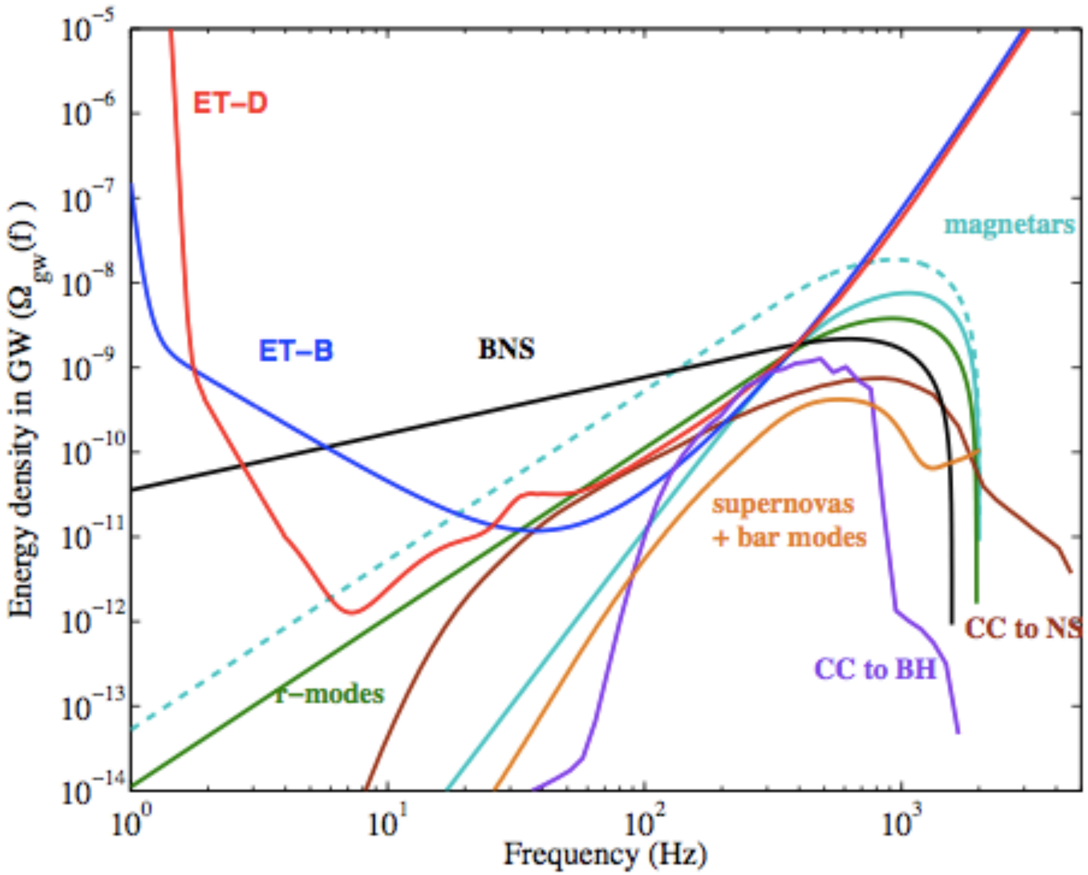
Stochastic GW background

- GW from many overlapping sources
  - Most cannot be individually resolved
- Sources
  - Astrophysical: many weak sources at large distance
  - Cosmological: processes in the early Universe
- Detect by cross-correlation of two detector outputs
- Contribution to energy density $\Omega_{GW}(f)$
  - Recent limit $\Omega_0 < 6.9 \times 10^{-6}$ $f \sim 100$ Hz
    LSC & Virgo Collaborations, Nature 2009
  - ET: projected limits $\Omega_{GW} \lesssim 10^{-11}$, $f \sim 5 - 1000$ Hz

Astrophysical sources

Many sources overlapping in time/frequency: "confusion noise"

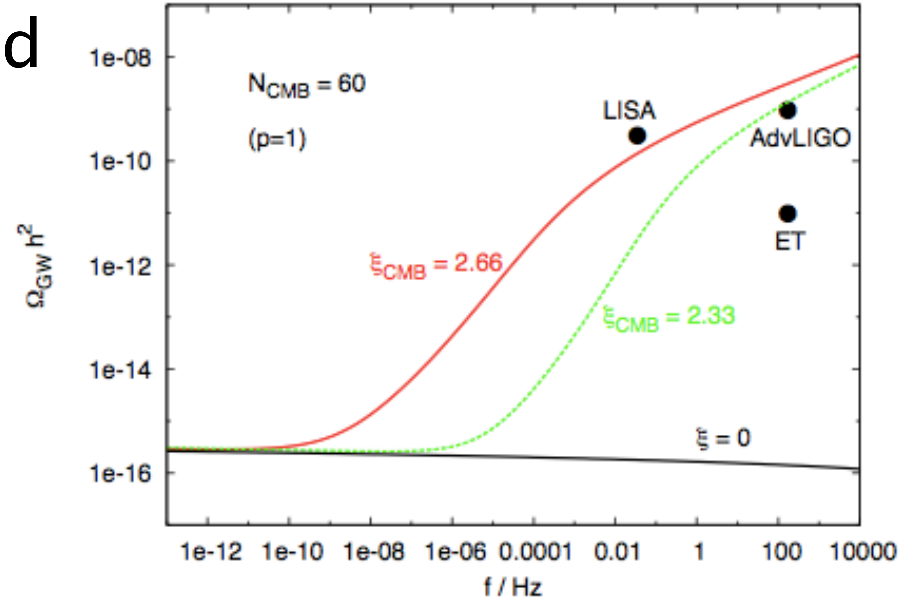
- Continuous : pulsars, magnetars
- Burst-like : CCSN
- Inspiral : BNS, BBH
- Large uncertainty on expected signals
- Some sources could be identified & removed – 'popcorn'?



T.Regimbau, ET DSD

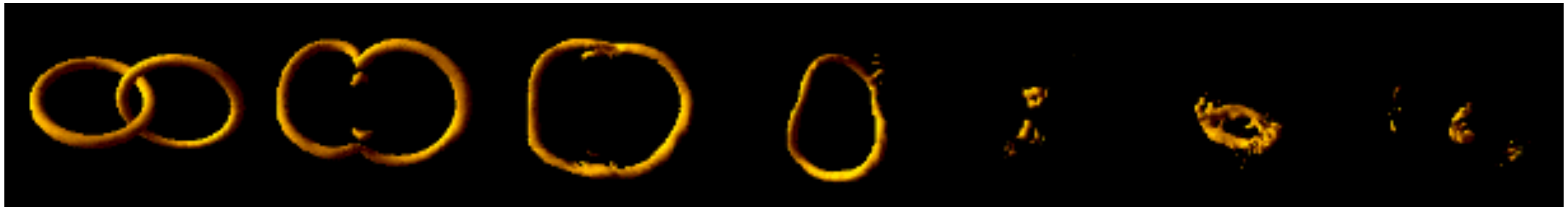
Early Universe sources: inflation?

- Fluctuations of quantum fields generate tensor modes – GW field h (t,x)
- GW background redshifted to low frequency
- Flat spectrum: $\Omega(f) \sim$ constant
- WMAP tensor bounds imply $\Omega(f) < 10^{-14}$
  - Unobservable at ground-based detectors
- Exception: inflaton coupled to light gauge fields A_μ
  - Light field quanta produced & source tensor modes
  - Close to end of inflation ⇔ higher frequency
  - Potentially observable!



Cook & Sorbo, arXiv:1109.0022
Barnaby et al., arXiv:1110.3327

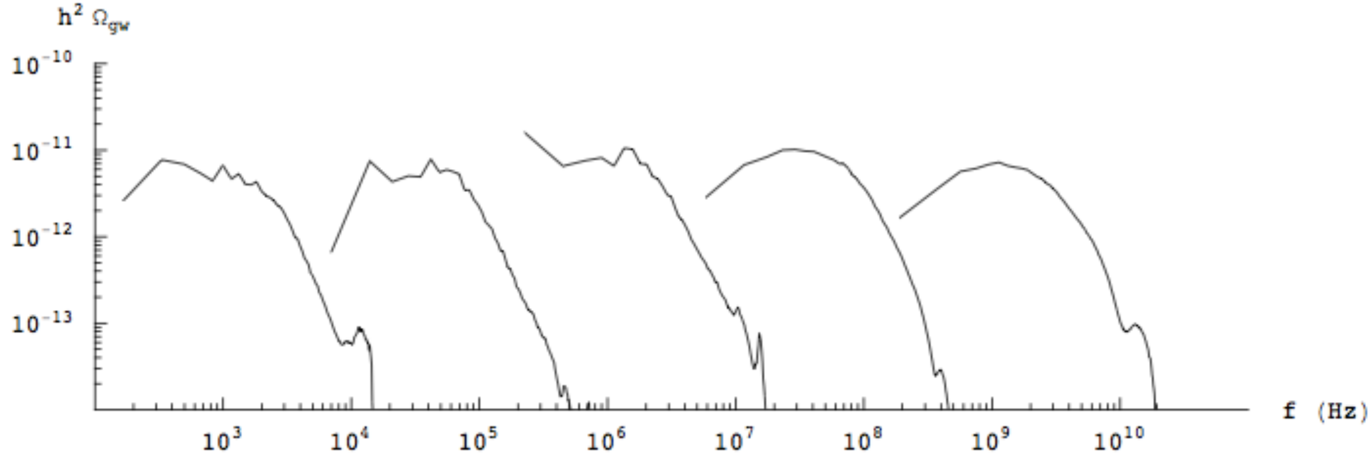
Cosmic strings / superstrings



R. Battye & P. Shellard

- Topological defects produced at phase transitions in early Universe
- Dimensionless string tension parameter Gμ
- Vibrations, kinks, intersections : GW emitted
- GW spectrum $\Omega(f)$ expected to be flat
  - Amplitude depends on Gμ and on string evolution

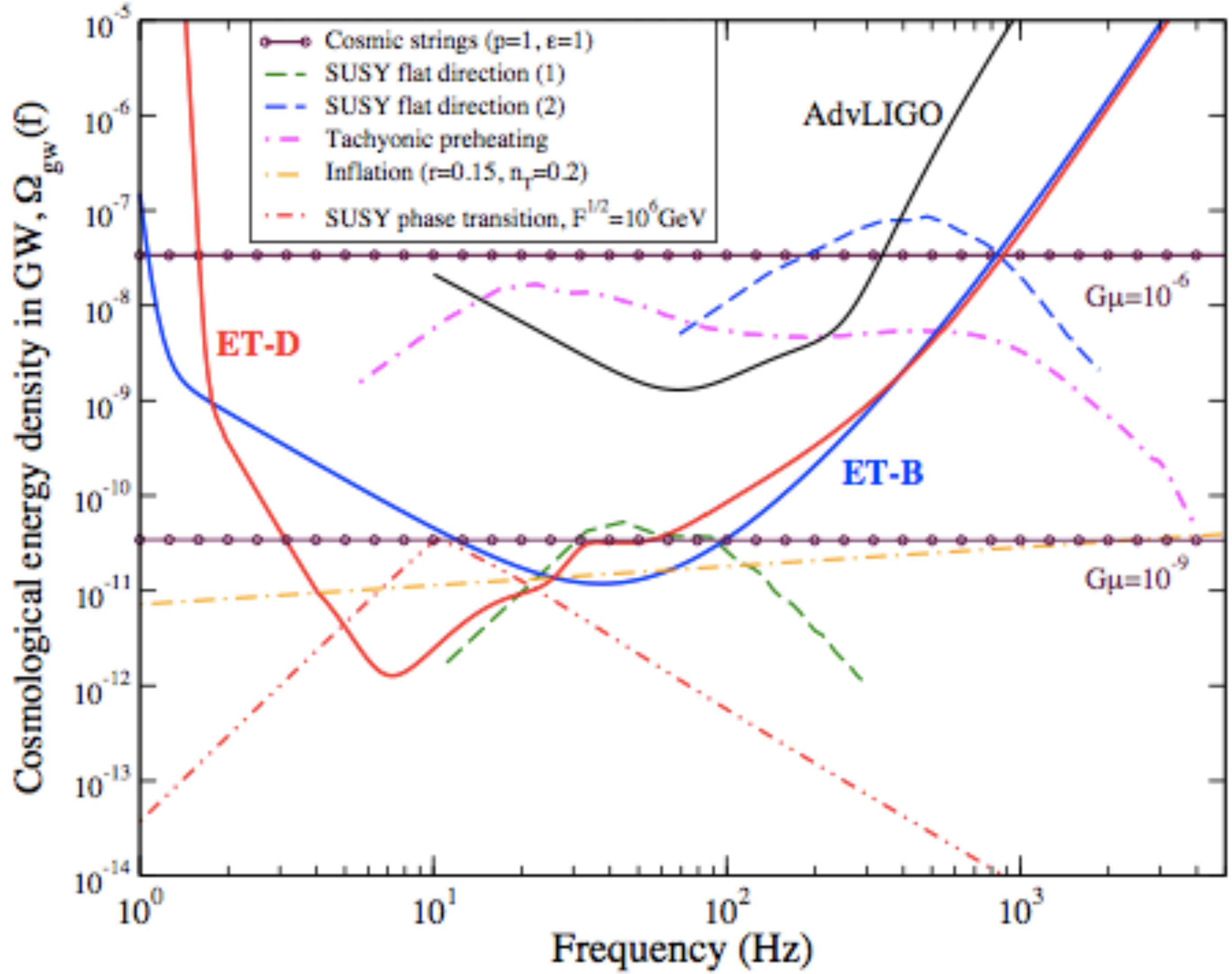
Narrow-band sources



- Processes occurring at given scale factor a^* and/or temperature T^*
  - Reheating after inflation: non-equilibrium classical fields
  - Phase transitions
    – bubbles nucleate, collide, turbulence, magnetic fields…
  - $\Omega(f)$ spectrum **peaked**
  - f_{peak} may be in ET band (5–1000Hz)
    – fine-tuned parameters ?
  - Amplitude and f_{peak} value ⇔ parameters of new physics

Plot: Easther et al., PRL 99 (2007) 221301

The stochastic landscape at ET

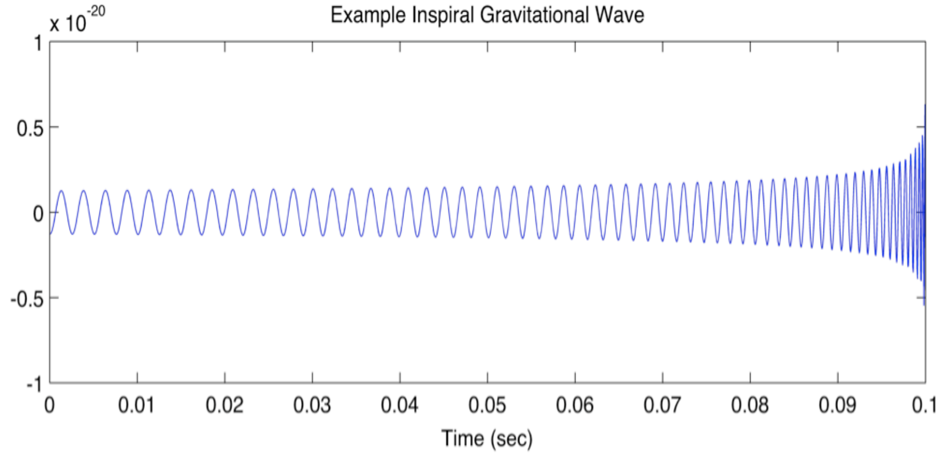


Cosmography with GW standard sirens

- Probing the expansion history of the Universe

GW standard sirens

- Binary inspirals emit 'chirp' waveforms
  - Frequency evolution gives 'chirp mass' M_c to high accuracy (up to redshift factor)
  - Absolute luminosity in GW known from M_c



- Observed amplitude ⇒ luminosity distance
  - 'Self-calibrating standard siren'
- Redshift z given from optical observation
  - Other methods possible – eg NS tidal deformation

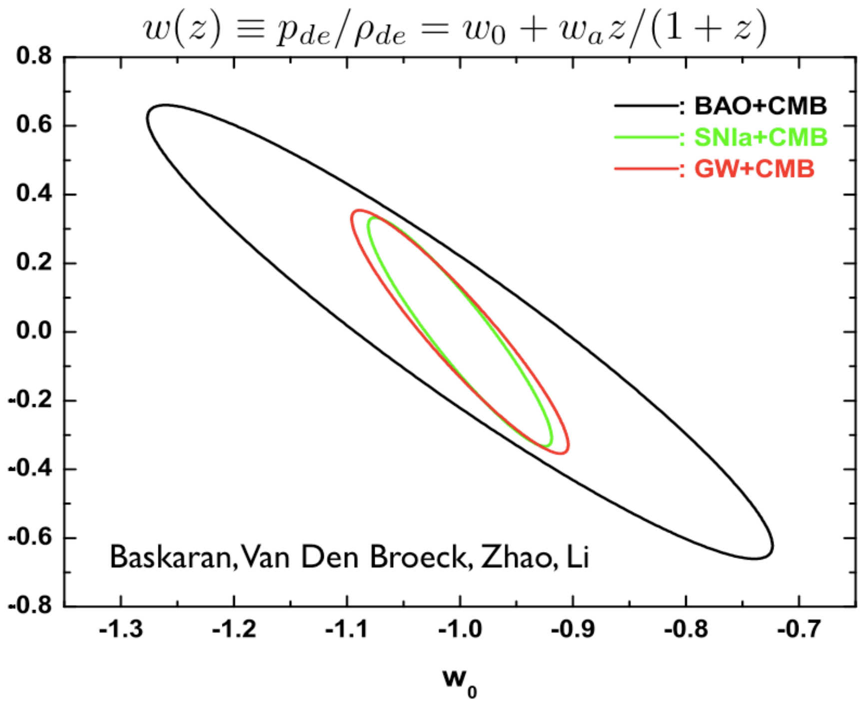
$$h_{obs} \propto M_c(\mathrm{obs})^{5/6}\, D_L^{-1}$$

$$M_c(\mathrm{obs}) = (1+z)\, M_c(\mathrm{phys})$$

Messenger & Read PRL 108 (2012) 091101

Cosmography with GW / sGRB

- Short hard GRB believed to originate from compact binary coalescence (mainly BNS)
- 10^5–10^6 events/year observable in ET
- GRB are *beamed* : only a small fraction seen with optical counterpart
- With ~1000 events : probe expansion of Universe via D_L–z
  - Comparable to SN1a, BAO probes of "dark energy"
  - Completely independent method



Zhao et al.: Phys.Rev.D (2011)

Summary

- ET expected to see 10^5-plus binary inspiral events per year
  - Use as ‘standard sirens’ in combination with EM observations (& possibly without)
  - Probe expansion history of Universe
  - Many other applications in cosmology
- ET sensitivity to stochastic BG: $\Omega(f) \sim 10^{-11}$
  - Many likely astrophysical sources
  - Possible primordial (early Universe) sources
  - Window to new physics?