The science potential of the Einstein Telescope

EINSTEIN TELESCOPE

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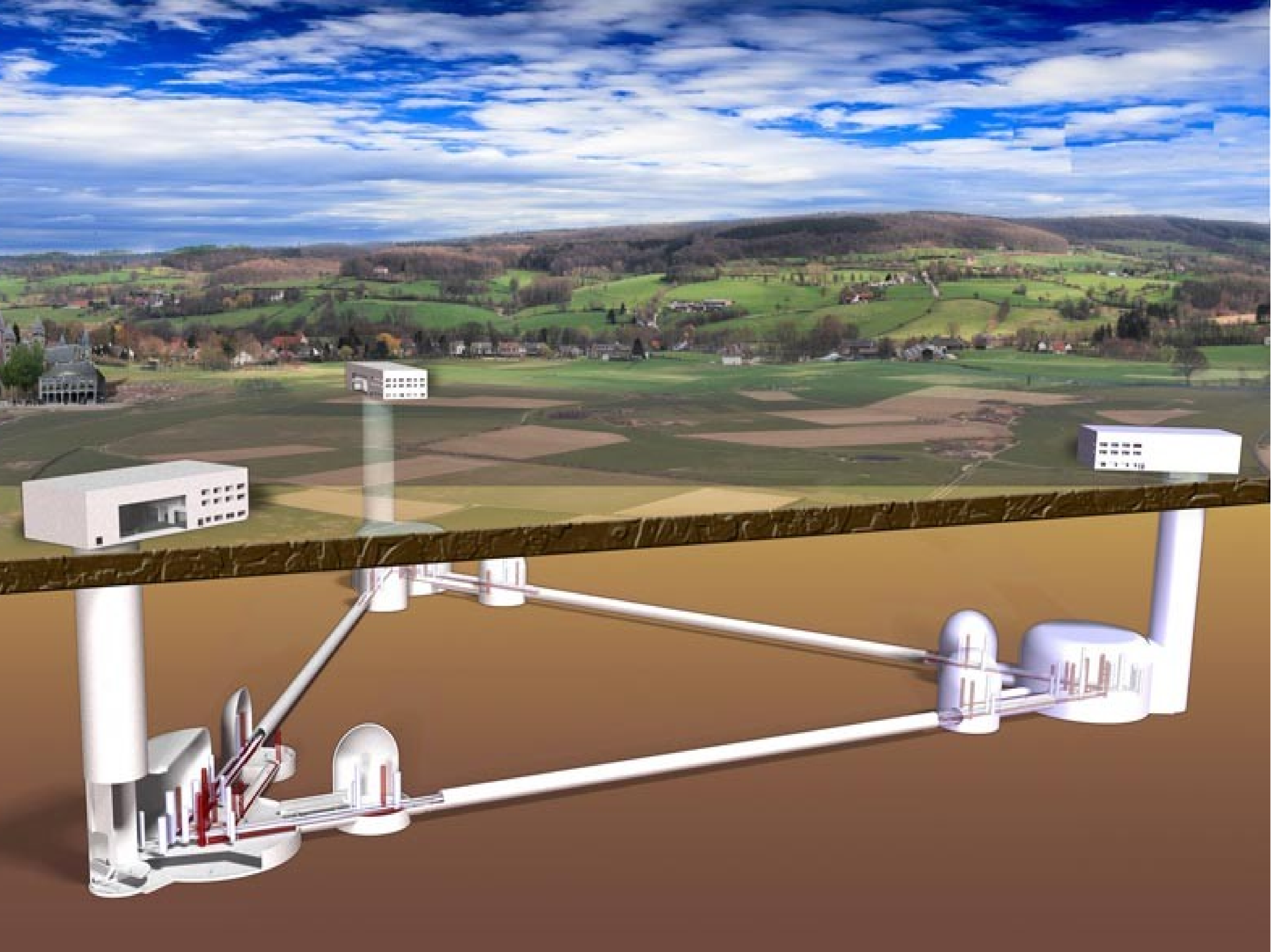
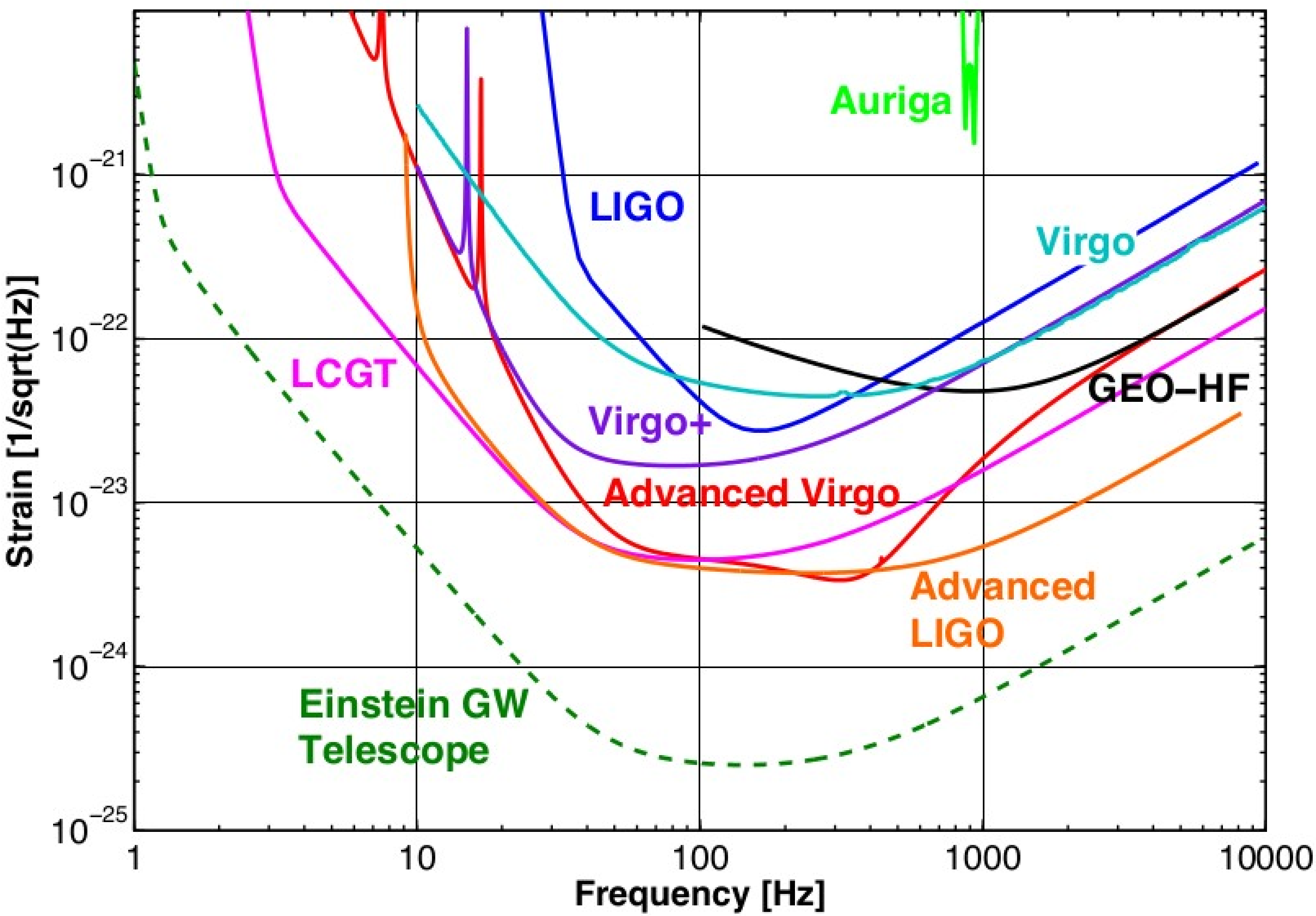
What is ET?

- The third generation gravitational wave detector.
- An underground interferometer.
- Triangle configuration



ET Sensitivity



ET capabilities: summary

- Spectral range: 10Hz-10kHz
- Sensitivity down strain $3 \times 10^{-25}\ Hz^{-1/2}$ in the best range
- Angular resolution:
  - depend on EM detections
  - long lasting sources – use the Earth motion modulation
  - would be improved by a network
- Excellent spectral resolution

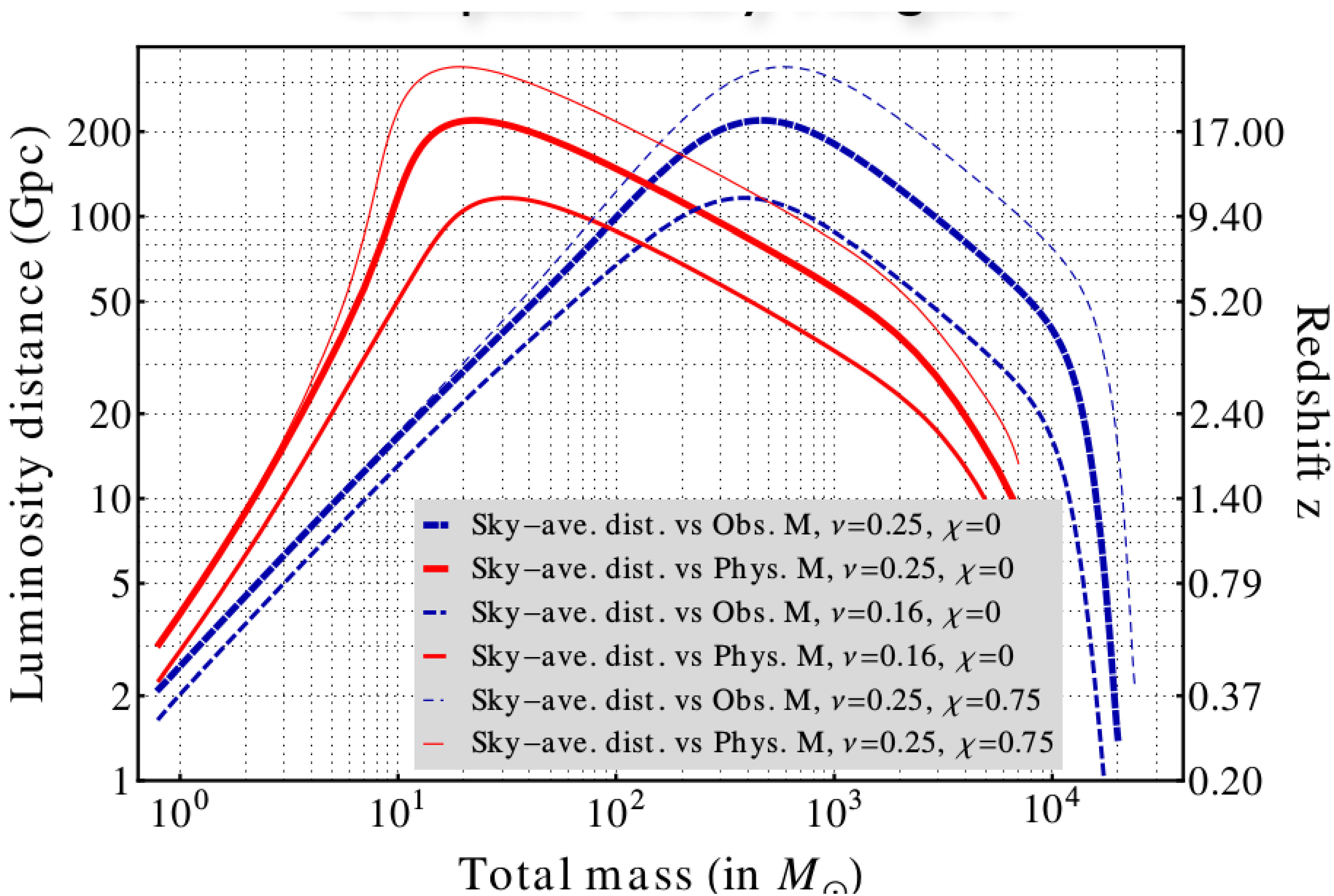
What does it mean?

- Sensitivity ~100 times better than current detectors
- Volume roughly 10^6 times larger
- 30 seconds of ET time is equivalent to 1 year of LIGO/VIRGO data

Astronomical sources

- Compact object binaries
- Core collapse supernovae
- Pulsars
- Backgrounds

ET range for coalescences



Compact object binaries

- Rates: up to 100s per day
- Large mass range: not only standard stellar sources but also intermediate Bhs
- For nearby sources very high S/N – detailed measurement of the waveform.

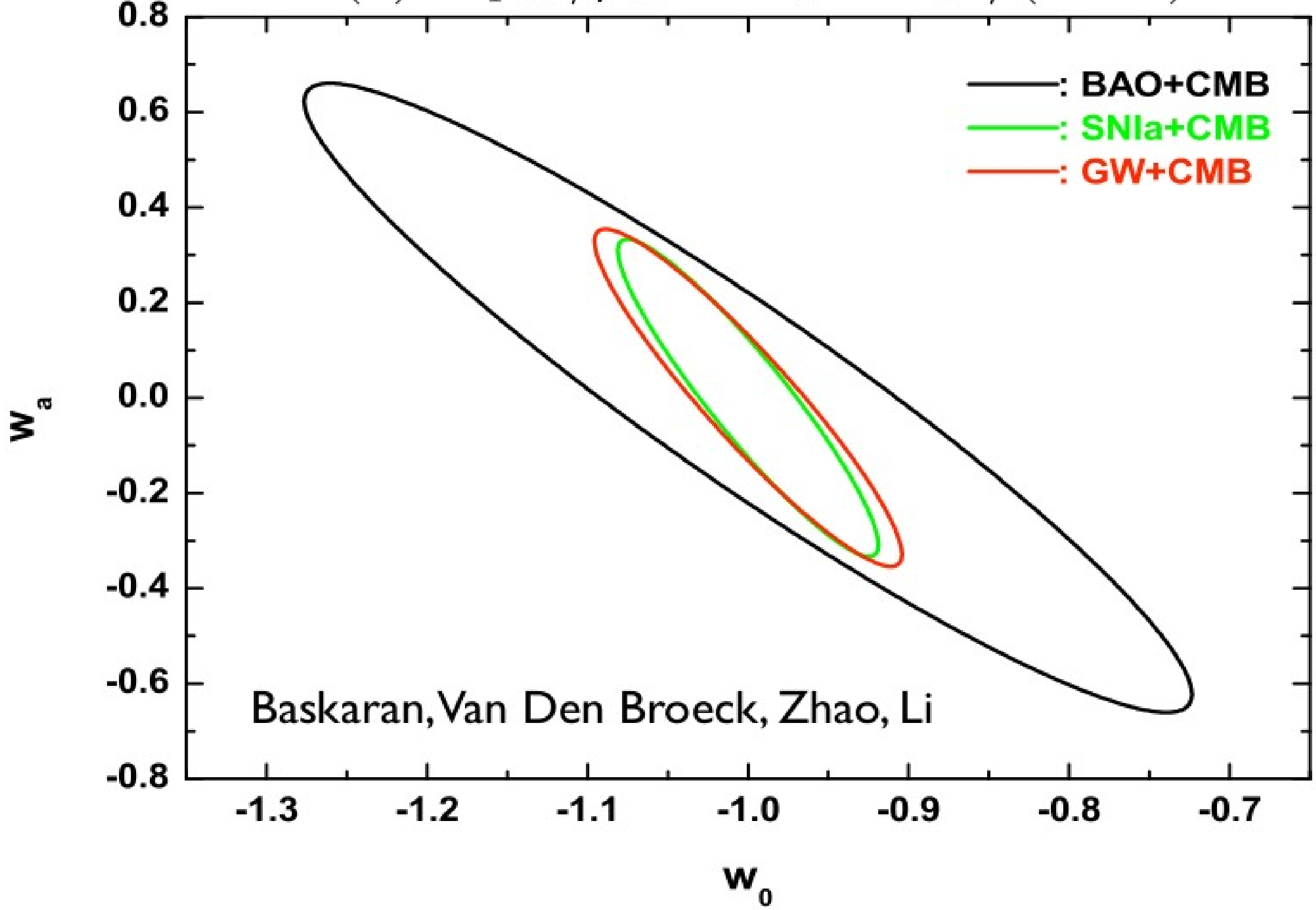
Astrophysics with compact object binaries

- Cosmology:
  - Standard sirens: amplitude and frequency change depend on the chirp mass only; need an independent redshift estimate
  - Possible measurement of the Hubble constant, w, and their variation with age
  - Anisotropic cosmologies tests
  - EoS of dark energy
- Star formation and compact object mass spectrum
- Gamma ray bursts
- Massive BH formation scenarios
- EoS of ultra dense matter

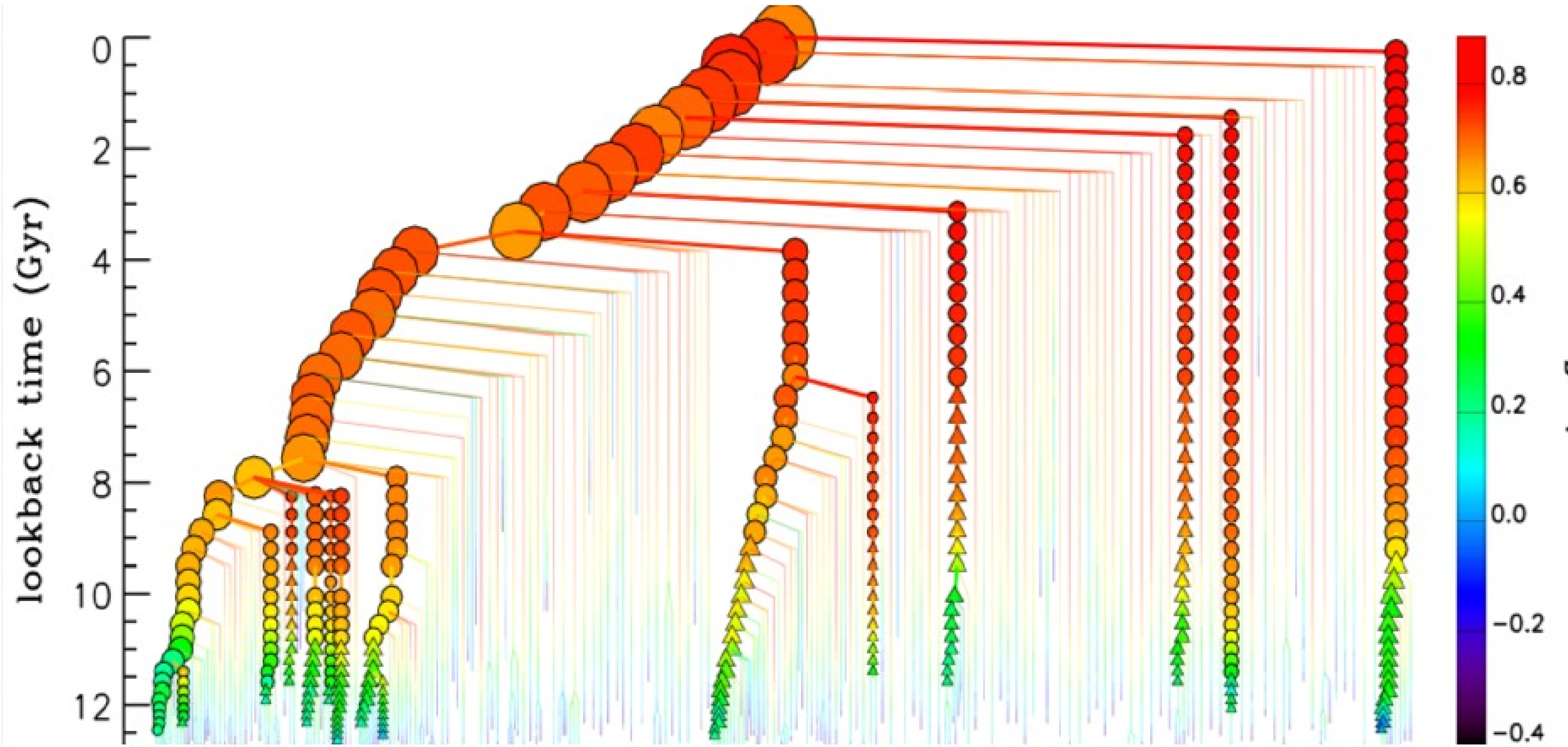
Cosmology

An example of w(z) possible mesasurment with ET:

$$w(z) \equiv p_{de}/\rho_{de} = w_0 + w_a z/(1+z)$$

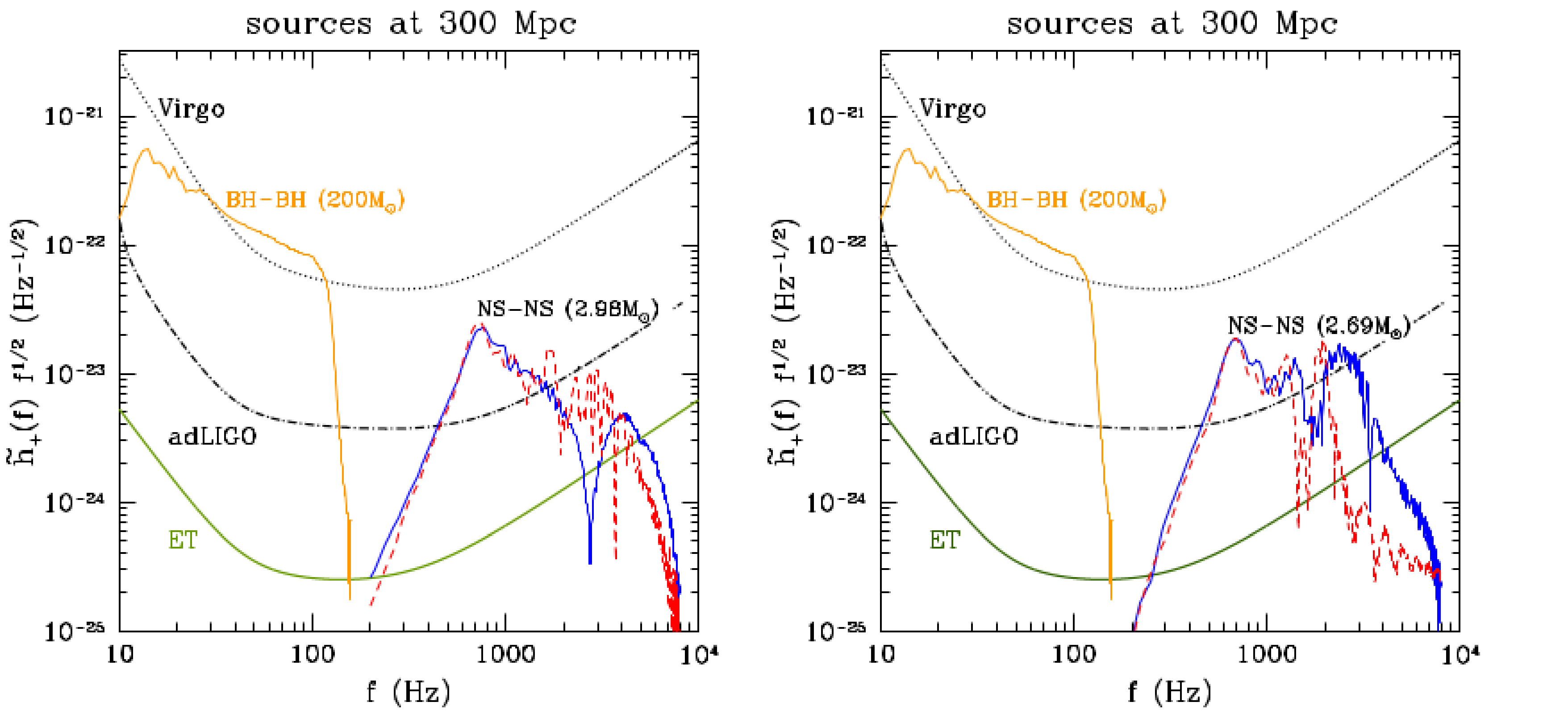


Formation of BHs in galactic nuclei



Small black holes merger hierarchically into larger ones. ET can detect mergers of black holes up to 1000 solar mass, enabling to trace the formation of massive ones.

Neutron star equation of state



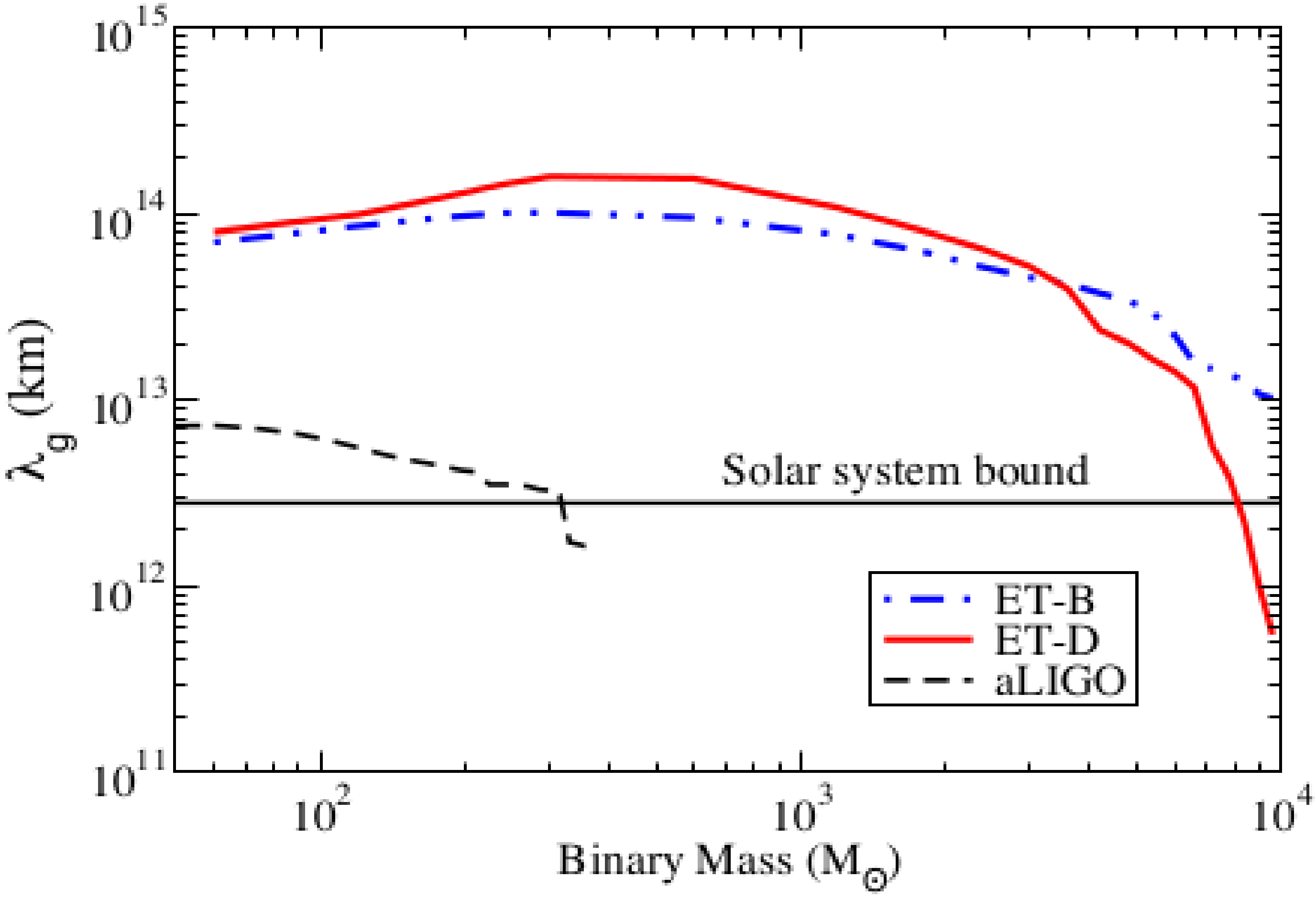
Fundamental physics with binaries

- The speed of gravity:
- Difference in the arrival time of EM and GW signal

$$\frac{\delta v}{c} = \frac{\delta t}{D/c} \approx 10^{-17}\left(\frac{\delta t}{1s}\right)\left(\frac{1\mathrm{Gpc}}{\mathrm{D}}\right)$$

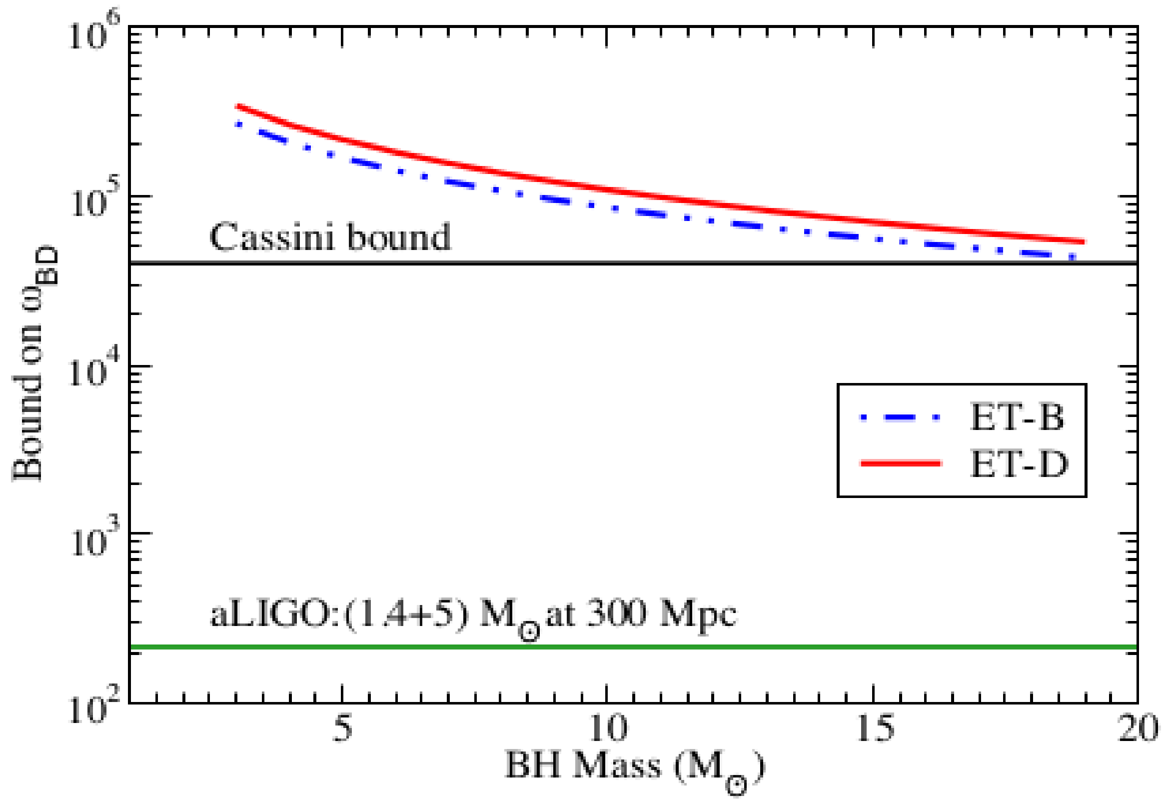
- Limiting the mass of graviton and it Compton wavelength, from measuring the dispersion
- Testing GW beyond the quadrupole formula
- How many GW polarizations there are?

Bounds on the graviton Compton wavelength



Fundamental physics with binaries

- Testing the no hair theorem:
  - BH spectrography
- Testing alternative theories of gravity

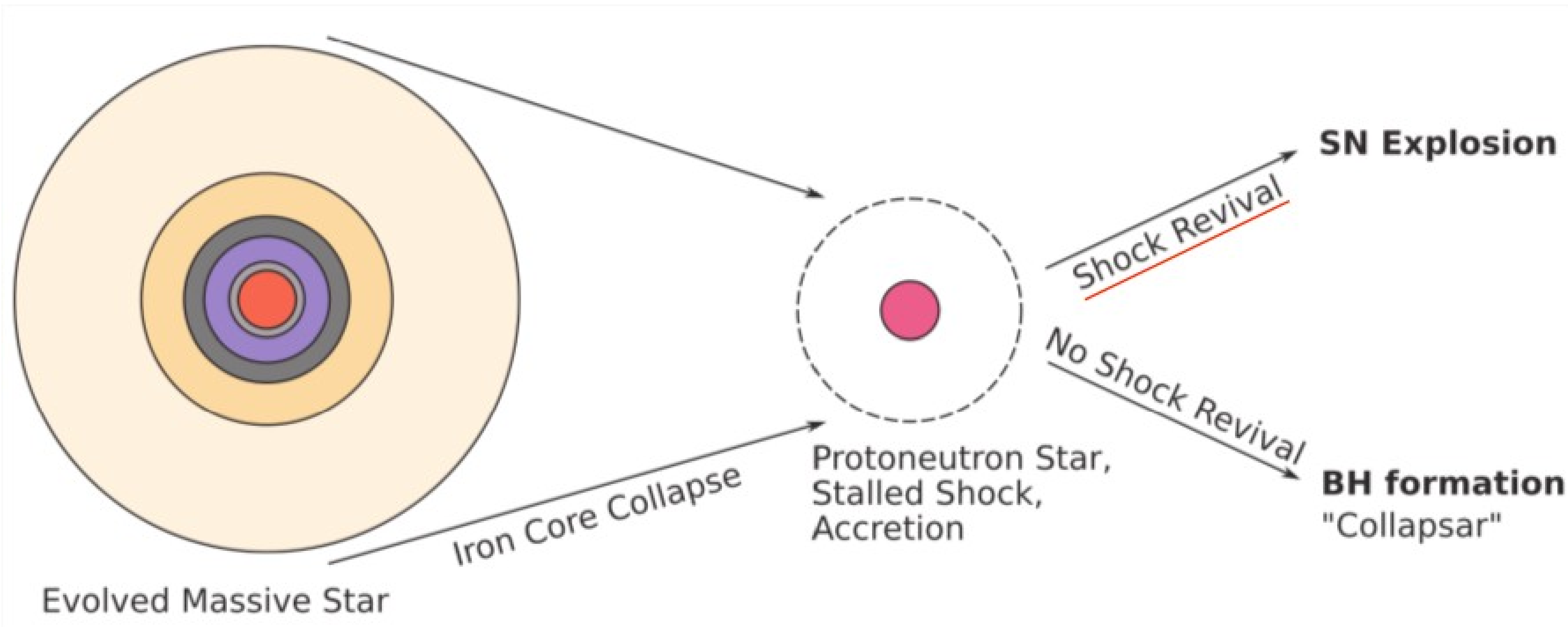


Potential bounds on the Brans-Dicke gravity parameter. The bound stems form the existence of a dipolar term in the BD theory.

Core collapse supernovae

- Rates: current LIGO/VIRGO range in the Milky Way.
- Advanced LIGO/VIRGO will reach M31
- ET – up to 5Mpc
- Rates up to one per year – optimistic.

Core collapse supernova



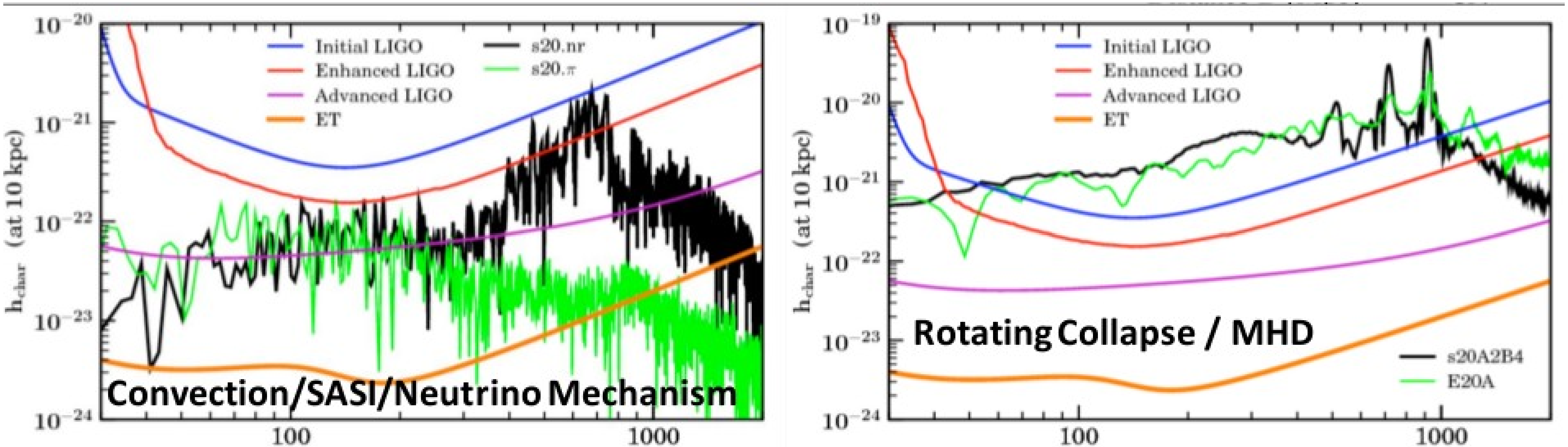
Energy up to 10^{51} erg.

Delay 1-2 seconds after bounce

Formation of BH – and its mass growth

Physics with core collapse supernovae

- Mechanism of supenovae explosions
- Formation of a BH
- Quasi normal model and BH spectrography
- Could allow the measurement of neutrino mass.

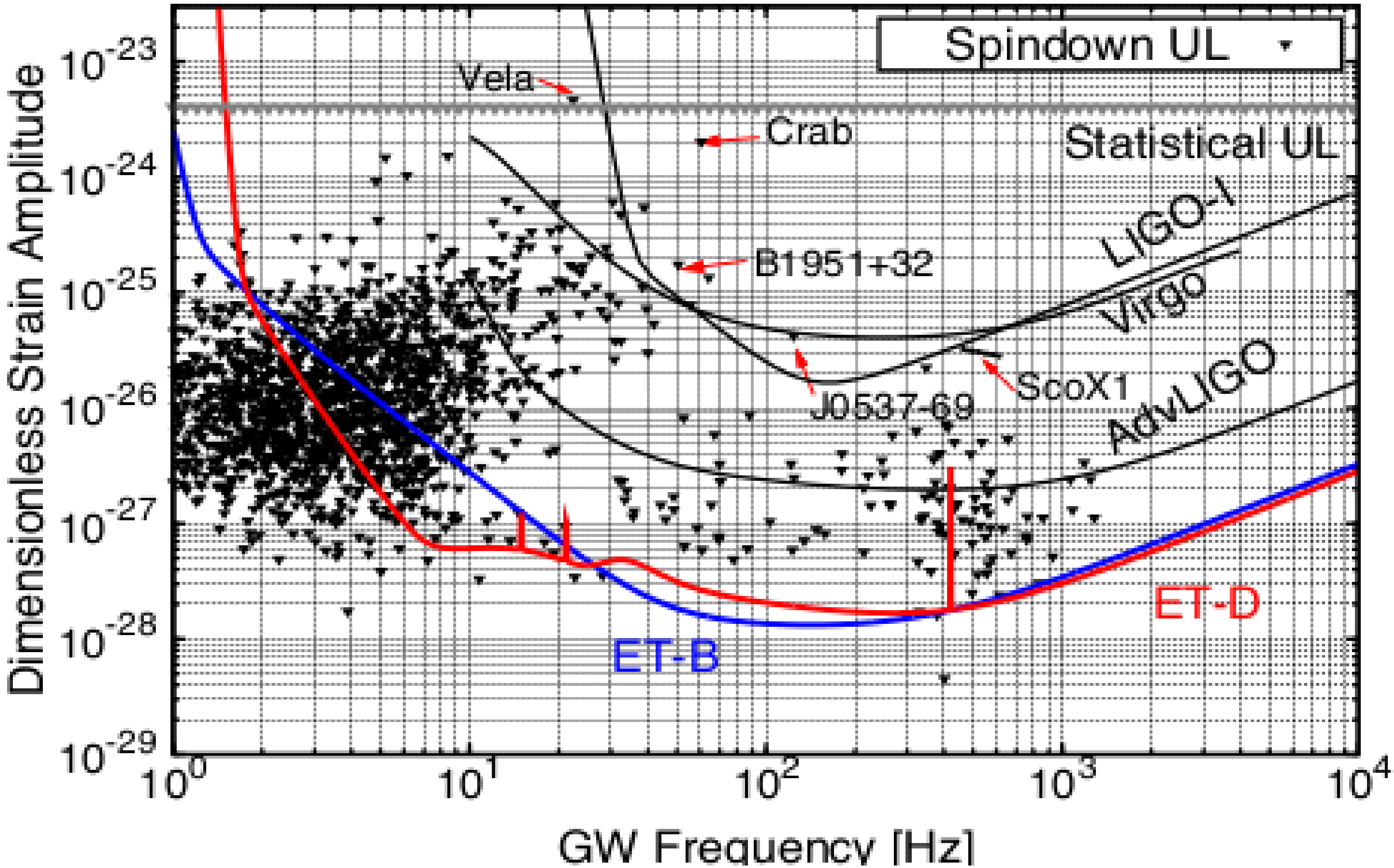


Example spectra for a SN in the center of the Milky Way

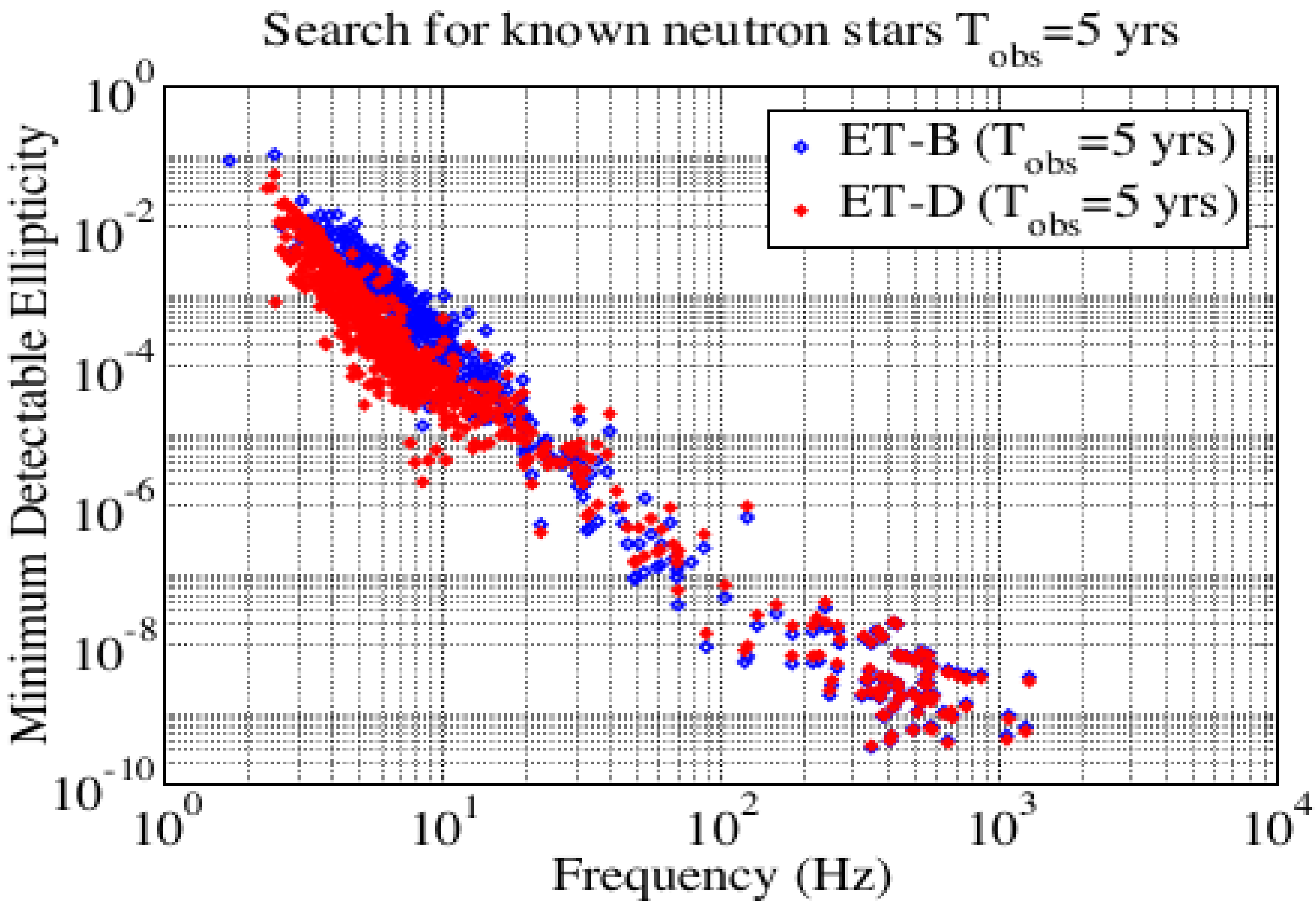
Rotating neutron stars

- Will emit GW if asymmetric
- All astrophysical objects are non spherical to some degree
- Can form mountains on the crust of a NS
- Supported by magnetic fields
- Glitches as NS asymmetry indicators
- See also the talk by M. Kucaba

Spin down limit for pulsar luminosity



ET sensitivity

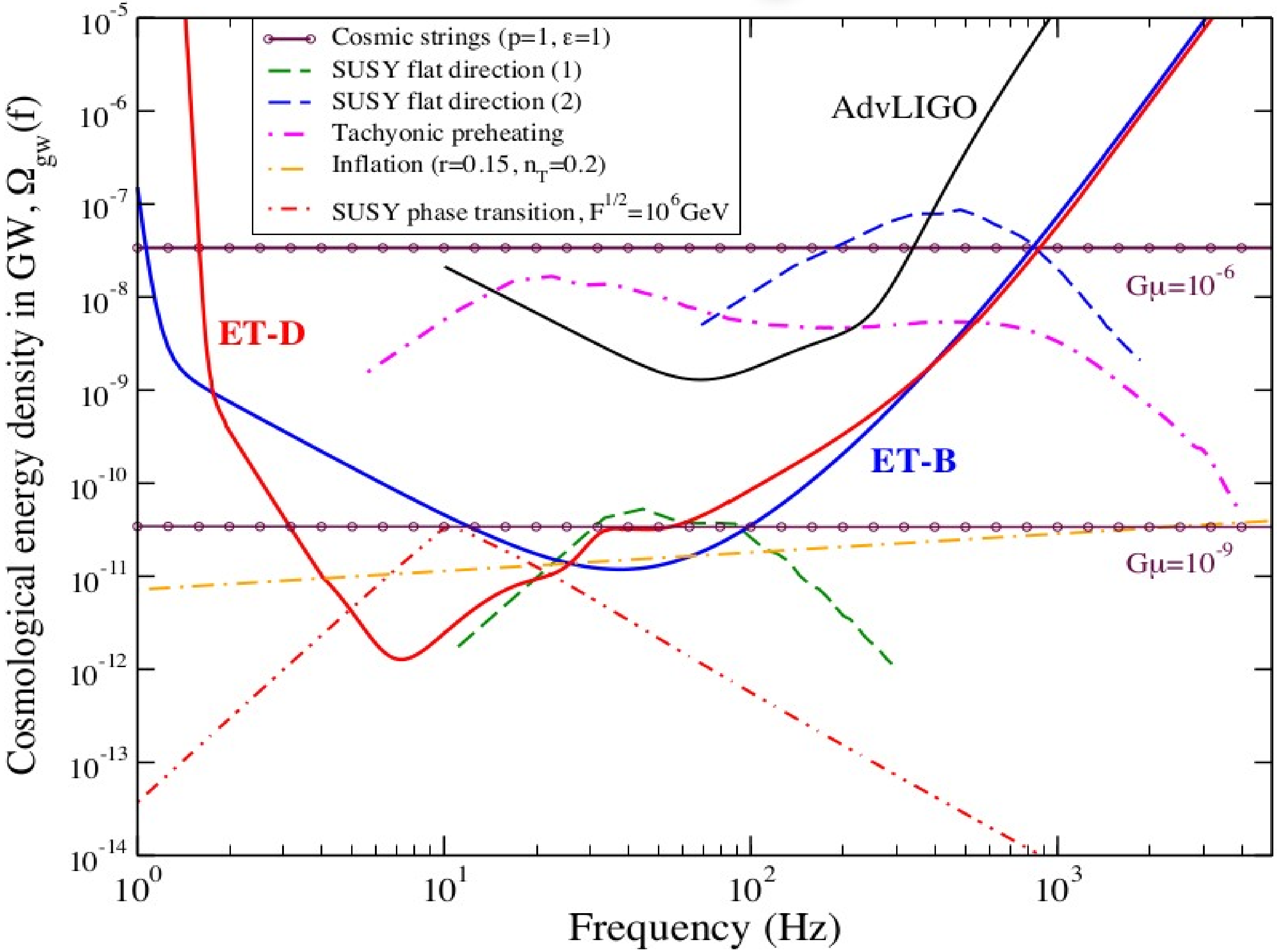


Mountains as small as 10um can be detected !

Backgrounds

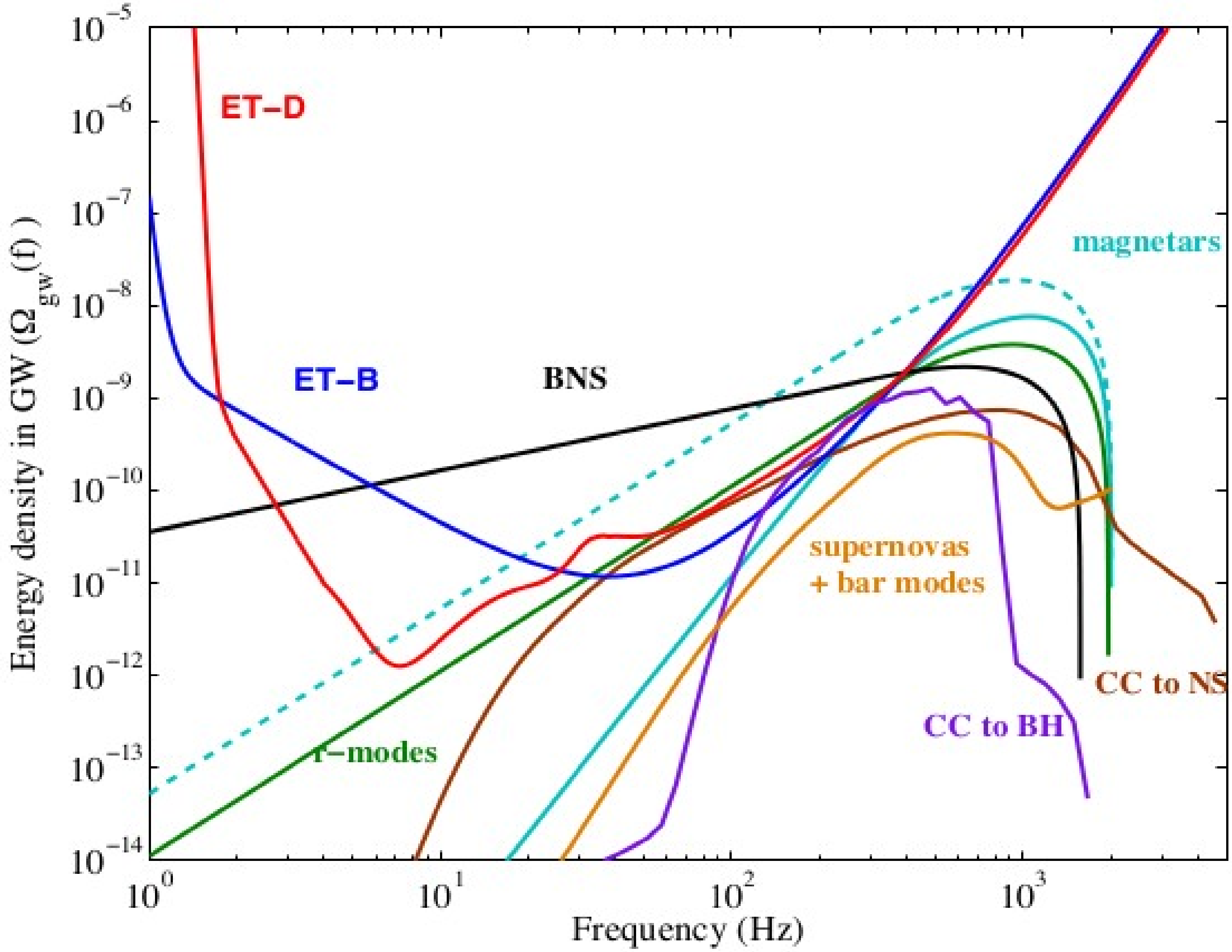
- Stochastic backgrounds can be detected by correlating signals from independent interferometers
- Compact object background, discussed by T. Regimbau, see I.Kowalska talk
- Primordial background, see the forthcoming discussion

Primordial backgrounds



Insight into the phase transitions at the early Universe, however need to subtract the foreground!

Astronomical foregrounds



Summary

- Astrophysics:
  - The mechanism of SN
  - The origin and mechanism of gamma ray bursts
  - Formation history of compact objects: BH and NS
- Fundamental physics:
  - The nature of gravitational waves?
  - Is GR the correct theory of gravity
  - Are black holes hairy?
- Cosmology:
  - Is the Universe anisotropic?
  - What was the evolution of cosmic expansion?
  - What is the nature of dark energy?
  - Wat phase transitions took place in the early Universe?

For more information see the ET Design Study Document

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