Science objectives with the Einstein Telescope

Some highlights: aims and challenges

Micaela Oertel

micaela.oertel@obspm.fr

With input from the Paris-Caen group within the ET collaboration

Laboratoire Univers et Théories (LUTH)
CNRS / Observatoire de Paris/ Université Paris Cité

Assemblée Générale, GdR Ondes gravitationnelles, Toulouse, October 10-12, 2022

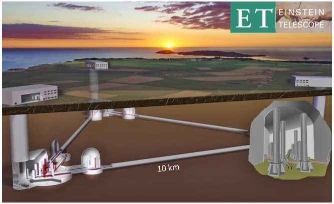
Einstein Telescope : a 3rd generation ground-based detector

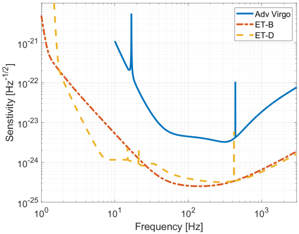
Instrument design

- Underground
- 10-km long arms
- Triangle configuration →polarisation
- "Xylophone"
- Cryogenics (thermal noise reduction)

Timeline

- In the ESFRI roadmap since 2021
- Collaboration launched in June 2022
- Site decision within next two years
- First data taking planned for mid-2030's

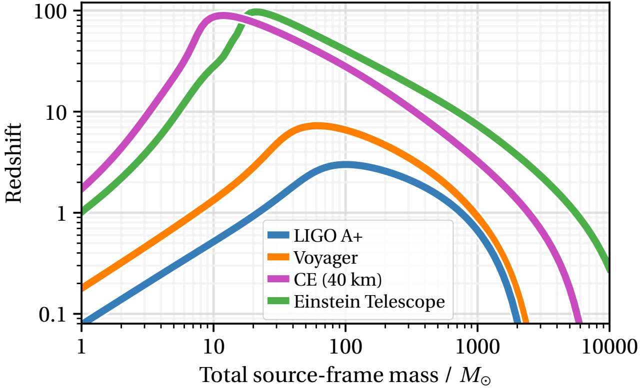




[ET science case, 1912.02622]

American project for 3rd detector with similar timeline : Cosmic Explorer

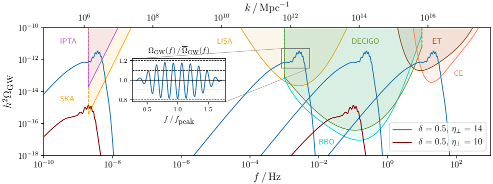
Horizon for compact binary mergers



[CE horizon study, 2109.09882]

- $\sim 10^5$-10^6 BBH mergers per year ; stellar and intermediate masses ; up to redshift $z \sim 20$
- $\sim 10^5$ BNS mergers per year ; up to redshift z ∼2-3
- New astrophysical GW sources (CCSN in galactic neighbourhoud, pulsars, . . .)

Gravitational wave backgrounds



[Fumagalli+2021]

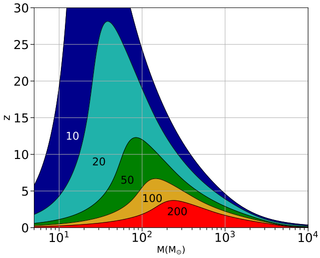
Cosmological

- Stochastic background from early Universe ; GWs from different inflationary scenarios, particle production, phase transitions, . . .
- Angular resolution allows to distinguish (extra-)galactic backgrounds

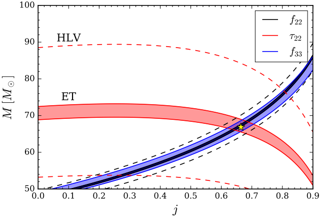
Astrophysical

- Unresolved sources too faint to be detetcted individually
  - Burst sources (CCSN, proto-neutron stars)
  - Periodic long-lived sources (pulsars)
  - Compact binaries (main source for ground-based detectors)
- BNS merger population interesting for heavy-element nucleosynthesis and chemical evolution

Binary black hole mergers



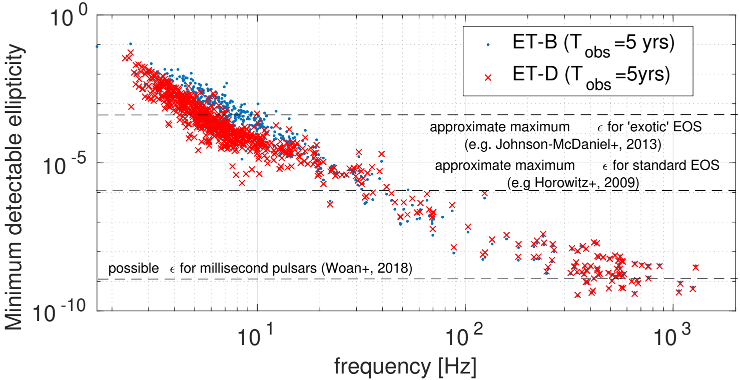
[ET science case, 1912.02622]



[GWIC 3G Science book 2021]

- Population synthesis of black holes up to a mass $\sim 10^3 M_\odot$ and redshift $z \sim 20$
  $\rightarrow$ progenitors, stellar evolution
  $\rightarrow$ intermediate mass BH, seeds of supermassive BHs at galaxy centers
- BBH inspiral and quasi-normal modes with very high precision
  $\rightarrow$ quantitative tests of general relativity
  $\rightarrow$ exotic compact objects ?
- BH population of primordial origin in the mass range $\sim 0.1\text{-}100 M_\odot$
  $\rightarrow$ candidates for dark matter
- Challenge for precision waveform models, in general relativity and beyond, e.g. improve on spinning objects

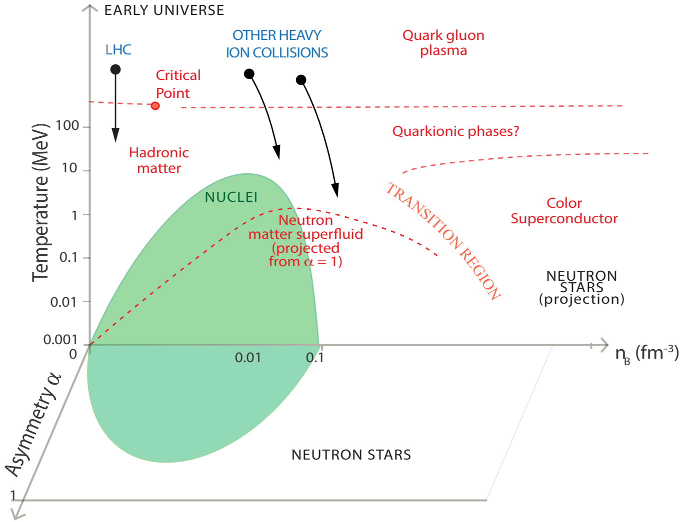
Continuous waves from spinning neutron stars



[ET science case, 1912.02622]

- Deformed (Crust, magnetic effects, accretion, density perturbations, ...) spinning neutron stars emit GW
- Not yet detected, detectable with ET for "expected" deformations
- Possible burst signals from glitches, magnetar flares

The QCD phase diagram



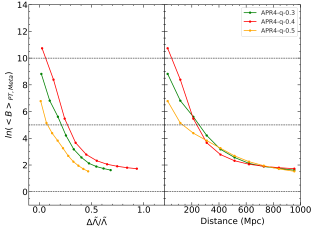
[Watts+2015]

Can we detect a phase transition in NS ?

- Transition to a quark-gluon plasma ? Other kind of first order phase transition in dense matter ?

Inspiral

- Λ(M) deviates at onset of phase transition
- Detectability during inspiral depends on masses and precision
- Early PT detectable with ET ?



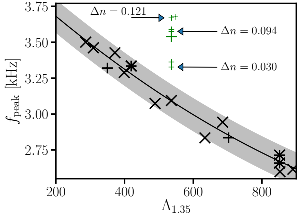
[Mondal+ in preparation]

Post-merger

- Even if no PT in NS prior to merger, the dense merger remnant might

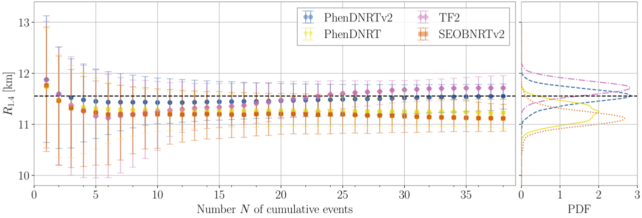
  [Bauswein+2019, Most+2018, Ecker+2019. . .]

- Post-merger oscillation frequencies show imprint of matter properties
  → clear signal of phase transition



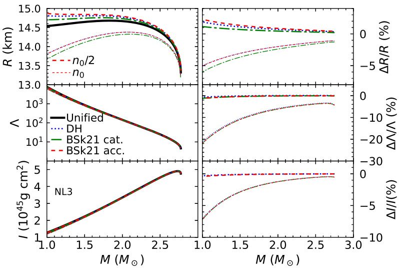
[Bauswein+2019]

Measuring the NS radius



[Kunert+2022]

- Measuring tidal deformability + EoS allows to extract NS radius
- Statistical uncertainty decreases $\sim 1/\sqrt{N}$
  $\rightarrow$ for ET systematic uncertainties dominate (waveform, NS core-crust transition, ...)
- Work needed to have more accurate waveform models and EoS for data interpretation !

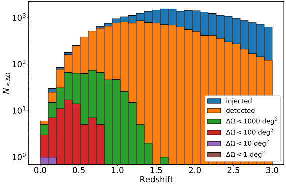


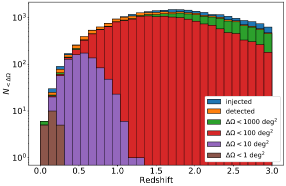
[Suleiman+2021]

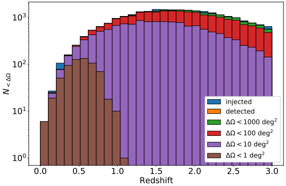
l'Observatoire de Paris — LUTH — Laboratoire Univers et Théories

Multi-messenger perspectives

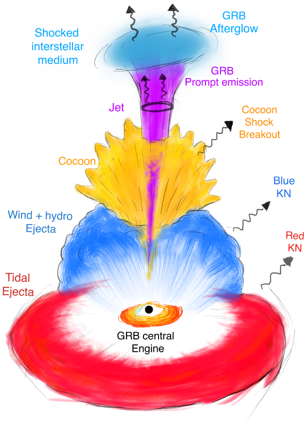
- BNS detected well before merger → better localisation and early alert
- GW detector network improves localisation and joint detection probability
- Kilonova emission detectable only for close and well localised sources
- Detection of high energy emission for larger distances, too
- Neutrinos from galactic events
- Big efforts for multi-messenger detections



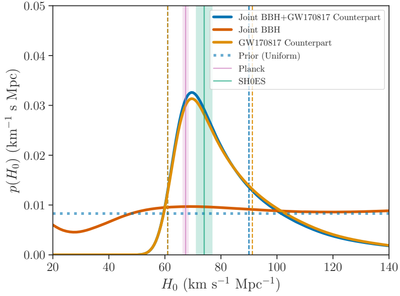




Some multi-messenger science aspects



[Ascenzi+2021]



[LVK 2021]

- Measurement of H_0 to percent level with 2G and sub-percent by 3G
- Test dark energy and theory of gravity
- Heavy element formation
- (short) Gamma ray physics

Summary

What 3rd generation detectors will see

- Stellar black hole population including those formed by first stars
- Multi-messenger counterparts (heavy element formation, sGRB ...)
- Neutron star structure

What they will potentially detect

- Modified gravity and/or exotic compact objects
- QCD phase transition
- Early Universe physics

There are many challenges ...

- Need for accurate waveform models in GR and beyond
- Overlapping signals