

Cosmology and fundamental physics with gravitational waves

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Cosmofondue

Geneva, June 10-13, 2025



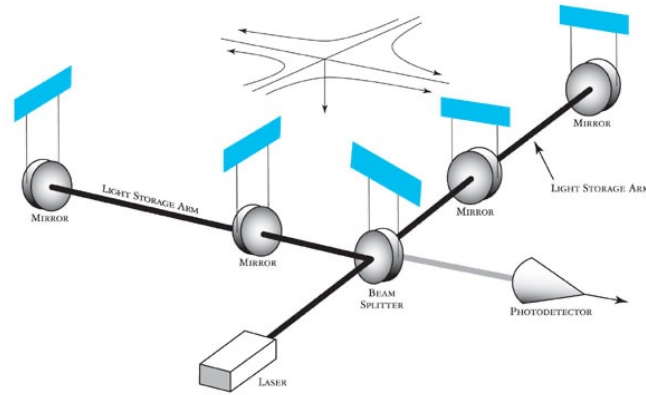
**UNIVERSITÉ
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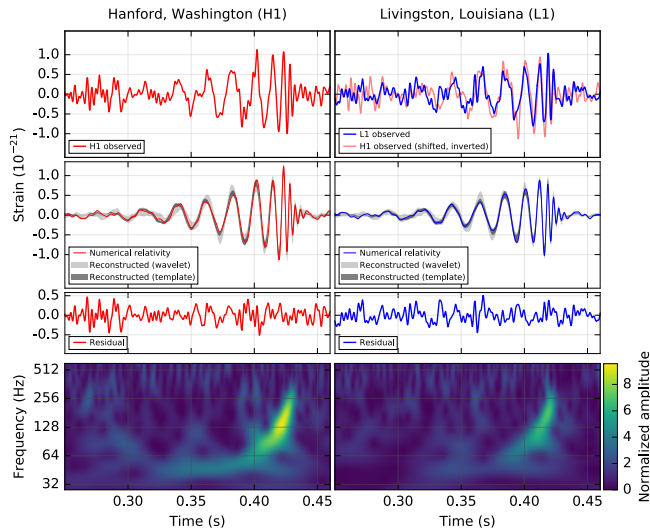
Département de physique théorique

Exploring the Universe with gravitational waves

- first direct detection of GWs in 2015 after 50+ yr of developments



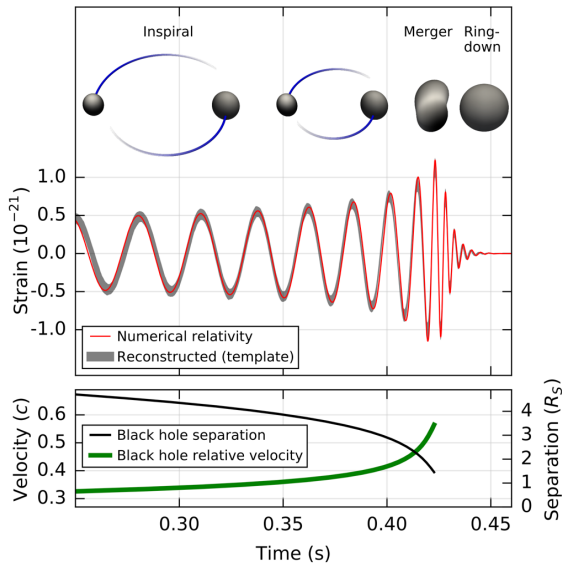
First detection of a BH-BH coalescence, Sept. 14, 2015



parameter estimation from
matched filtering:

primary BH mass	$36^{+5}_{-4} M_{\odot}$
secondary BH mass	$29^{+4}_{-4} M_{\odot}$
final BH mass	$62^{+4}_{-4} M_{\odot}$
final BH spin $\hat{a} \equiv Jc/(GM^2)$	$0.67^{+0.05}_{-0.07}$
luminosity distance	$410^{+160}_{-180} \text{ Mpc}$
source redshift	$0.09^{+0.03}_{-0.04}$

3 solar masses
radiated in
GWs in a few ms !!

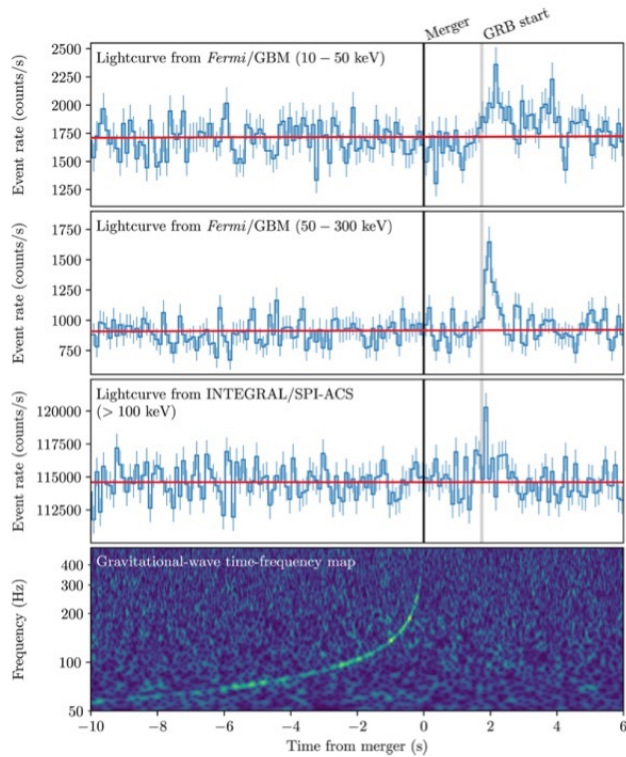


$v/c \sim 0.4$ at merger !

Nobel Prize 2017



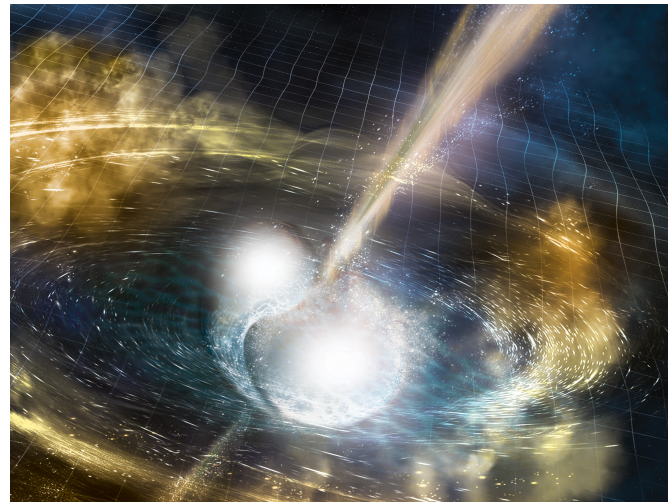
Another milestone was the first NS-NS binary, GW170817



Observed in coincidence with a GRB

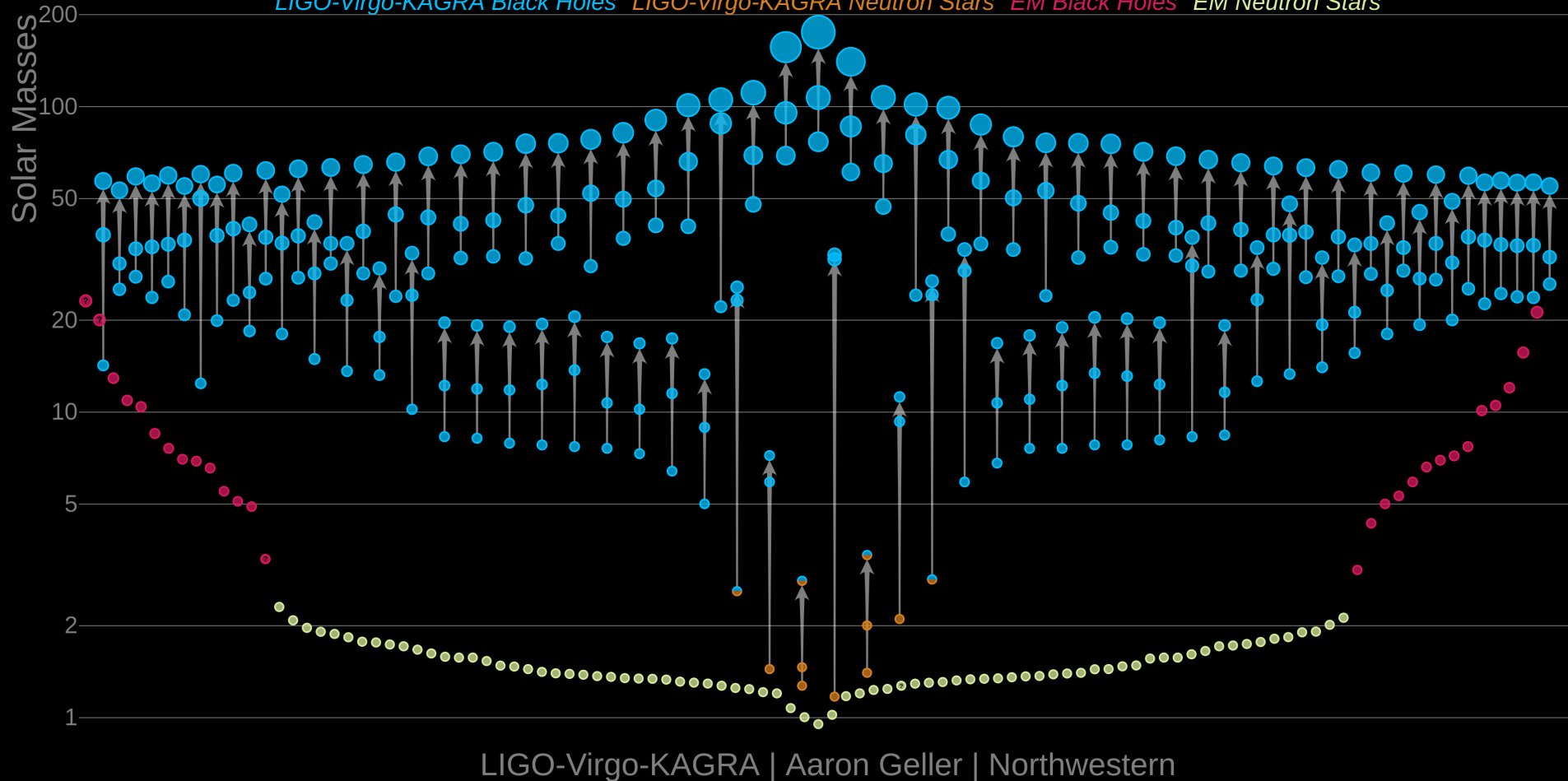
detection and follow-up of the counterpart
in all wavelengths of the EM spectrum

⇒ multi-messenger astronomy



Masses in the Stellar Graveyard

LIGO-Virgo-KAGRA Black Holes *LIGO-Virgo-KAGRA Neutron Stars* *EM Black Holes* *EM Neutron Stars*



After 3 observing runs, about 90 BBHs, 2 BNS and 2 NS-BH
During O3, detections made every few days
O4 run ongoing

What have we learned ? Some highlights:

Astrophysics

- GW170817 solved the long-standing problem of the origin of (at least some) short GRB
- NS-NS mergers are a site for the formation of some of the heaviest elements through r-process nucleosynthesis
- BH-BH binaries exist and merge within the age of the Universe
- discovered a new population of stellar-mass BHs, much heavier than those detected through X-ray binaries

Cosmology/fundamental physics

- speed of GWs equal to speed of light ($1:10^{15}$)
- first measurement of the Hubble constant with GWs
- the tail of the waveform of GW150914 consistent with the prediction from General Relativity for the quasi-normal modes of the final BH
- deviations from GR (graviton mass, post-Newtonian coefficients, modified dispersion relations, etc.) could be tested and bounded

Still, 2G detectors lack the sensitivity to make
really stringent tests of fundamental physics/cosmology

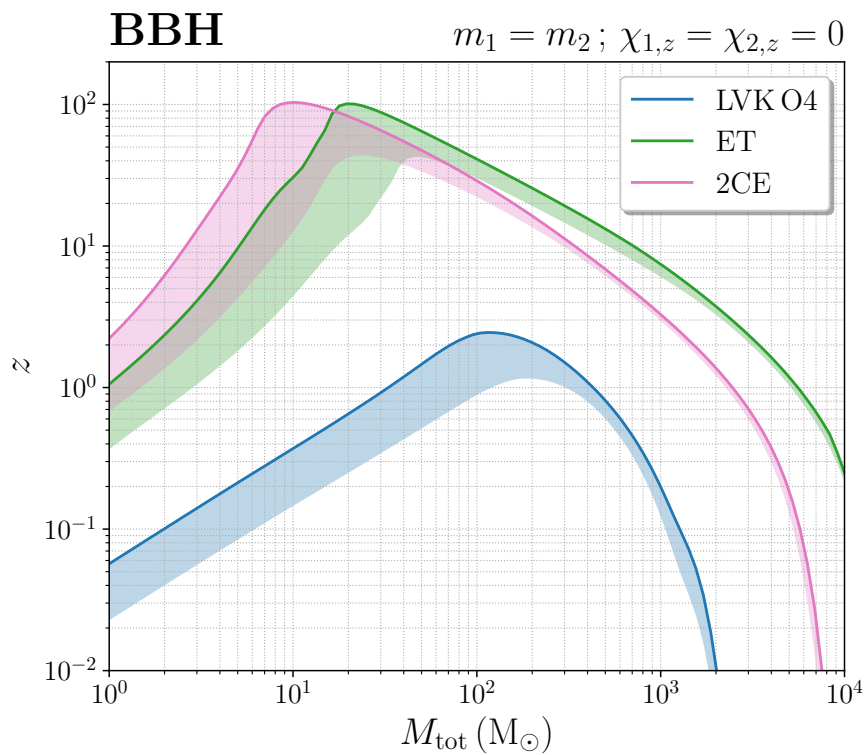
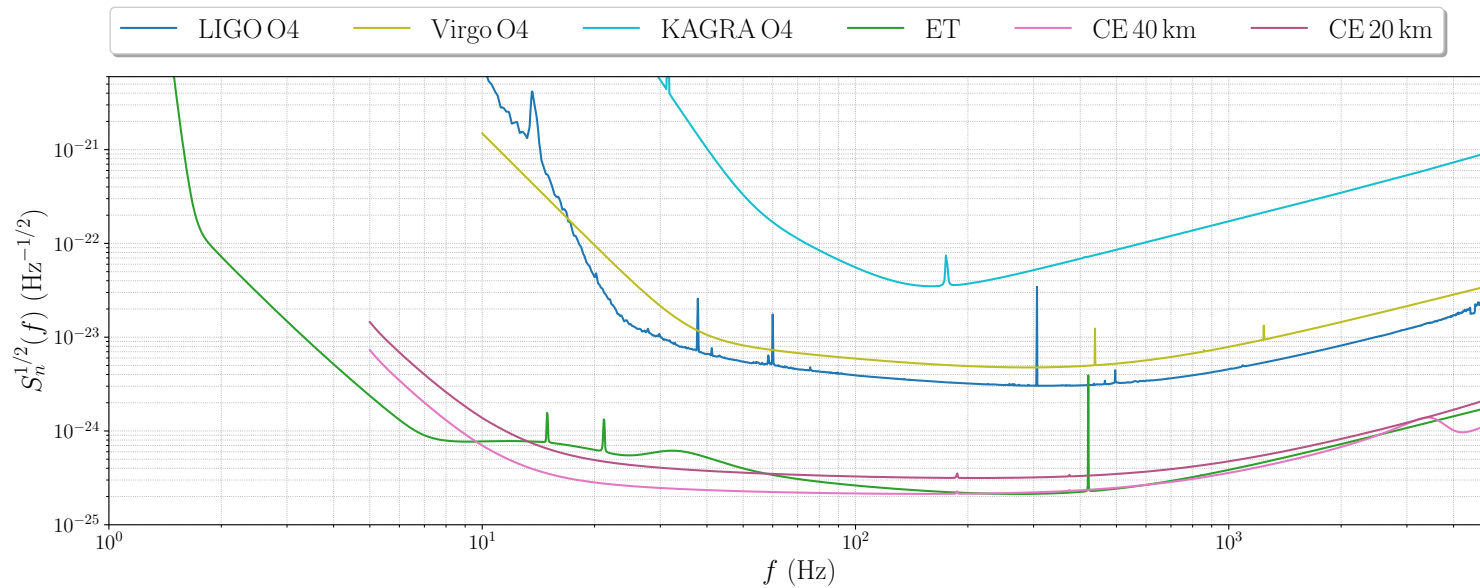
2G detectors have opened a new window

3G ground-based detectors (ET, CE) will look deeply into this
window

We will focus on the science that can be done with ET

useful references

- MM et al “Science Case for the Einstein Telescope”, JCAP, 1912.02622
(written for the ESFRI RoadMap)
- Iacovelli, Mancarella, Foffa, MM, ApJ, 2207.02771
- M. Branchesi, MM et al, JCAP, 2303.15923 (the “Science-CoBA” paper)
- Abac et al, ET Collaboration, 2503.12263 (the “BlueBook”)
880 pages, 200 figures, 4 yrs of work, 490 authors
coordinated by M. Branchesi, A. Ghosh and MM



BBH up to $z=0(50-100)$!!

BNS up to $z \sim 3$

Detection distance of BBHs

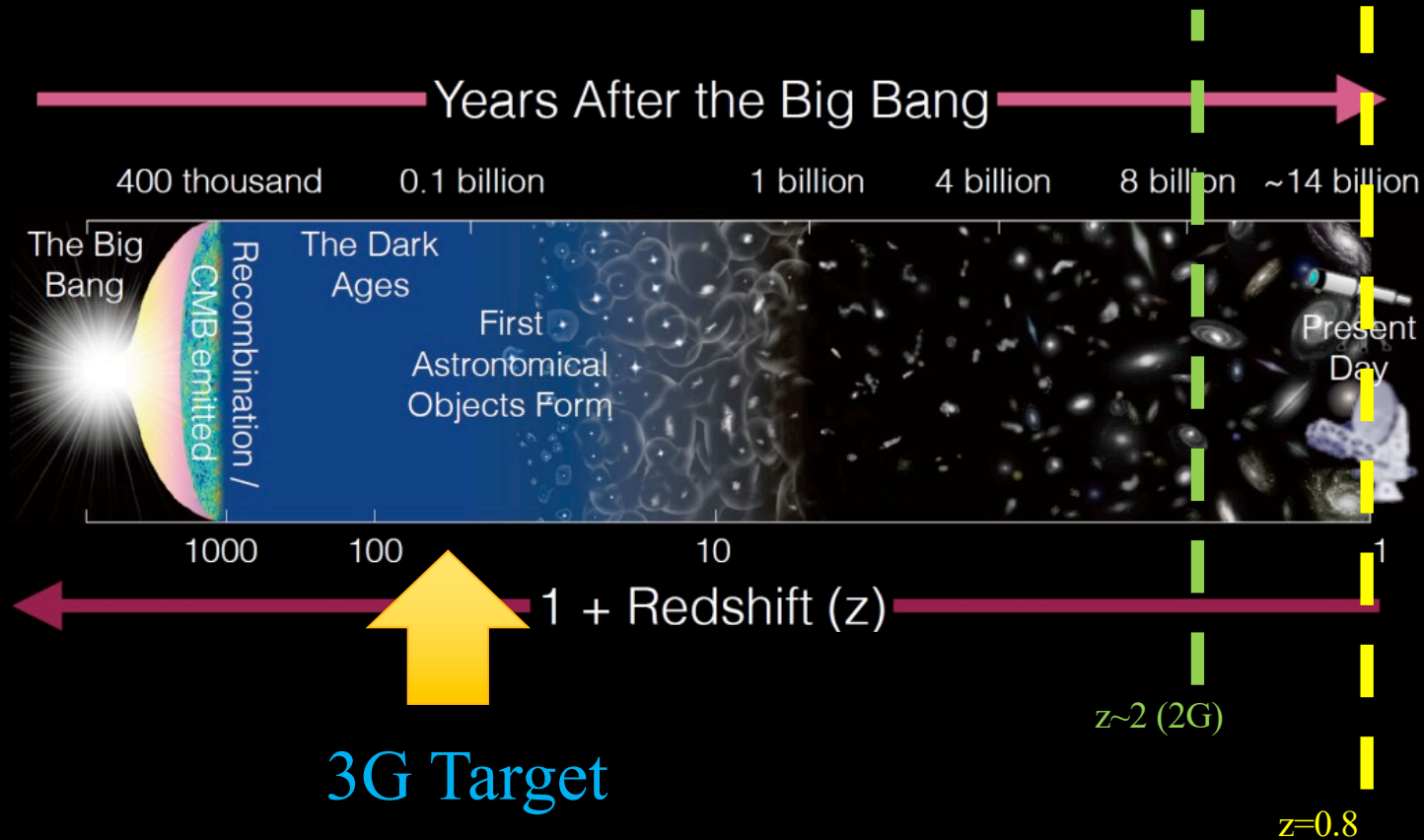
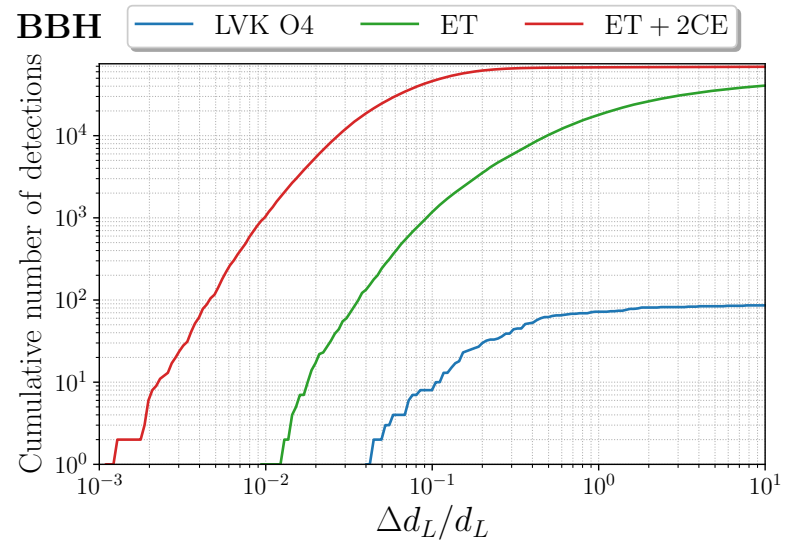
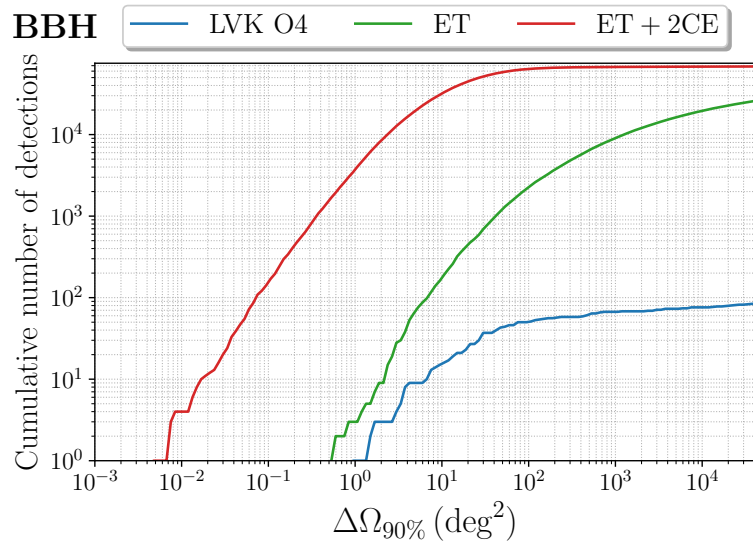
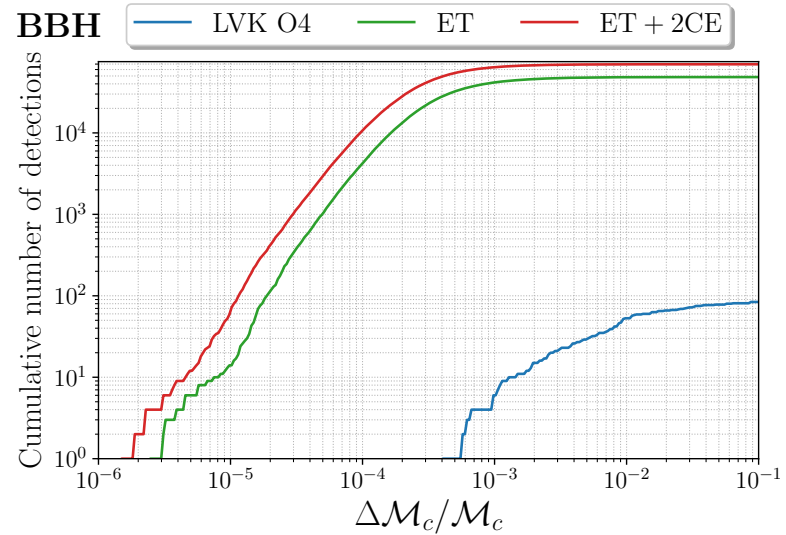
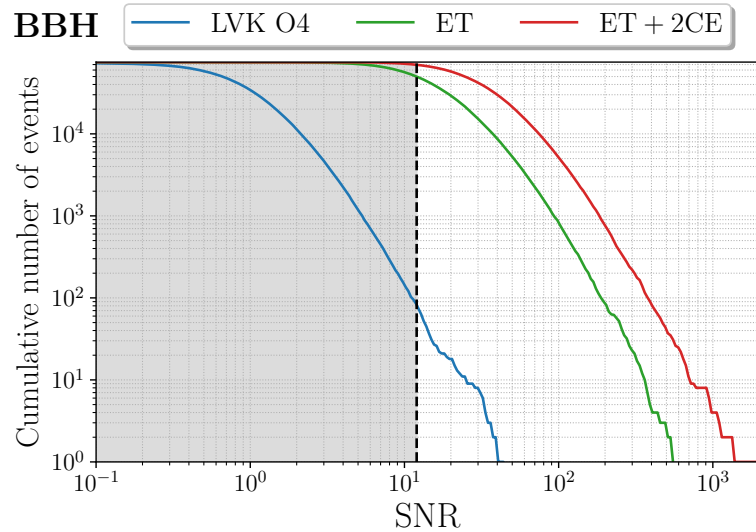


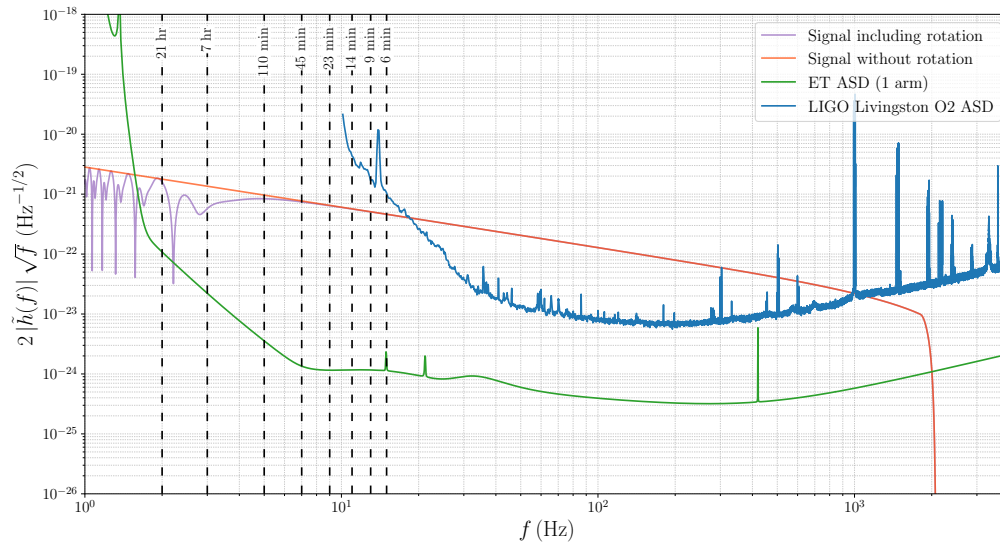
Image credit: NAOJ/ALMA <http://alma.mtk.nao.ac.jp/>

SNR distribution and examples of parameter reconstruction (BBH)

Iacovelli et al. 2022

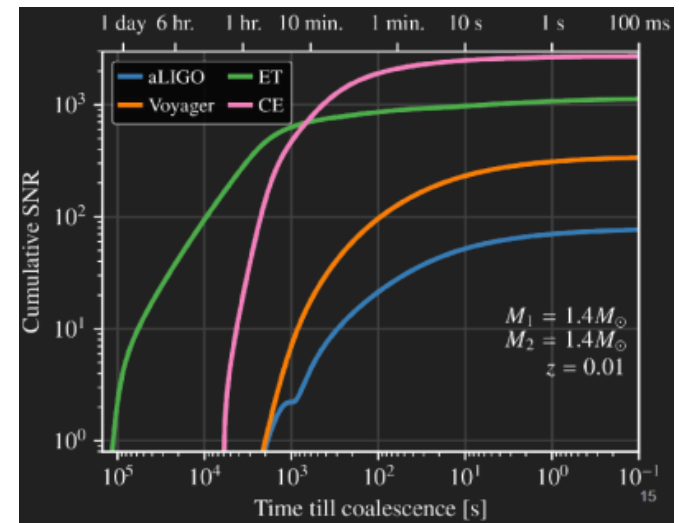


GW170817 at LVC-O2 and at ET



If we can accumulate enough SNR before the merging phase, we can trigger e.m. observations before the emission of photons

Keyword: low frequency sensitivity



The combination of

- distances and masses explored
- number of detections
- detections with very high SNR

will provide a wealth of data that have the potential of triggering revolutions in astrophysics, cosmology and fundamental physics

The Science Case of ET is very broad

a “teaser”: a glimpse from the table of content of the BlueBook chapters

1 Fundamental Physics with ET	4		
1.1 Introduction	4		
1.2 Testing the fundamental principles of the gravitational interaction	5		
1.2.1 Tests of the inspiral dynamics	5		
1.2.2 Extra polarizations	7		
1.2.3 Anomalous gravitational-wave propagation, tests of Lorentz violation and minimal length	8		
1.2.4 Gravitational-wave memory	10		
1.2.5 Fundamental aspects of the two-body problem	11		
1.3 Testing the nature of compact objects & horizon-scale physics	15		
1.3.1 Inspiral tests	16		
1.3.2 Ringdown and post-merger tests	18		
1.3.3 Neutron stars and fundamental physics	24		
1.4 Searches for dark-matter candidates & new fields	26		
1.4.1 Direct detection of ultralight dark matter with interferometers	26		
1.4.2 Environmental effects	27		
1.5 Synergies with other Divisions	33		
1.6 Executive summary	35		
		2 Cosmology with ET	37
		2.1 Stochastic gravitational-wave backgrounds	37
		2.1.1 Definition and characterisation	38
		2.1.2 Anisotropies of the GWB	41
		2.1.3 Polarization of the GWB and parity violation	46
		2.1.4 Source separability	48
		2.1.5 Impact of correlated noise on GWB	50
		2.1.6 Reconstruction of GWBs in presence of correlated noise	51
		2.2 Probing the early Universe	54
		2.2.1 GWs from inflation	54
		2.2.2 GWs from phase transitions	61
		2.2.3 GWs from cosmic strings	65
		2.2.4 GWs from domain walls	70
		2.2.5 Primordial black holes	73
		2.2.6 GWs as probes of the early Universe expansion history	78
		2.3 Probing the late Universe with Einstein Telescope	85
		2.3.1 Cosmography with coalescing binaries	85
		2.3.2 Modified GW propagation	96
		2.3.3 GW lensing	104
		2.4 Probing the large scale structure of the Universe	108
		2.4.1 Cross-correlation GWxLSS	108
		2.4.2 Cross-correlation of AGWB with CMB	115
		2.4.3 Probing LSS with GWs alone	116

3	Population studies and astrophysical background	120
3.1	Introduction: formation channels of binary compact objects	120
3.1.1	Isolated channel: compact binary mergers from pairs and multiples in galactic fields	120
3.1.2	Dynamical channel: stellar systems as factories of merging compact objects	126
3.1.3	Fingerprints of different formation channels	131
3.2	Merger rate density of CBC across cosmic time	132
3.2.1	The key ingredients of compact binary coalescence rates	133
3.2.2	Part (i): cosmic star formation history as a function of metallicity and environment	136
3.2.3	Part (ii): intrinsic properties of the CBC populations set by binary compact object formation efficiencies and delay times	140
3.2.4	Future outlook	142
3.3	Mass function of BHs and its evolution with redshift	144
3.3.1	The scientific potential of the mass function	144
3.3.2	Reconstructing the mass distribution	146
3.3.3	BH mass spectrum and outstanding questions	148
3.4	Constraining the mass function of neutron stars	152
3.4.1	Observations of radio pulsars and accreting NSs	152
3.4.2	Overall shape of empirical NS mass distribution	153
3.4.3	Theoretical expectations	154
3.4.4	Anticipated impact from ET data	155
3.5	Spins of stellar-origin BHs and NSs	156
3.5.1	BH spins – theoretical expectations	156
3.5.2	BH spins – empirical evidence from X-ray binaries and GWs	158
3.5.3	NS spin periods – theoretical expectations and limitations	159
3.5.4	Spins of double NS systems: evidence from Galactic sources and expectations for mergers	160
3.5.5	BH/NS spin-axis direction and core collapse	161
3.5.6	BH/NS spins in light of ET	161
3.6	Primordial versus stellar-origin BHs	161
3.6.1	Constraints on high-redshift merger rate evolution	164
3.6.2	Subsolar PBH binary searches	166
3.6.3	Spins of primordial black holes	168
3.6.4	Tests based on mass and spin distributions	168
3.7	Revealing Population III stars with the first BHs	170
3.7.1	The nature of Pop III stars	170
3.7.2	The evolution of Pop III stars and binary black holes	174
3.7.3	Gravitational waves from Pop III remnants	176
3.8	Intermediate-mass BHs (IMBHs): formation channels and merger rate	177
3.8.1	Formation Scenarios	178
3.8.2	IMBH binaries	182
3.8.3	Can ET decipher the origin of IMBHs?	182
3.9	The host galaxies of binary compact object mergers	186

3.9.1	Multi-messenger detections and sky localization of the host galaxies	186
3.9.2	Formation channels and their link with galaxy properties	187
3.10	Populations backgrounds	188
3.10.1	Study of BBH formation channels	190
3.10.2	Study of Population III stars	191
3.10.3	Primordial black hole contribution	193
3.10.4	Astrophysical Uncertainties in background description	194
3.10.5	Sources other than CBCs	195
3.10.6	Anisotropies and cross-correlation with electromagnetic observables	195
3.10.7	Spectral shape reconstruction	198
3.11	Executive summary	199

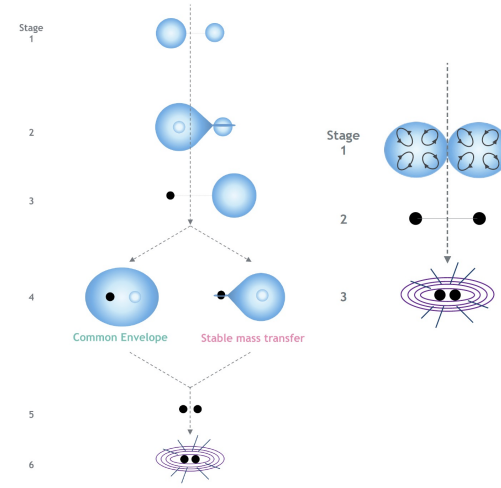


Figure 3.1: Evolutionary pathways to form a GW source for isolated binary evolution. Left: the common-envelope channel and the stable mass transfer channel. Stage 1) Zero-Age-Main-Sequence (ZAMS) 2) First phase of mass transfer 3) Formation of BH or NS 4) Second phase of mass transfer 5) Formation of double compact object 6) GW merger. Right: chemically homogeneous evolution. Stage 1) ZAMS 2) Formation of binary BH 3) GW merger.

4 Multi-messenger observations in the ET era

4.1	State of the art	202
4.1.1	Multi-messenger Astronomy	202
4.1.2	GW170817	203
4.1.3	GRBs and KN as counterparts of compact binary mergers	210
4.1.4	Alternative signatures of mergers	211
4.2	Modeling the EM counterparts of ET detected CB mergers	212
4.2.1	Dynamics and emission components of compact binary mergers	213
4.2.2	Multi-messenger BNS & BHNS population models	216
4.2.3	EM properties of the GW-detectable sub-population	220
4.2.4	GW sky localization of multi-messenger events	225
4.2.5	ET in a network with Cosmic Explorer	229
4.3	Observational facilities/strategies	230
4.3.1	The ET change of paradigm	230
4.3.2	Kilonovae	230
4.3.3	Off-axis afterglows	232
4.3.4	On-axis GRBs	233
4.3.5	ET pre-merger detection and ET and early warnings alerts	233
4.3.6	ET as an alert receiver	234
4.4	Neutrinos from Compact Binary Coalescence	235
4.4.1	Common environments for neutrinos and GWs	235
4.4.2	Current and future neutrino telescopes	237
4.4.3	Multi-messenger neutrino and GW frameworks	238
4.5	Multi-messenger infrastructure challenges	239
4.6	Executive Summary	240

202
202
202
203
210
211
212
213
216
220
225
229
230
230
230
232
233
233
234
235
235
237
238
239
240

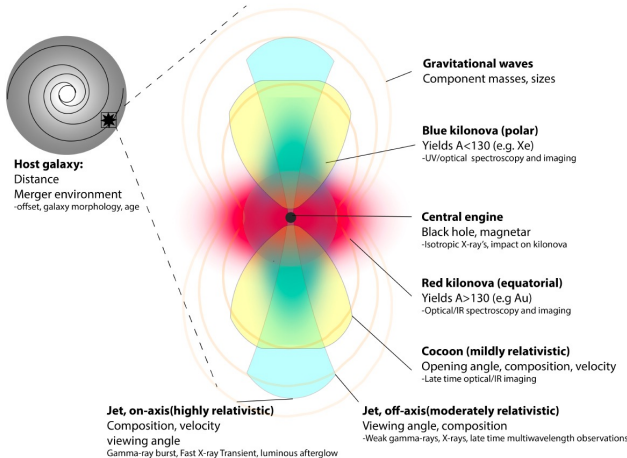
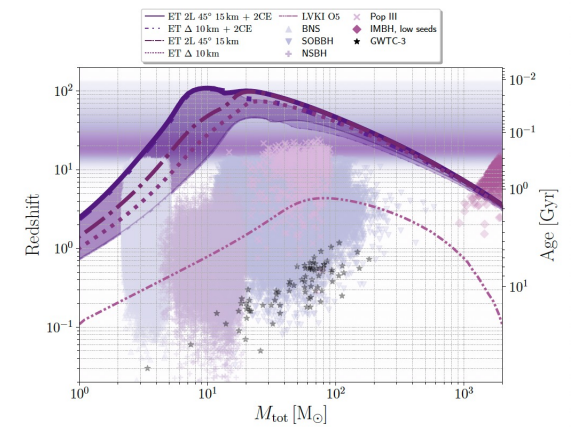
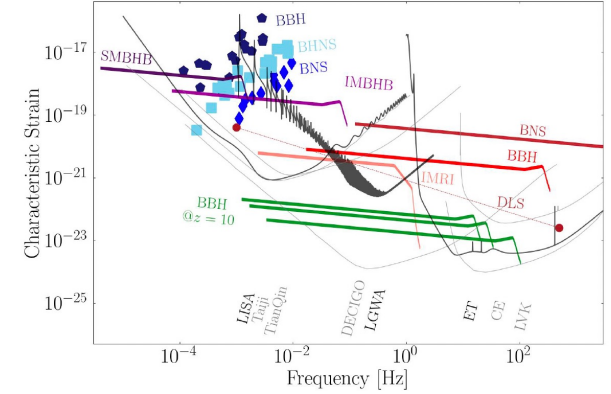


Figure 4.2: The physical process ongoing in the merger of a binary system of neutron stars (or a neutron star and a black hole), their multi-messenger observational signals and the scientific insight enabled from them (updated from an original concept by [2173]). Gravitational wave observations provide robust measurement of the component masses, and constraints on their sizes and spins. Many possible electromagnetic signals are also possible, including the detection of associated GRBs, cocoon emission, and kilonova signatures.

5 Synergies of ET with other gravitational-wave observatories	243
5.1 Introduction	243
5.2 Compact object binaries	246
5.2.1 Synergy with ground-based detectors	247
5.2.2 Synergies with space-borne detectors	250
5.2.3 Stochastic background from compact binaries	251
5.3 Nuclear physics	252
5.3.1 Population approaches for nuclear physics	253
5.3.2 Measurability of the post-merger phase signal	254
5.3.3 Interring exotic nuclear phenomena with binary neutron star mergers	254
5.4 Fundamental physics	256
5.4.1 Tests of the inspiral phase	257
5.4.2 Tests of the merger and ringdown	258
5.4.3 Tests of frequency-dependent speed of GWs	259
5.4.4 Tests of the GW polarization	259
5.5 Hubble tension and cosmography	260
5.5.1 Bright sirens cosmology	261
5.5.2 Dark sirens cosmology	262
5.5.3 Multi-band sources	263
5.6 The origin of supermassive black holes	264
5.6.1 Seed black holes	265
5.6.2 Synergies between ET and LISA	267
5.6.3 IMBH populations across frequency bandwidths and detectors	269
5.7 Early Universe cosmology	271
5.7.1 Synergies between ET and LISA	272
5.7.2 Synergies between ET and PTAs	275
5.8 Executive summary	277



6 Subatomic Physics with ET

6.1 Introduction

6.2 Current status of microphysics properties

6.2.1 Equation of state modeling

6.2.2 Current constraints on EOS and matter composition

6.2.3 Reaction rates

6.3 Prospects for constraints on microphysics with ET data

6.3.1 Constraints on low-temperature microphysics

6.3.2 Constraints on microphysics at finite temperature

6.3.3 Nucleosynthesis and multi-messenger signals

6.4 Uncertainties and degeneracies in our measurements

6.4.1 Impact of waveform-model uncertainties

6.4.2 Uncertainties in simulations and microphysics input

6.4.3 Degeneracies with modified gravity and Beyond-Standard-Model physics

6.5 Executive summary

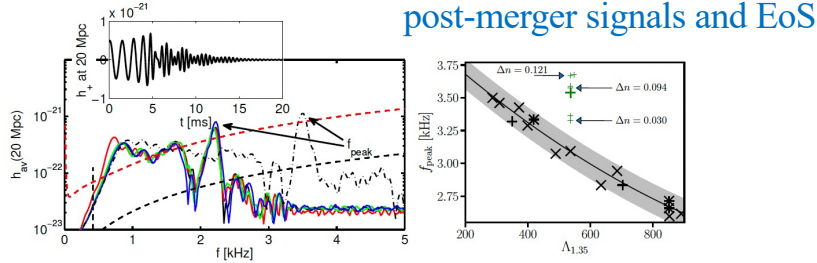


Figure 6.9: Left panel: Orientation-averaged spectra of the GW signal for different EOS and the Adv LIGO (red dashed) and ET (black dashed) sensitivity curves. The inset shows the GW amplitude of the + polarization at a distance of 20 Mpc for one of the EOSs. Figure from ref. [2932]. Right panel: Peak frequency of the postmerger GW emission as a function of tidal deformability Λ for a $1.35M_{\odot} - 1.35M_{\odot}$ NS-NS merger. Black symbols are for purely

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280

283

283

290

293

298

299

314

322

332

332

335

338

344

SN explosion driven by QCD phase transition

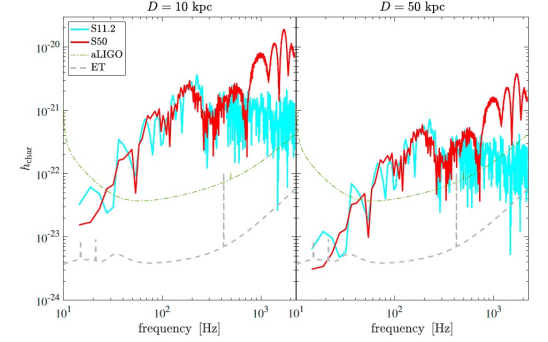


Figure 6.14: Characteristic GW spectral amplitudes, h_{char} , for the two models S11.2 (light blue solid lines) and S50 (red solid lines) shown in figure 6.13, assuming a source distance of 10 kpc (left panel) and 50 kpc (right panel). The noise amplitudes of aLIGO (green dashed lines) and ET (grey dashed lines) are plotted as references. Figure reproduced based on data from ref. [3019].

EoS constraints from multi-messenger observations

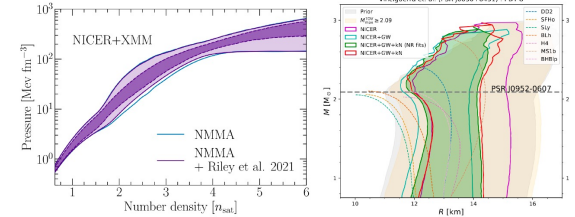


Figure 6.18: Examples of constraints on the nuclear EOS obtained by joint multimessenger analysis combining astrophysical observations of pulsars, NICER measurements, GW170817 and GW190425, kilonova AT2017gfo and GRB170817A modeling. Left: Posteriors for the pressure as a function of number density with (purple) and without (blue) NICER and XMM observations of PSR J0740+6620. Right: Posteriors in the M - R diagram of the GW-only (blue), joint (red), and NR-informed joint analysis (green). Figures adapted from [3132] (left) and [3138] (right).

7 Stellar collapse and rotating neutron stars

- 7.1 Introduction
- 7.2 Stellar collapse
 - 7.2.1 Stellar evolution toward stellar collapse
 - 7.2.2 Modelling, explosion mechanisms, and dynamics
 - 7.2.3 GW and neutrino emission
 - 7.2.4 Observations: state of the art
 - 7.2.5 Observed rates and expected rates in the local Universe
- 7.3 Neutron stars
 - 7.3.1 Observed NS population
 - 7.3.2 GWs from rotating NSs
- 7.4 ET observational prospects
 - 7.4.1 Bursts
 - 7.4.2 Continuous waves and long transients
 - 7.4.3 Synergies with neutrino and electromagnetic observatories
- 7.5 Executive Summary

347

347

348

348

353

357

365

368

379

379

384

388

388

395

401

409

SNR for SNe with different progenitors

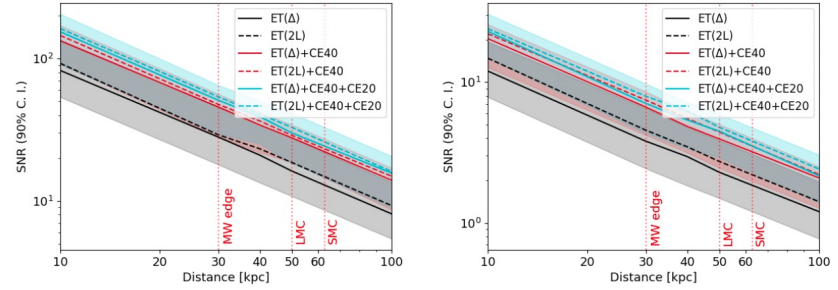


Figure 7.16: Expected SNR as a function of distance for the 15.01 (top plot) and 9a (bottom plot) models corresponding to a progenitor mass of 15.01 $M_{\odot}$ and 9 $M_{\odot}$ [2991], respectively.

core-collapse SN, PSN oscillations

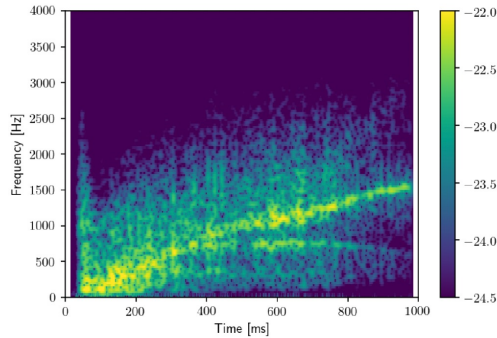


Figure 7.8: Spectrogram of a typical core-collapse simulation showing the tracks of different oscillation modes of the PNS [2997].

GWs from f-mode excitation by pulsar glitches

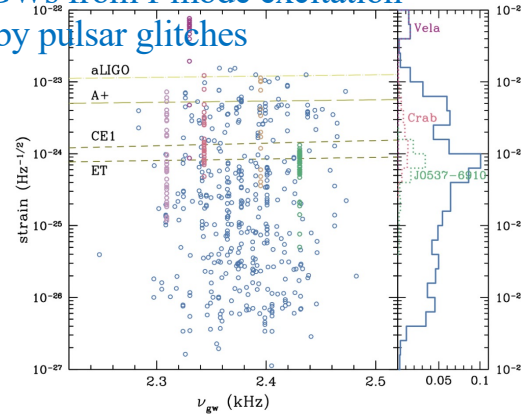


Figure 7.17: Each circle represents a value of $h_0\sqrt{\pi G\omega}$ for f -modes excited by glitches of different pulsars and the sensitivity of several GW detectors are plotted as horizontal dashed lines. Points that lie above the sensitivity curve have signal-to-noise ratio estimates greater than 1. Typically, one would require a signal-to-noise greater than ~ 10 before a detection is

continuous waves

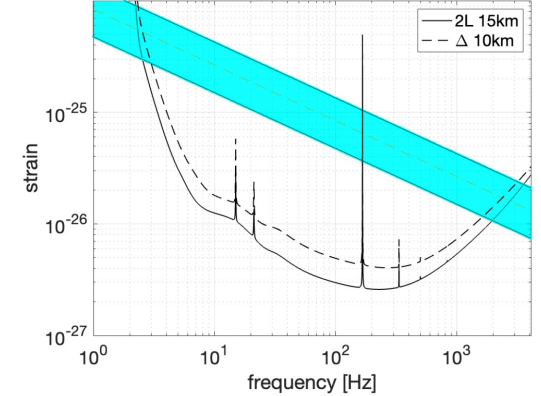


Figure 7.18: Estimated ET sensitivity (solid line: 2L 15 km configuration, dashed line: triangular 10 km configuration - 1 year of data, duty cycle 85%, drift time of 10 days) to CW emission from Sco-X1 using the semi-coherent Viterbi algorithm [3651]. The transversal orange dashed line represents the standard torque balance limit (with an average over the star rotation axis inclination), assuming surface accretion. The cyan band indicates torque balance strains from circular polarization (lower) to linear polarization (upper).

8	Waveforms	412
8.1	Introduction	412
8.2	Waveform systematics and accuracy requirements for 3G	413
8.3	Techniques for waveform modeling: Current state and advances	416
8.3.1	Numerical Relativity	416
8.3.2	Weak-field Expansions	422
8.3.3	Gravitational Self-Force	426
8.3.4	Inspiral-Merger-Ringdown Models	430
8.3.5	Alternative Theories of Gravity	433
8.4	Waveform Models for Specific Sources	436
8.4.1	Binary black holes	436
8.4.2	Binary Neutron Stars	441
8.4.3	Neutron Star – Black Hole Binaries	444
8.4.4	Modelled sources beyond binary inspirals	449
8.4.5	Waveforms in alternative theories of gravity	453
8.5	Waveform Acceleration Techniques	458
8.6	Executive summary	461

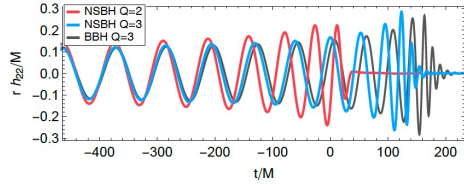


Figure 8.5: Features of NSBH waveforms from the SXS catalog [3836] for nonspinning systems, which were aligned at early times. The case with mass ratio $Q = 2$ (red curve) clearly shows the shutoff due to tidal disruption. For $Q = 3$, the NSBH waveform (blue curve) is similar to the corresponding BBH case (dark grey curve) up to a small dephasing due to tidal effects and details in the evolution near the plunge-merger (not visible on this

NSBH: plunge or tidal disruption

hyperbolic BBH encounters

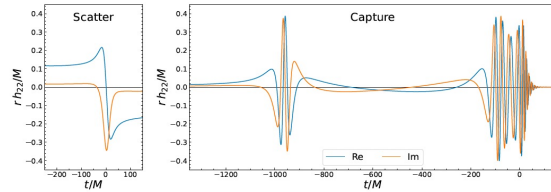


Figure 8.2: Exemplary waveforms of hyperbolic BBH encounters where the two BHs are initially unbound. The left panel shows a scattering event where the BHs remain unbound,

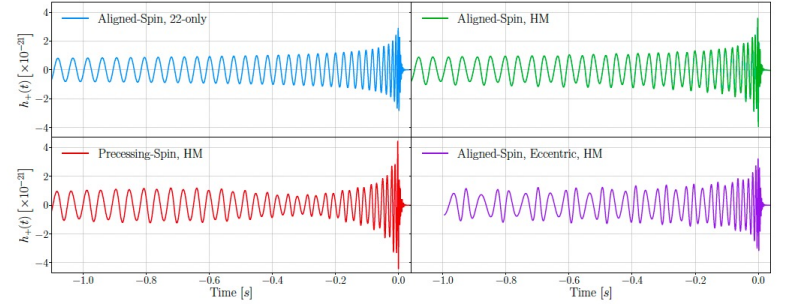


Figure 8.3: Exemplary IMR waveforms of coalescing binary black holes with mass ratio $1 : 3$ and a total source-frame mass of $60M_{\odot}$ located at a distance of 100 Mpc and viewed under an inclination angle of $\pi/3$ relative to the line-of-sight. The initial GW frequency is

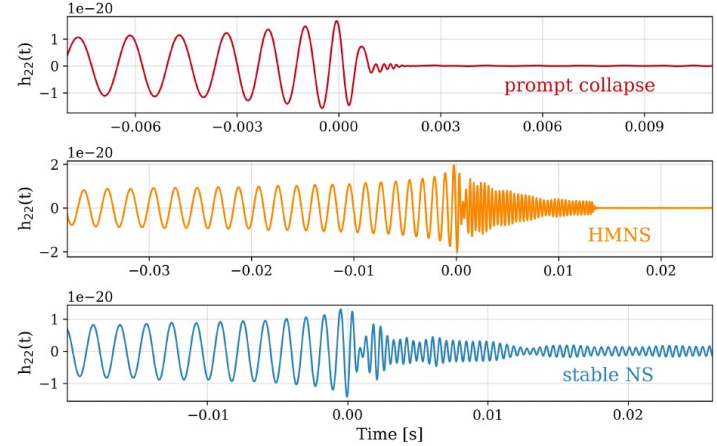


Figure 8.4: Selection of binary neutron star waveforms from NR simulations showcasing three different postmerger phenomenologies: The top panel shows prompt collapse to a black hole; the middle panel shows the formation of a hypermassive neutron star (HMNS), and the bottom panel shows the formation of a stable neutron star. The simulations are BAM:0005 [4448], THC:0084 [3091] and BAM:0080 [2386], publicly available from the CoRE database [2258].

9	Tools for assessing the scientific potentials of detector configurations	463
9.1	Basic formalism	463
9.1.1	Detection and parameter estimation of resolved signals	463
9.1.2	Fisher information matrix formalism	468
9.2	Software tools for CBC sources	469
9.2.1	Sky location-polarisation-inclination averaged SNR	470
9.2.2	Fisher Matrix pipelines	471
9.2.3	Improvements of Fisher baseline models	474
9.2.4	Inference at the population level	481
9.3	Metrics for CBCs	483
9.3.1	Pattern functions and Earth rotation	483
9.3.2	Horizons and Signal to Noise Ratios	484
9.3.3	Distance reconstruction and merger and pre-merger sky localization	489
9.3.4	Inference of intrinsic parameters, and golden binaries	492
9.3.5	Detection of population features	494
9.4	Tools for the ringdown phase of binary mergers	499
9.5	Stochastic searches	502
9.5.1	Characterization of stochastic backgrounds	503
9.5.2	Power-Law Sensitivity	505
9.5.3	Subtraction of the astrophysical background	507
9.6	Tools for the null stream	513
9.7	Conclusions	515
9.8	Executive summary	516

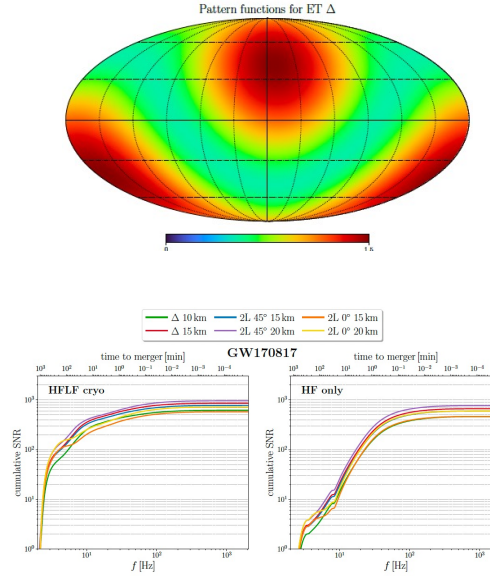
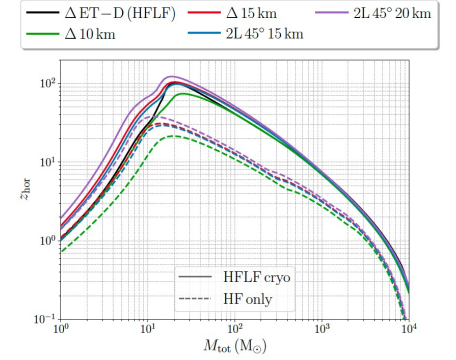


Figure 9.10: Cumulative SNR for a system with the maximum likelihood parameters of GW170817, observed by different ET configurations, as a function of GW frequency. The corresponding time to merger is shown in the upper horizontal axis. Left panel: using the ET sensitivity curve which includes both the HF and the LF interferometers, with the latter at cryogenic temperatures. Right panel: using only the HF interferometer.



e 9.8: Detection horizons for equal-mass non-spinning binaries as a function of the frame total mass for different ET configurations.

	GWBench	GWFast	GWFish	TiDoFM	GWJulia
link	GWBench	CosmoStatGW/gwfast	GWFish	TiDoFM	GWJulia
domain	Frequency	Frequency	Frequency	Time	Frequency
language	Python	Python	Python	Python	Julia
waveforms	LALSsimulation	self+LALSsimulation	LALSsimulation+num.	Pycbc	self
derivatives	an.+fd.	an.+AD or +fd.	an.+fd.	num.	AD
inversion	mpmath	Cho.,LU,SVD+mpmath	SVD		Cho.
reference	[4633]	[2275]	[256]	[4634, 4635]	[4636]

Table 9.1: Summary of main characteristics of the five Fisher matrix codes. Abbreviations used are: an. for analytical, fd. for finite differences method, num. for numerical, AD for automatic differentiation, Cho. for Cholesky. See text for other pipeline-specific features.

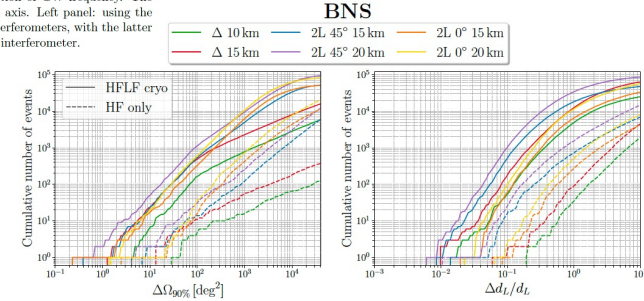
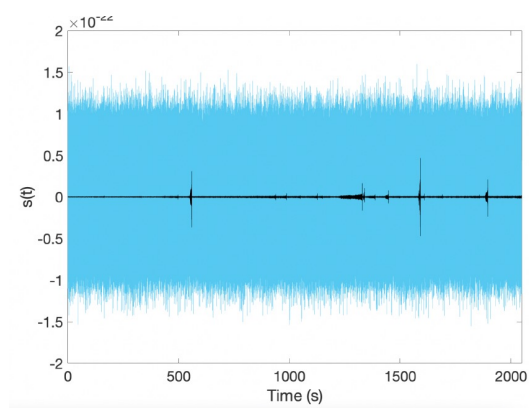


Figure 9.13: Cumulative distributions of the accuracy on angular localization (left panel) and luminosity distance (right panel) for BNSs observed by ET in the different configurations studied in [16].

10 Data Analysis	518
10.1 Introduction	518
10.2 Challenges	518
10.2.1 Long duration Compact Binary Coalescence signals	518
10.2.2 Overlapping signals	521
10.2.3 Noise Background estimation	522
10.2.4 Source subtraction for CBCs	523
10.3 Innovative methods: machine learning applications	523
10.4 Signal detection method	524
10.4.1 Data analysis methods for Compact Binary Coalescences	524
10.4.2 Data analysis for Gravitational Wave Background	526
10.4.3 Data analysis for Continuous Wave searches	528
10.4.4 Data analysis for burst signals	530
10.5 Parameter estimation methods	532
10.5.1 Analysis of overlapping signals	533
10.5.2 Innovative methods for faster inference	533
10.5.3 Computational Requirements	539
10.6 Peculiarities of a triangular ET	540
10.6.1 Null stream	540
10.6.2 Correlated noise	545
10.7 Simulations and Mock Data Challenges	546
10.7.1 Description of the first MDC	546
10.8 Challenges	549
10.9 Synergies in data analysis developments	549
10.10 Conclusion	550
10.11 Executive summary	551



first MDC data

effect of overlapping signals on posteriors

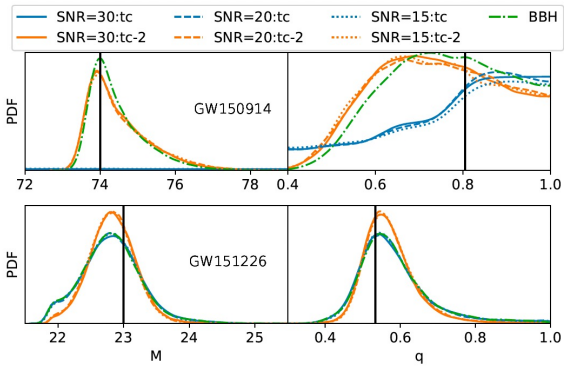
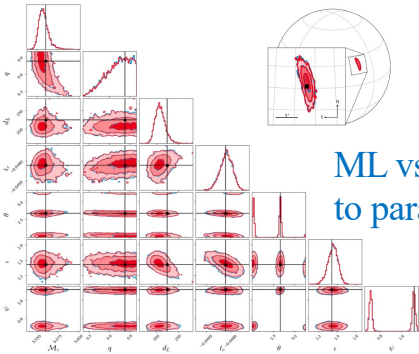


Figure 10.2: Posterior PDFs for total mass and mass ratio, for the GW150914-like signal (top panel) and the GW151226-like signal (bottom panel) when they are respectively being overlapped with a BNS signal with SNR = 30 (solid lines), SNR = 20 (dashed lines), and SNR = 15 (dotted lines). The overlaps are made so that the BBH and the BNS end at the



ML vs standard approach
to parameter estimation

Figure 10.4: Representation of the posteriors obtained with the approach from [4796] (red) and the posteriors obtained with traditional approaches (blue) for a system with a chirp mass of $5 M_{\odot}$ injected in an LVK network. A good agreement is obtained between the two posteriors, which required an adapted training procedure due to the relatively low mass of the system. To obtain this agreement, the priors during the training process have been adapted to have an effectively uniform coverage of the mass parameter space.

and we should not forget that ET will be a 'discovery machine': expect the unexpected!

In the following, we elaborate just on some
'selected highlights'
relevant to fundamental physics and cosmology

1. The nature of Gravity

BHs are one of the most extraordinary predictions of GR

(e.g. $10M_{\odot}$ concentrated in 30 km)

how can we be sure that the compact objects observed by LIGO/Virgo are the BHs predicted by GR?

- can we ‘quantify’ the existence of horizons?
- can we test the existence of Exotic Compact Objects?

no shortage of proposals in the literature:

boson stars (self-gravitating fundamental fields)

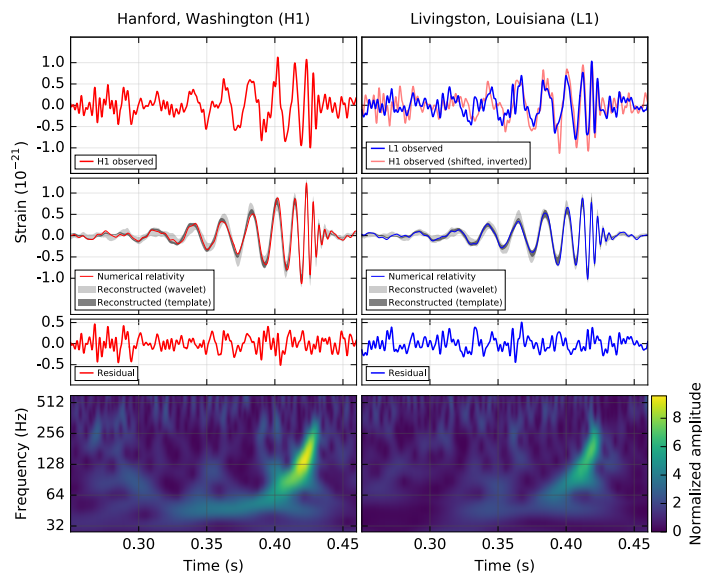
firewalls, fuzzballs... (quantum effects near the horizon motivated by the Hawking information loss problem):

BH quasi-normal modes (QNM)

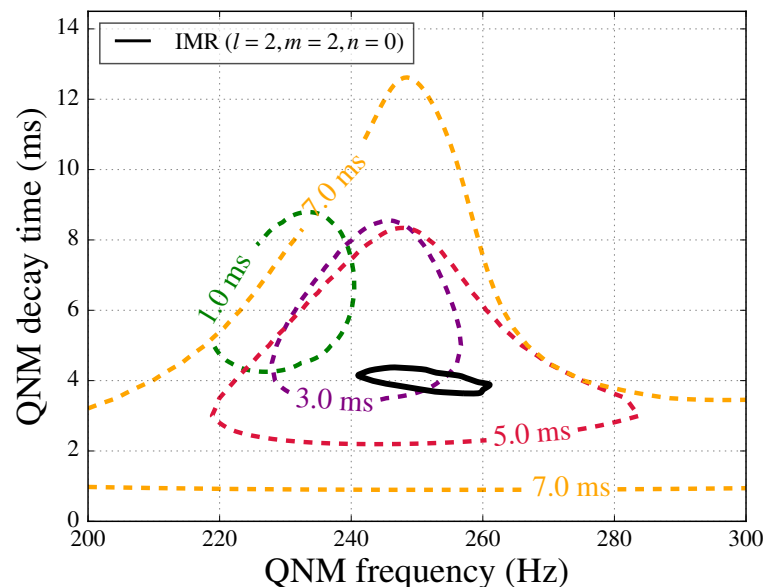
the elasticity of space-time in the regime of strong gravity!

GR predicts frequency and damping time as a function of mass and spin

classic chapter of GR: Regge-Wheeler, Chandrasekhar, Teukolsky...

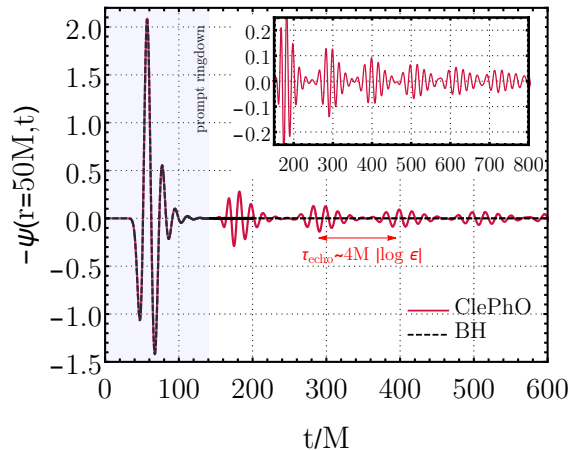


already observed in GW150914 (LVC)



consistent with GR, but we cannot say much more

Echoes from Exotic Compact Object



Cardoso, Franzin, Pani 2016

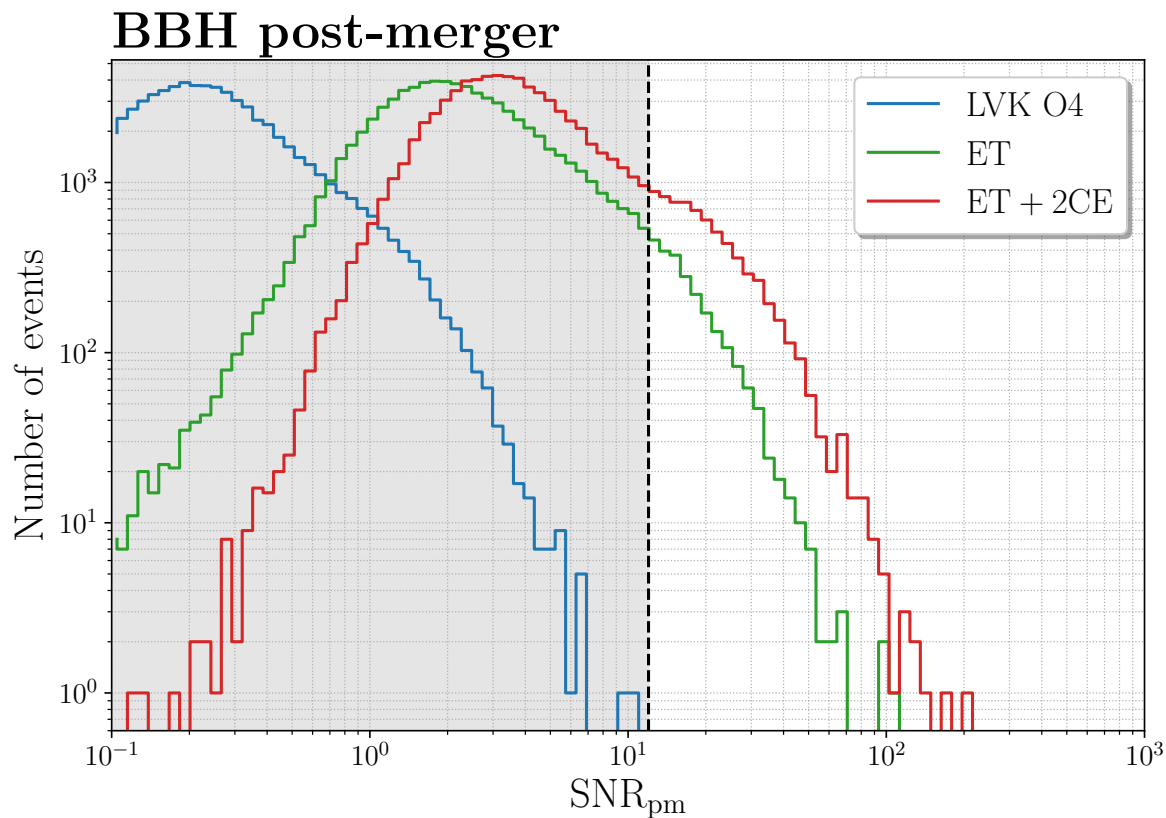
$$\tau_{\text{echo}} = (2R_S/c) \log(R_S/\ell_{\text{new physics}})$$

even possible to have signals from the Planck scale. Eg:

$$\ell_{\text{new physics}} = \ell_{\text{Pl}}, \quad M = 60M_{\odot} \rightarrow \tau_{\text{echo}} \simeq 50 \text{ ms}$$

- quite different from accelerator physics, where the Planck scale is unreachable
- detecting echoes might require $\text{SNR} = \mathcal{O}(100)$ in the ringdown phase, achievable only with 3G detectors (ET, CE)

BBH post-merger at ET

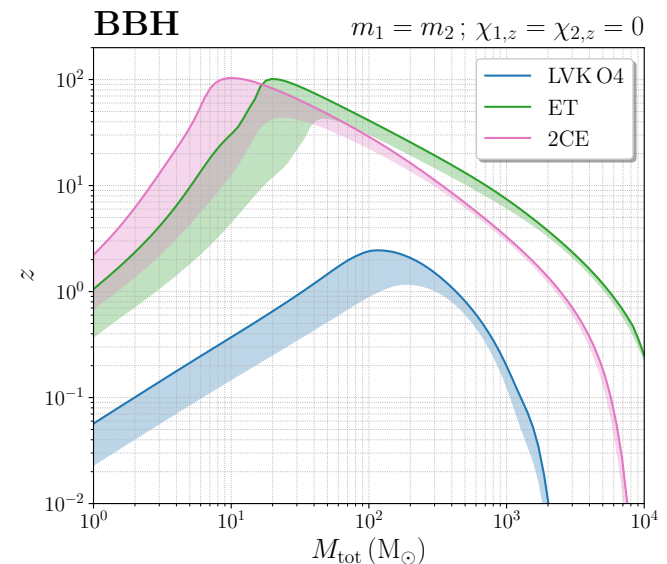
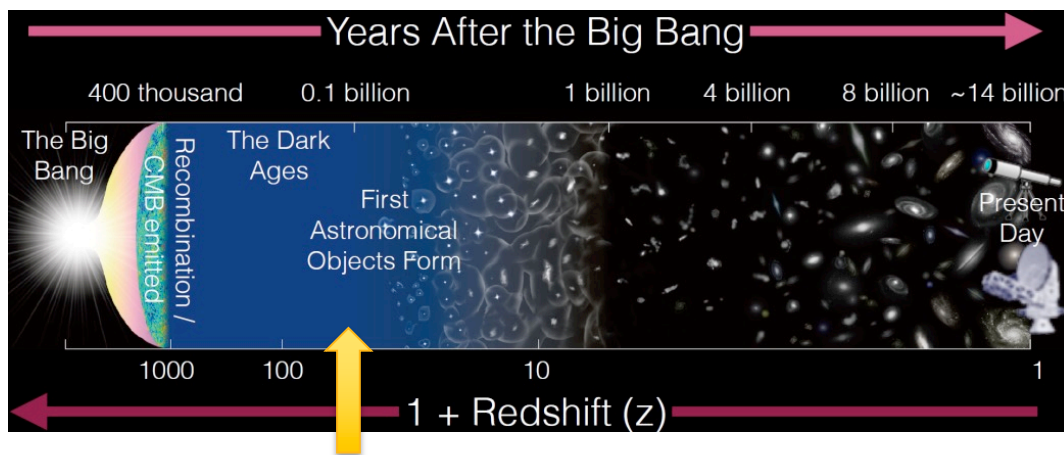


Iacovelli et al. 2022

- accurate BH spectroscopy already from single events
- 10^3 events/yr with detectable ringdown
- 20-50 events/yr with detectable higher multipoles or overtones

2. The origin of BHs: astrophysical vs primordial

ET will uncover the full population of coalescing stellar BBH since the end of the cosmological dark ages



BHs can also be generated by the collapse of large over-densities in the early Universe (PBHs) → window on inflationary scales

PBHs might also contribute to dark matter

Disentangle astrophysical from primordial BH

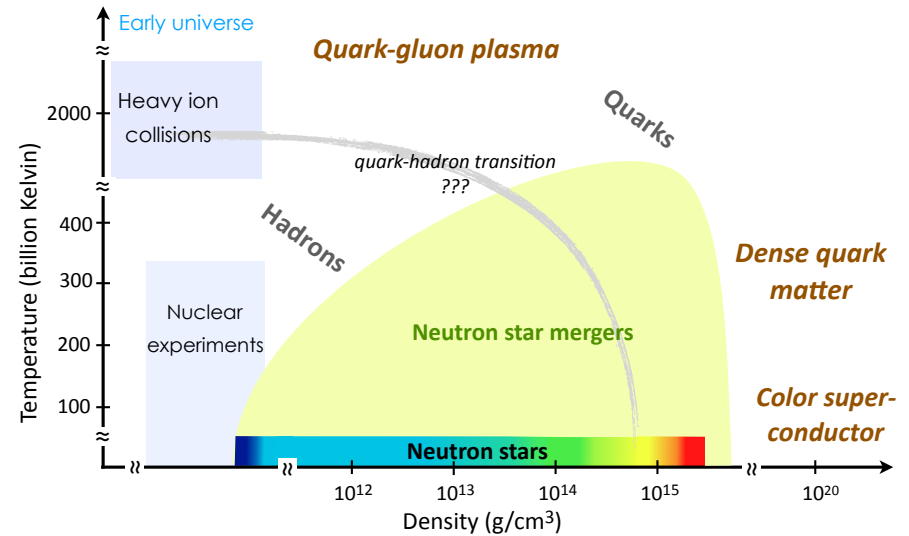
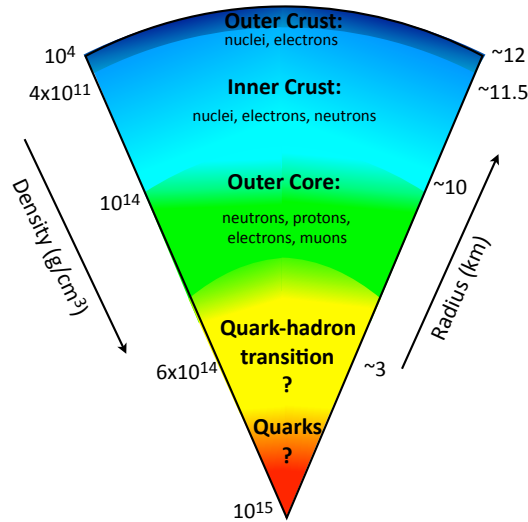
- the PBH merger rate increases with redshift, up to $z = \mathcal{O}(10^3)$

Any BBH merger at $z > 30$ (very conservatively) will be of primordial origin. ET can reach $z \sim 50-100$!!

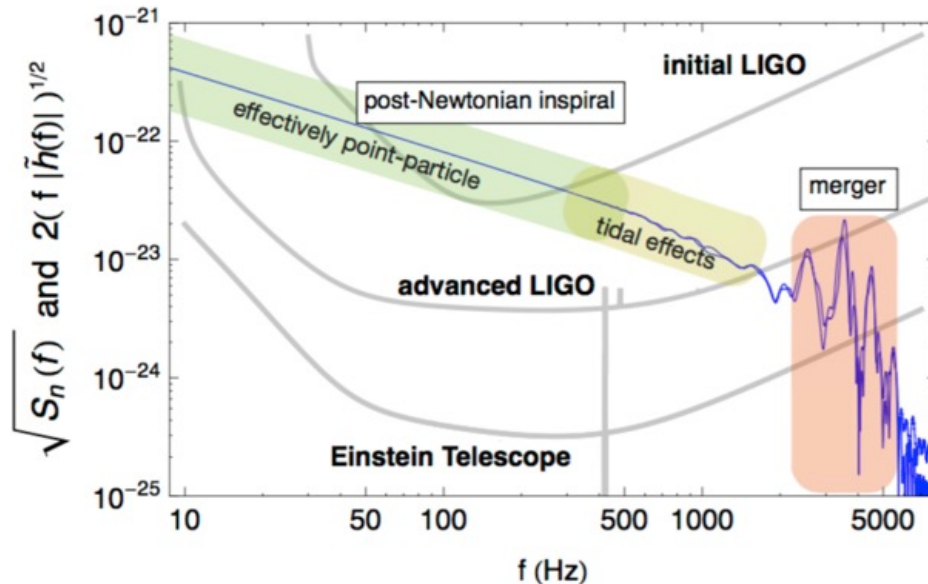
Accurate measurement of z is also needed (Ng et al 2108.07276)

- subsolar mass BH must be primordial

3. QCD with neutron stars



MM et al, ESFRI paper,
1912.02622



BNS merger @100 Mpc
(from J. Read)

4. GWs as probes of cosmology

GWs from coalescing binaries provide an absolute measurement of the luminosity distance to the source

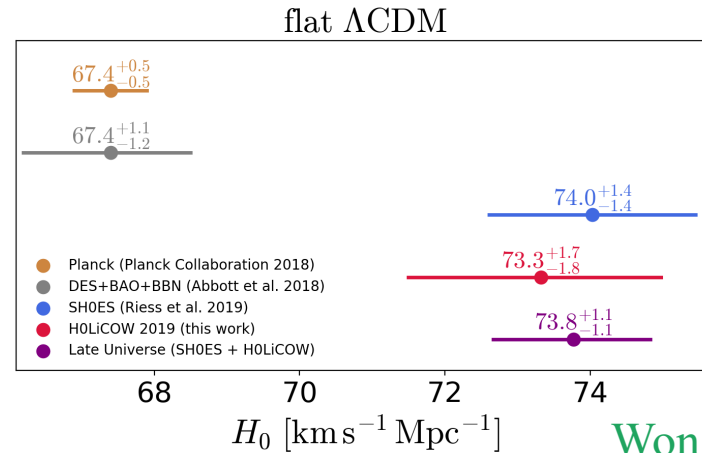
$$d_L(z) = \frac{1+z}{H_0} \int_0^z \frac{d\tilde{z}}{\sqrt{\Omega_M(1+\tilde{z})^3 + \rho_{DE}(\tilde{z})/\rho_0}}$$

$$\Omega_M = \frac{\rho_M(t_0)}{\rho_0}, \quad \rho_0 = \frac{3H_0^2}{8\pi G}$$

- need an independent determination of z
(electromagnetic counterpart, statistical methods)
- low z : Hubble law, $d_L \simeq H_0^{-1} z$
- moderate z : access $\Omega_M, \rho_{DE}(z)$

low z: measuring H_0

Observational tensions,
in particular early- vs
late-Universe probes of H_0



Wong et al.,
H0LiCOW 2019

O(50-100) standard sirens at 2G needed to arbitrate the discrepancy

already solved by the time of 3G detectors? (possible, but not sure, no counterpart in O3, no BNS candidate currently in O4)

depending on the network of electromagnetic facilities at the time of ET,
ET can detect several tens BNS with counterpart per year

At higher z , accessible only to 3G detectors or LISA, we access the redshift evolution of the dark energy density

$$p_{\text{DE}}(z) = w_{\text{DE}}(z) \rho_{\text{DE}}(z) \quad \Rightarrow \quad \frac{\rho_{\text{DE}}(z)}{\rho_0} = \Omega_{\text{DE}} \exp \left\{ 3 \int_0^z \frac{d\tilde{z}}{1 + \tilde{z}} [1 + w_{\text{DE}}(\tilde{z})] \right\}$$

Several studies of forecasts for w_{DE} at ET

Result: not a significant improvement on w_{DE} compared with what we already know from CMB+BAO+SNe

A potentially more interesting observable:

modified GW propagation

Saltas, Sawicki, Amendola, Kunz, 1406.7139

Belgacem, Dirian, Foffa, MM 1712.08108 ,
1805.08731

Belgacem, Dirian, Finke, Foffa, MM
1907.02047,
2001.07619

Belgacem et al, LISA CosWG, 1907.01487

Modified GW propagation

in GR : $\tilde{h}''_A + 2\mathcal{H}\tilde{h}'_A + k^2\tilde{h}_A = 0$

$$\tilde{h}_A(\eta, \mathbf{k}) = \frac{1}{a(\eta)} \tilde{\chi}_A(\eta, \mathbf{k})$$

$$\tilde{\chi}''_A + (k^2 - a''/a) \tilde{\chi}_A = 0$$

inside the horizon $a''/a \ll k^2$, so $\tilde{\chi}''_A + k^2\tilde{\chi}_A = 0$

1. GWs propagate at the speed of light

2. $h_A \propto 1/a$ For coalescing binaries this gives $h_A \propto 1/d_L(z)$

In several modified gravity models:

$$\tilde{h}_A'' + 2\mathcal{H}[1 - \delta(\eta)]\tilde{h}_A' + k^2\tilde{h}_A = 0$$

$$\tilde{h}_A(\eta, \mathbf{k}) = \frac{1}{\tilde{a}(\eta)}\tilde{\chi}_A(\eta, \mathbf{k}) \quad \frac{\tilde{a}'}{\tilde{a}} = \mathcal{H}[1 - \delta(\eta)]$$

$$\tilde{\chi}_A'' + (k^2 - \tilde{a}''/\tilde{a})\tilde{\chi}_A = 0 \quad \tilde{a}''/\tilde{a} \ll k^2$$

1. $c_{\text{GW}} = c$ ok with GW170817 (otherwise the model is ruled out)

2. $\tilde{h}_A \propto 1/\tilde{a}$

All dynamical theories of DE will display this effect!

(Belgacem et al., LISA CosmoWG, JCAP 2019)

coalescing binaries measure a ``GW luminosity distance'' different from the standard (electromagnetic) luminosity distance !

in terms of $\delta(z)$:

$$d_L^{\text{gw}}(z) = d_L^{\text{em}}(z) \exp \left\{ - \int_0^z \frac{dz'}{1+z'} \delta(z') \right\}$$

a general parametrization of modified GW propagation

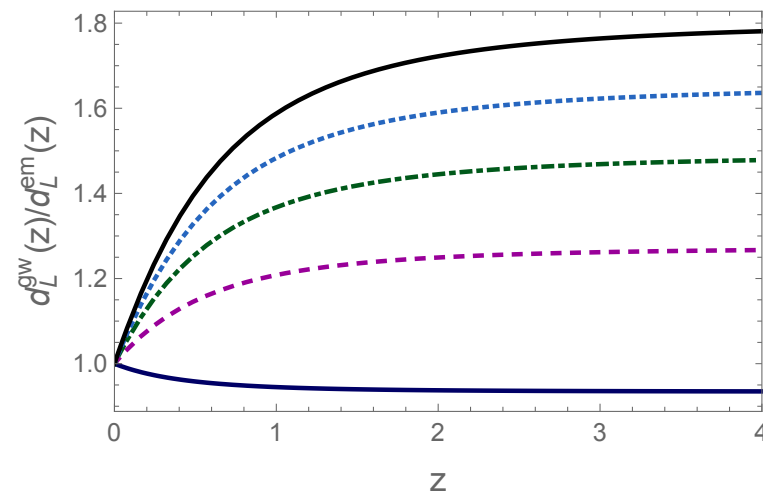
$$\frac{d_L^{\text{gw}}(z)}{d_L^{\text{em}}(z)} = \Xi_0 + \frac{1 - \Xi_0}{(1+z)^n}$$

Belgacem, Dirian, Foffa, MM
PRD 2018, 1805.08731

This parametrization is very natural, and fits the result of (almost) all modified gravity models

Belgacem et al (LISA CosmoWG), 2019

- for scalar perturbations, deviations from GR are bounded at the level (5-10)%
- one would expect similar deviations in the tensor sector. Instead, in a viable model (non-local gravity) the deviations at the redshifts explored by ET can reach 80% !

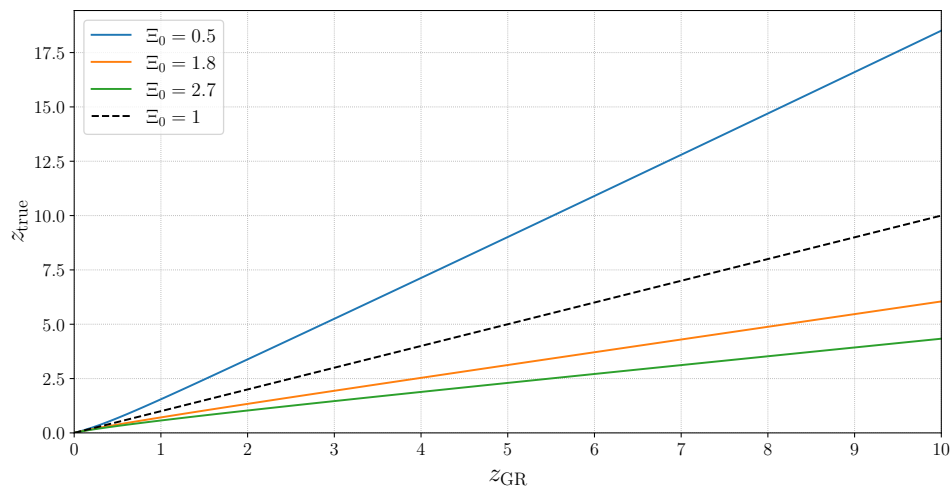


Belgacem, Dirian, Finke, Foffa, MM , 2020

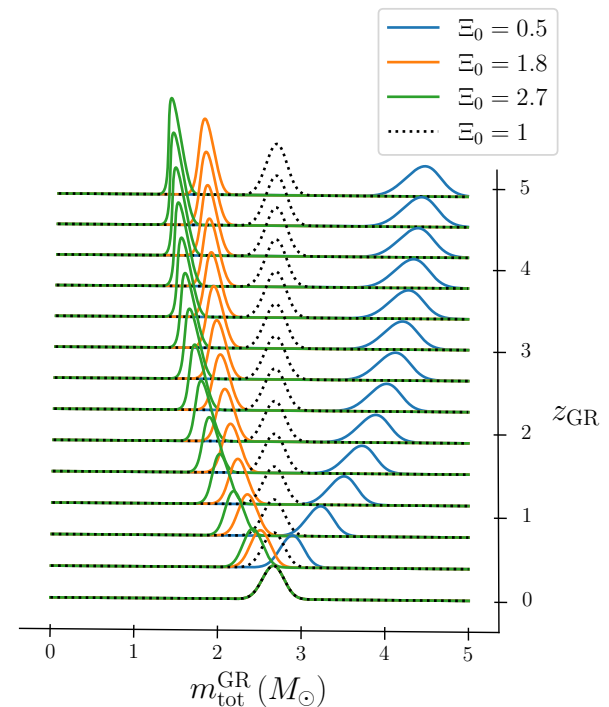
⇒ 3G detectors could be the best experiments for studying dark energy

“Dark sirens”: cosmology with the BNS mass function at ET

GW detectors measure the combination $m_{\text{det}} = (1+z)m$ and do not measure directly z but $d_L \Rightarrow$ here cosmology enters



Finke, Foffa, Iacovelli, MM, Mancarella 2021



5. Dark matter, new fundamental fields

Several DM candidates can be studied (only?) by ET

- primordial BHs
 - BBH at $z \sim 30-100$,
 - masses down to $(0.1-1) M_{\odot}$
 - correlation with Large Scale Structures
- DM particles captured in NS/BH
 - DM core in NS, drag in binary systems

Ultralight particles

particles with $m \sim 10^{-20}$ - 10^{-10} eV have Compton wavelength of order of the Schwarzschild radius of BHs with masses billions $M_\odot$ to a few $M_\odot$

10^{-22} - 10^{-10} eV : lower range $\rightarrow$ viable DM candidates

upper range $\rightarrow$ QCD axions

ultralight axions from string theory possibly covering the whole range

because of a super-radiance instability, they extract energy from rotating BHs and form a long-lived Bose condensate rotating with the BH

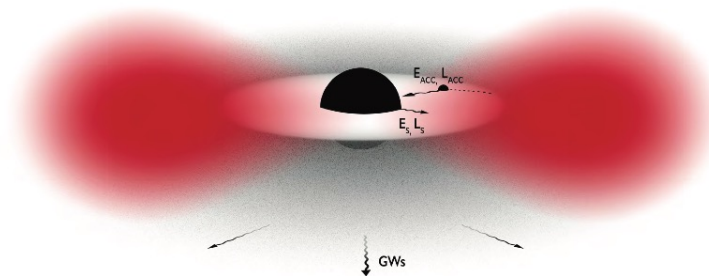


figure: Brito, Cardoso, Pani 2014

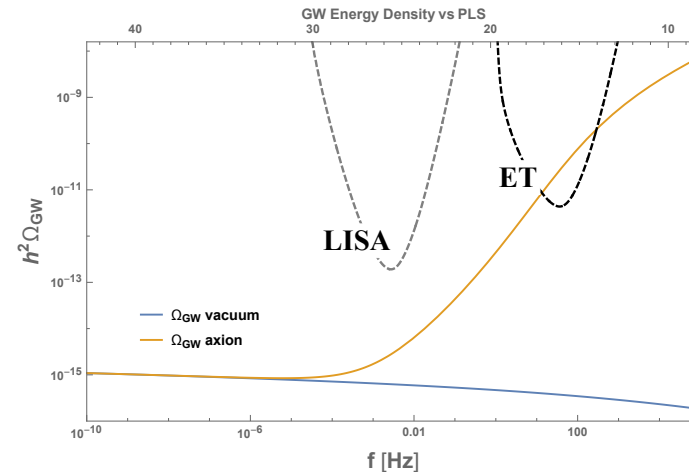
6. Stochastic GW backgrounds

GWs can carry uncorrupted information from the very earliest moments after the big bang and corresponding high-energy physics

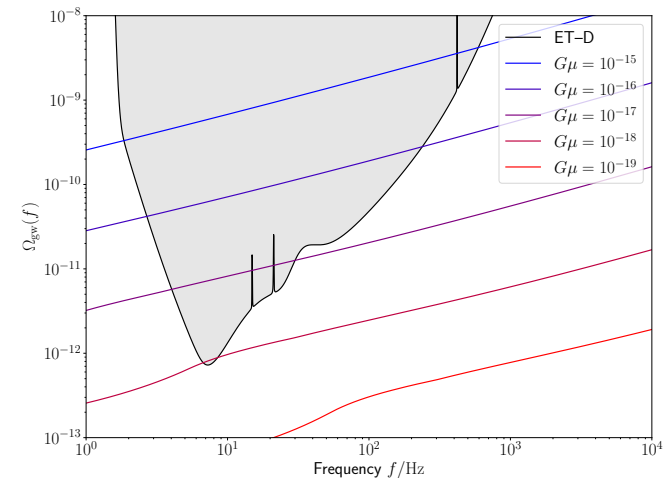
- photons decouple from primordial plasma when
 $z \simeq 1090$, $T \simeq 0.26 \text{ eV}$
CMB gives a snapshot of the Universe at this epoch
- neutrinos decouple at $T \simeq \text{MeV}$
- GWs are already decoupled below the Planck scale, 10^{19} GeV

ET improves the sensitivity to stochastic backgrounds by 2-3 orders of magnitude compared to LIGO/Virgo

vacuum fluctuations from
slow-roll inflation too small,
but other inflation-related
mechanisms can produce
detectable signals



- cosmic strings
- 1st order phase transitions
at $T \sim 10^7$ - 10^{10} GeV
- anisotropies, multipole expansion



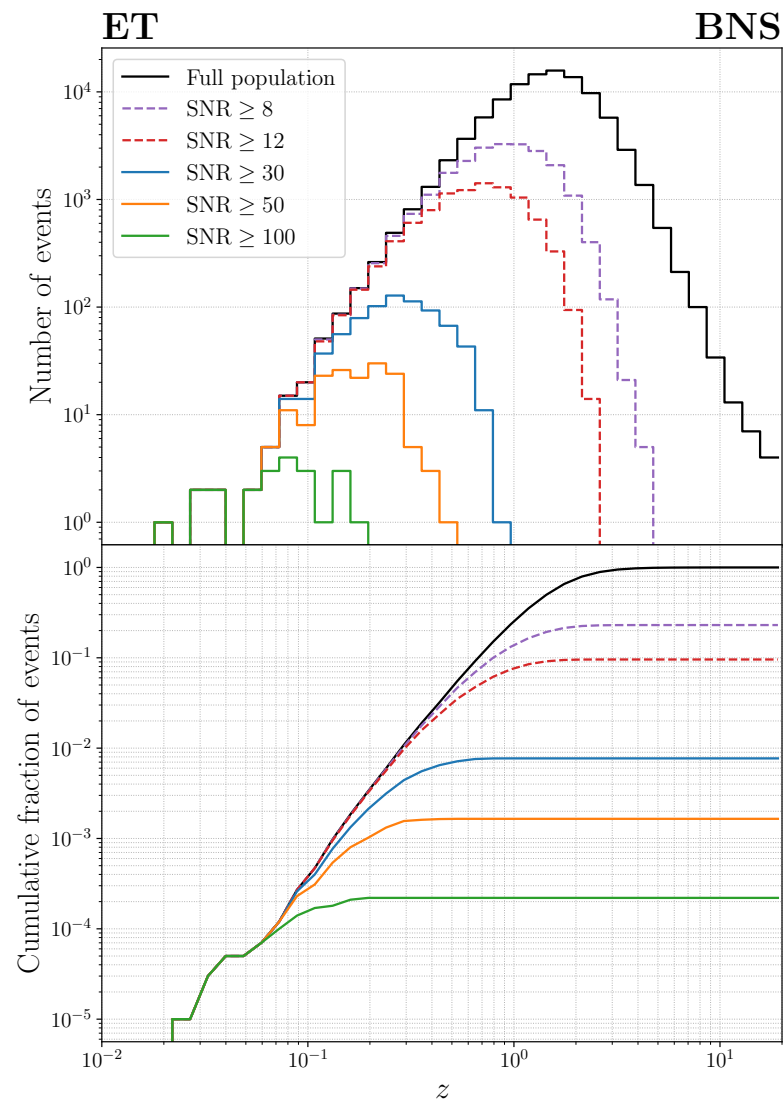
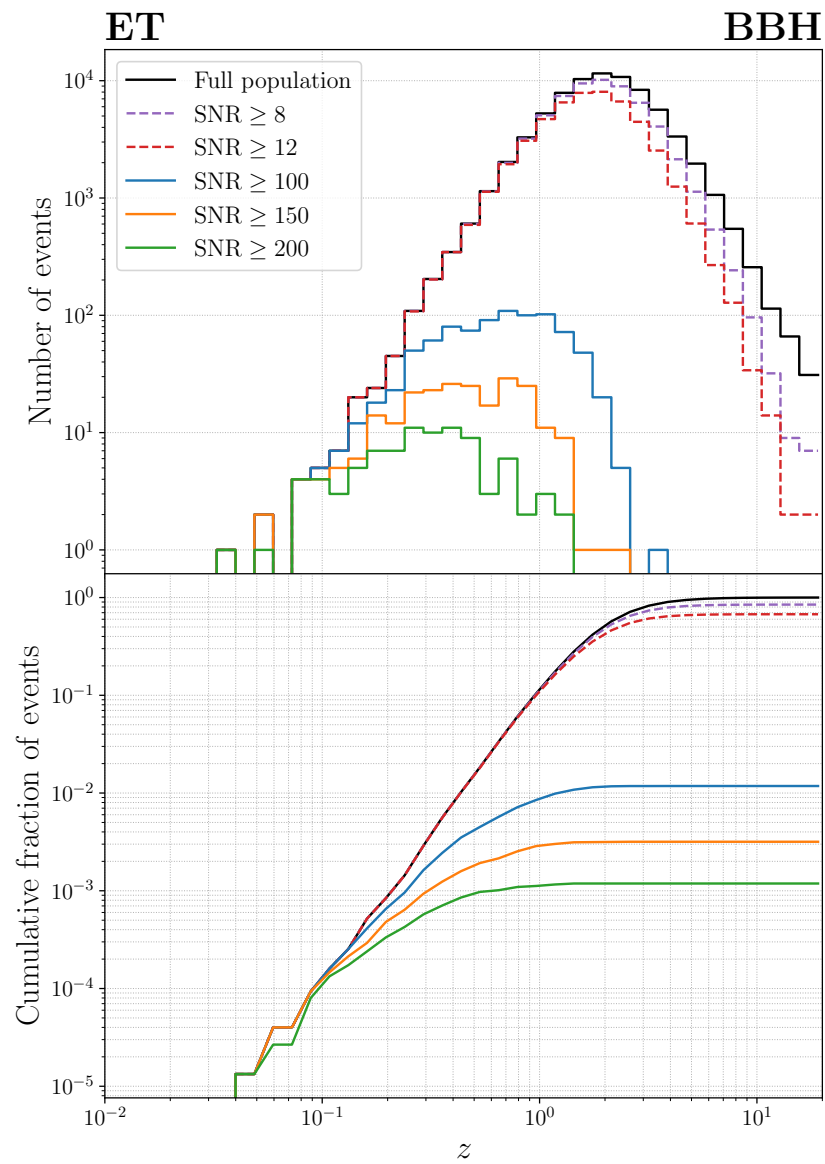
Take-away messages

ET has an exciting and broad science program,
ranging from astrophysics to cosmology and
fundamental physical

Thank you!

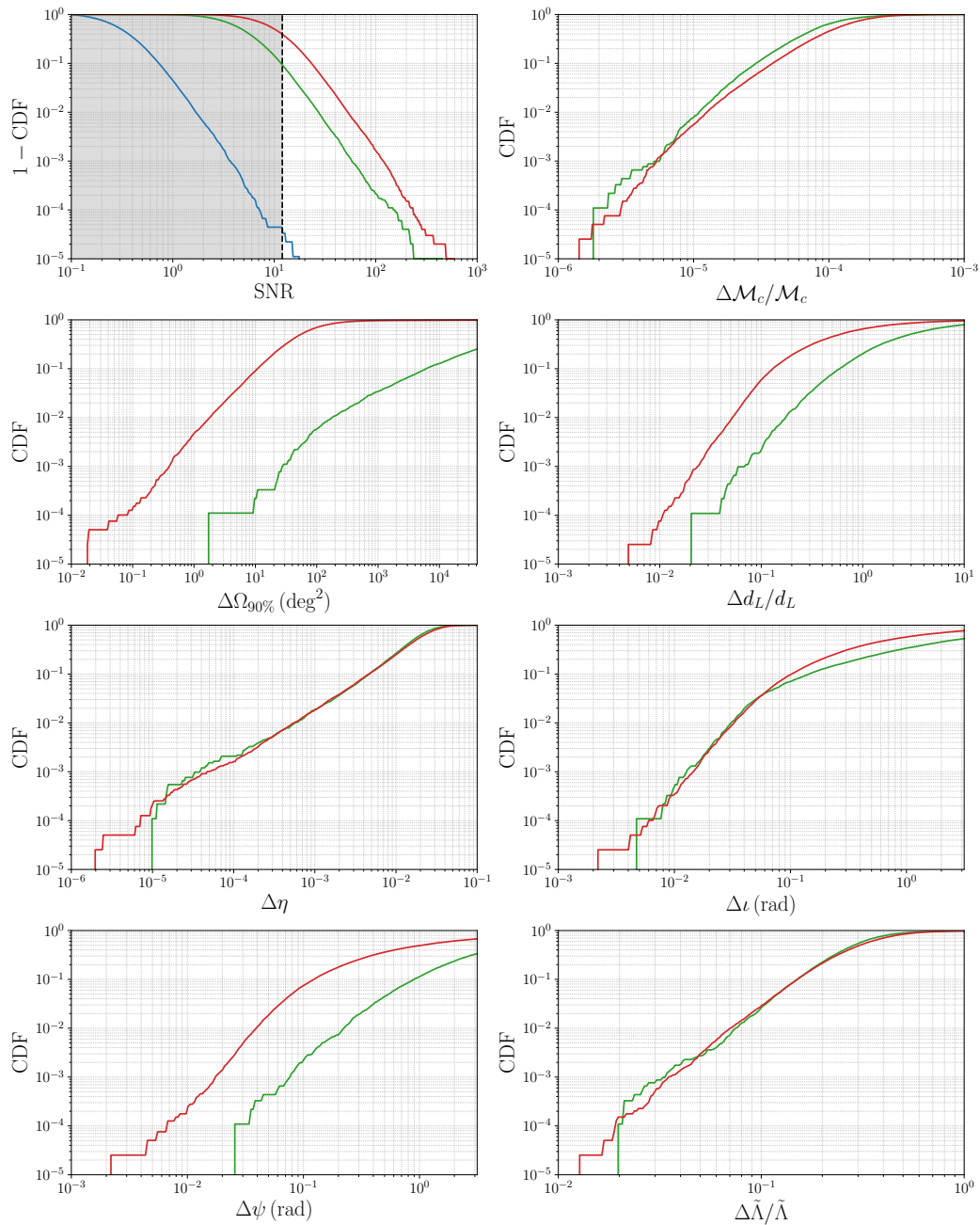
bkup slides

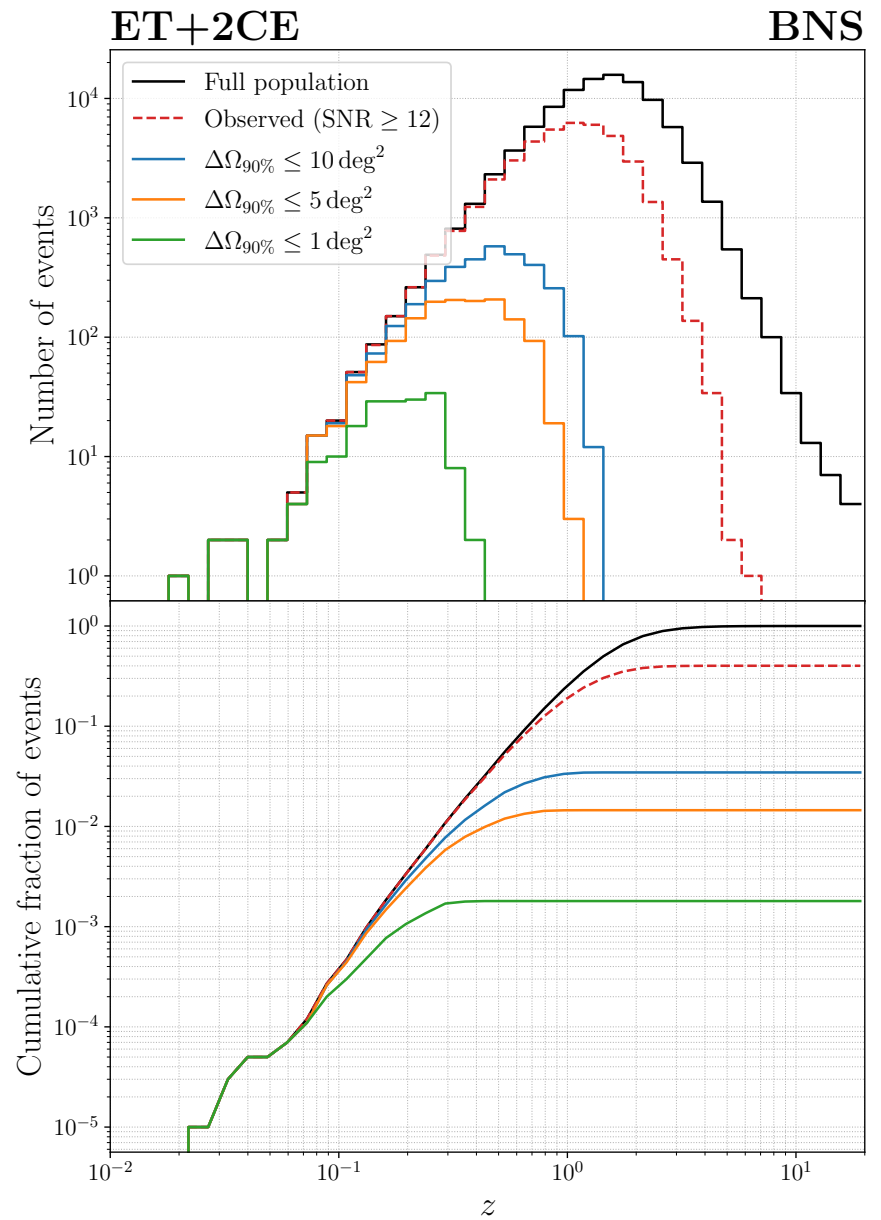
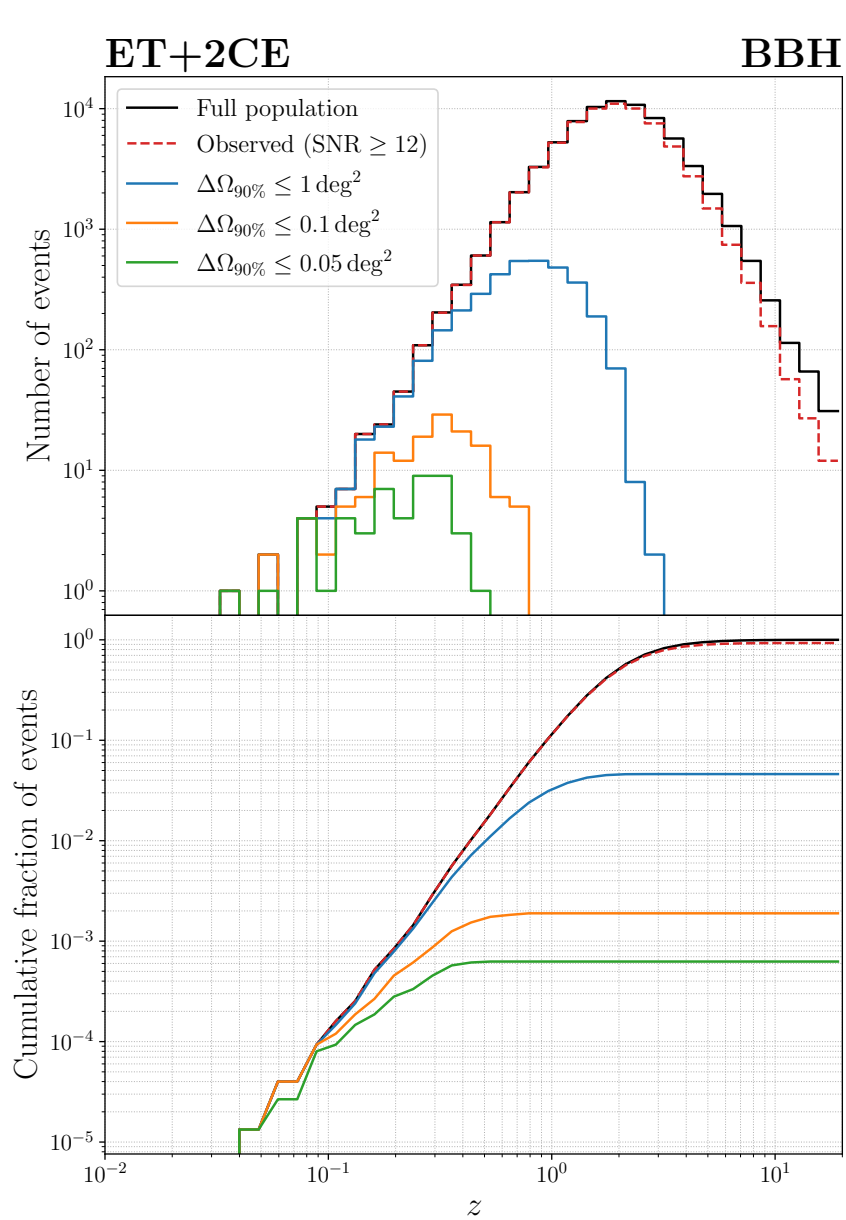
'golden events'



BNS

— LVK O4 — ET — ET + 2CE





Crucial Milestone: in June 2021 ET entered the ESFRI Roadmap

In 2021 ESFRI has approved the proposal of inserting in the Roadmap

- Largest project ever in the nella ESFRI Roadmap, 2.0 B€
- Science Case for the ESFRI submission coordinated by MM



Einstein Telescope: the concept and the current situation

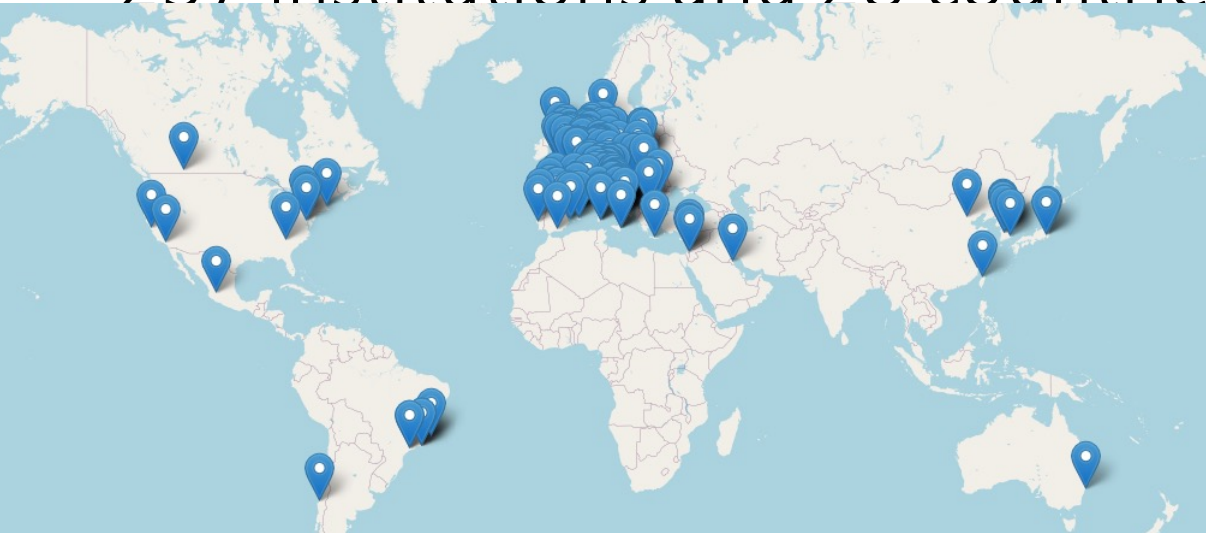
- single-site triangle, or 2L in different sites
- arms: $3 \rightarrow 10(15)$ km
- 200-300 m underground
- two instruments, LF (cryogenic) and HF

ongoing studies on the best geometry and configurations

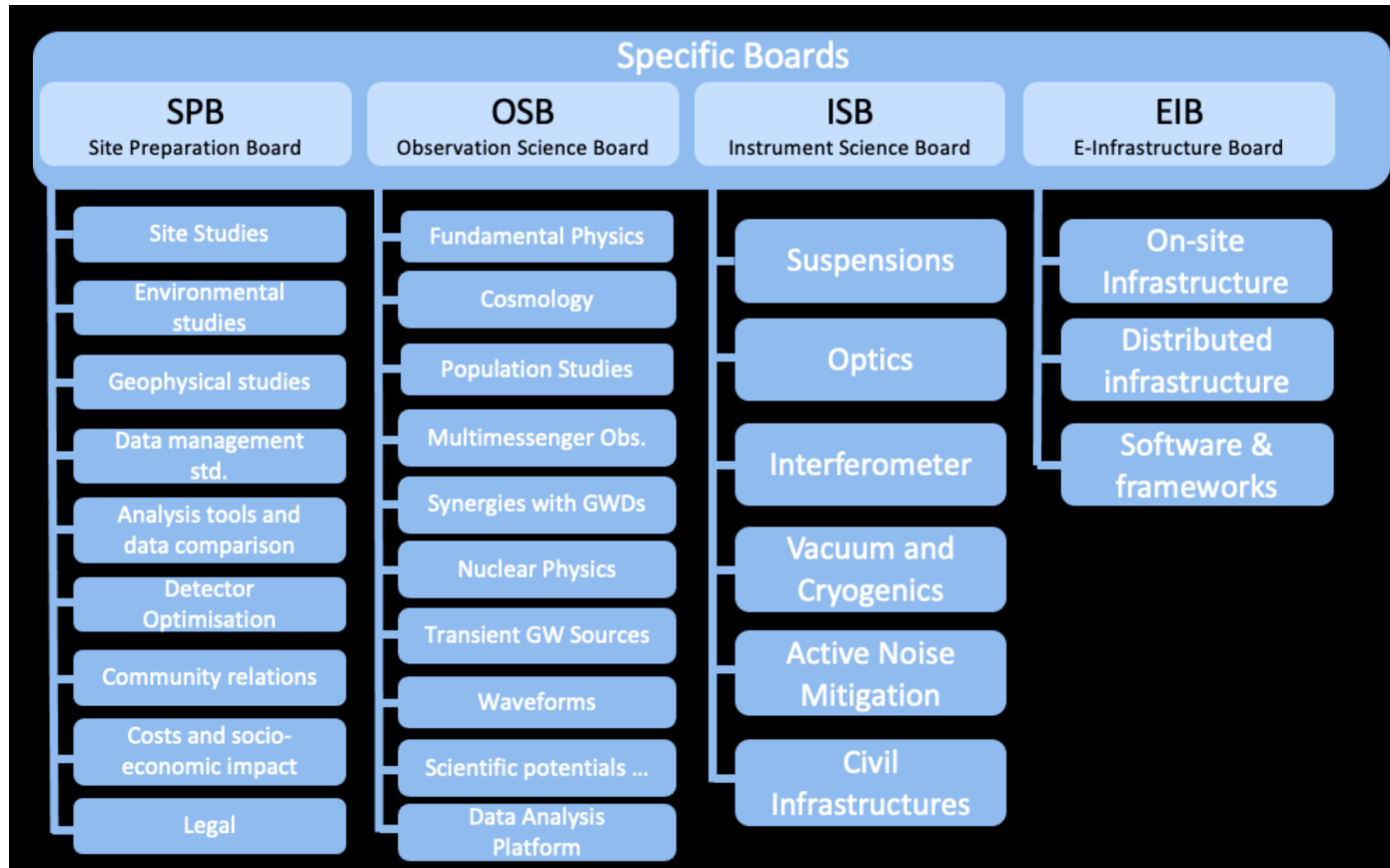
The ET Collaboration



- Currently the ET Collaboration has > 1700 members, organized in 90 Research Units, over 237 institutions and 28 countries



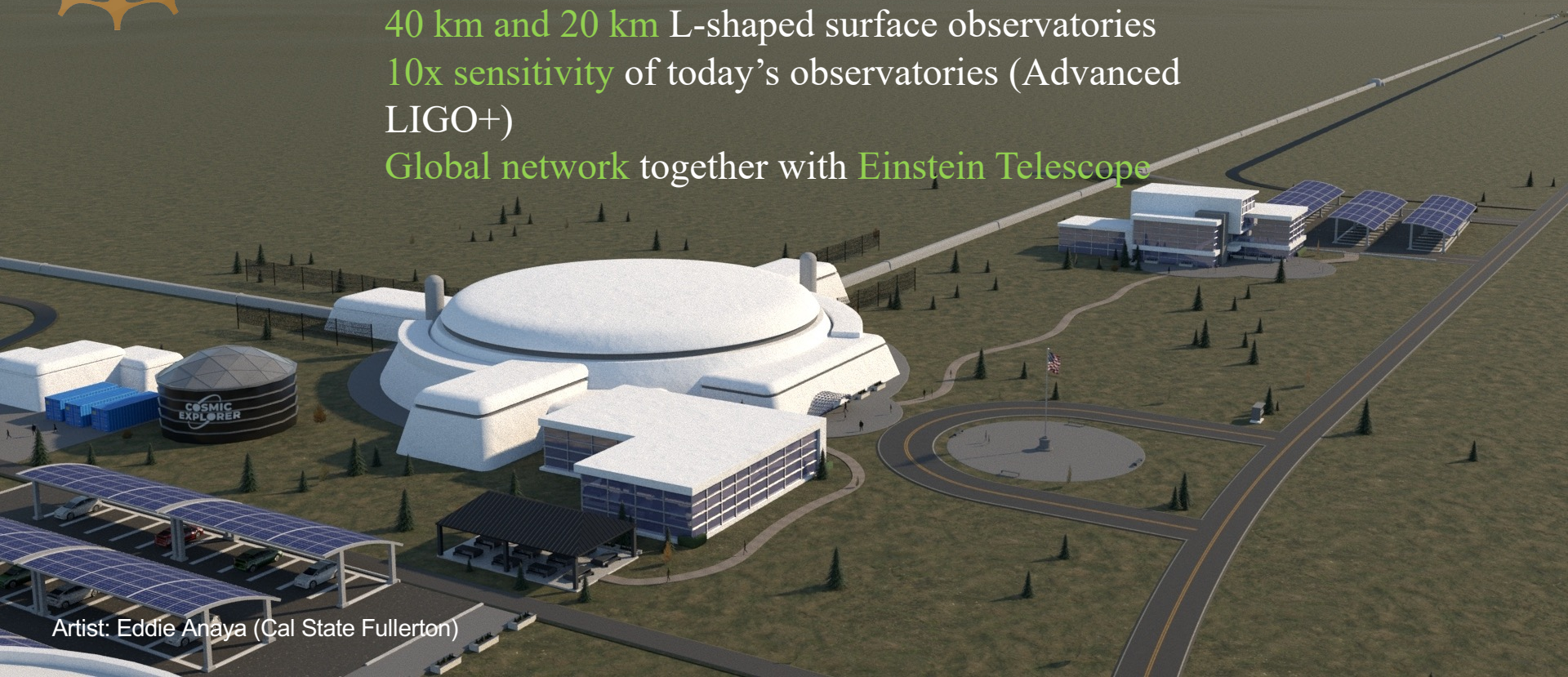
ET organization: Specific Boards



OSB responsible of the science ~ 470 scientists

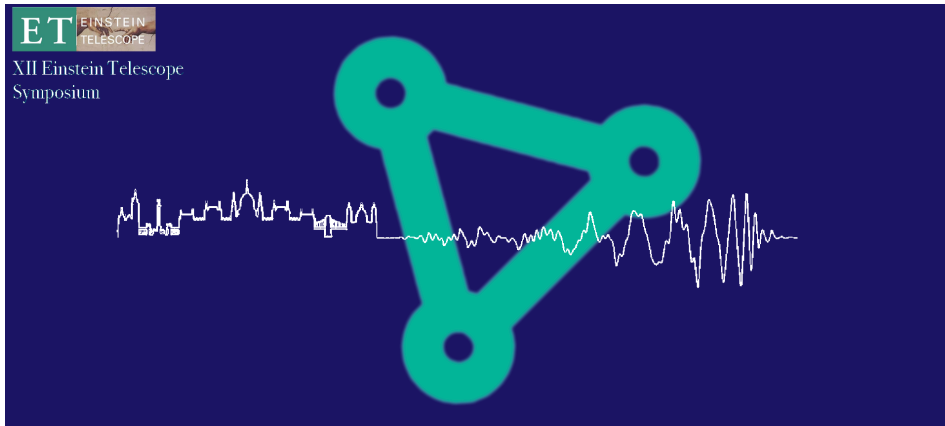


40 km and 20 km L-shaped surface observatories
10x sensitivity of today's observatories (Advanced LIGO+)
Global network together with Einstein Telescope



Artist: Eddie Anaya (Cal State Fullerton)

Formal birth of the ET Collaboration, Budapest 7-8 June 2022



Overview

[ET Collaboration
Announcement](#)

[Timetable](#)

[Registration](#)

[Participant List](#)

[ET Information](#)

[TRAVEL INFORMATION](#)

[ACCOMMODATION](#)

[Code of Conduct](#)

[GDPR](#)

[Conference photo](#)

[Some more photos](#)

XII Einstein Telescope Symposium

(The birth of the ET Collaboration)

The XII symposium of the Einstein Telescope (ET) took place in Budapest, at the Hungarian Academy of Sciences, on the 7th - 8th of June. The ET scientific community met in Budapest for a crucial step in the long Einstein Telescope journey: the formal establishment of the ET Collaboration.

More than 400 scientists, out of more than 1200 members of the Collaboration, participated in the meeting in person or remotely. The ET members discussed the status of the experiment, the technical challenges, the scientific case, and the scientific and technical progresses made by each of the ET boards. The ET Project Directorate presented the perspective of the funding agencies. Finally, the approved INFRA-DEV Horizon EU project, for supporting the preparation phase of the experiment, and the INFRA-TECH Horizon EU proposal, recently submitted to Brussels for supporting technological R&D activities, were introduced to the whole Collaboration.

The 12th ET symposium is a milestone of the Einstein Telescope project. The ET project is on the ESFRI roadmap since July 2021. A collection of European research institutions, universities and research teams is on the way to establishing the Einstein Telescope Collaboration. That is the primary goal of the

