



Institut national de physique nucléaire
et de physique des particules



Computing and low latency alerts for Einstein Telescope



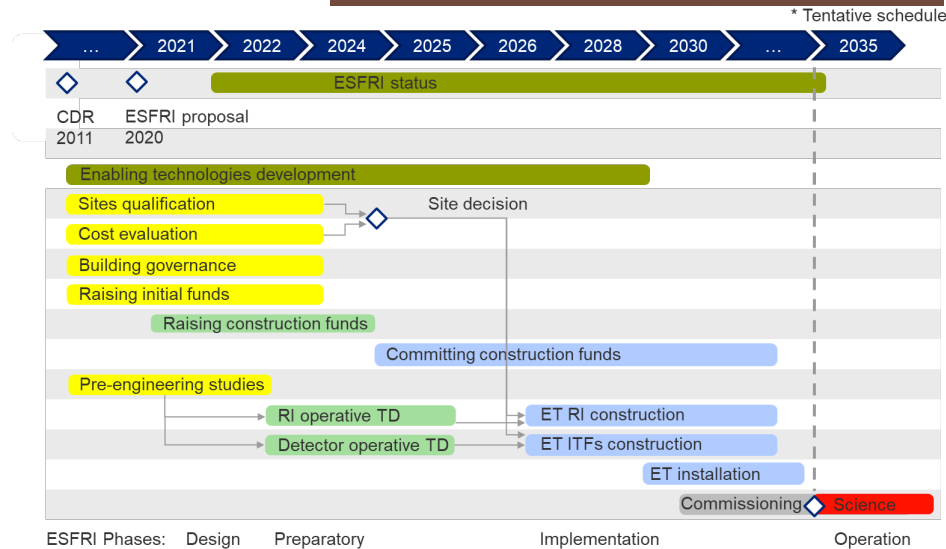
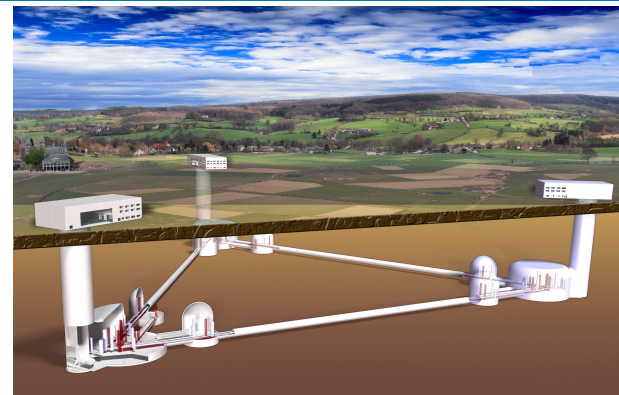
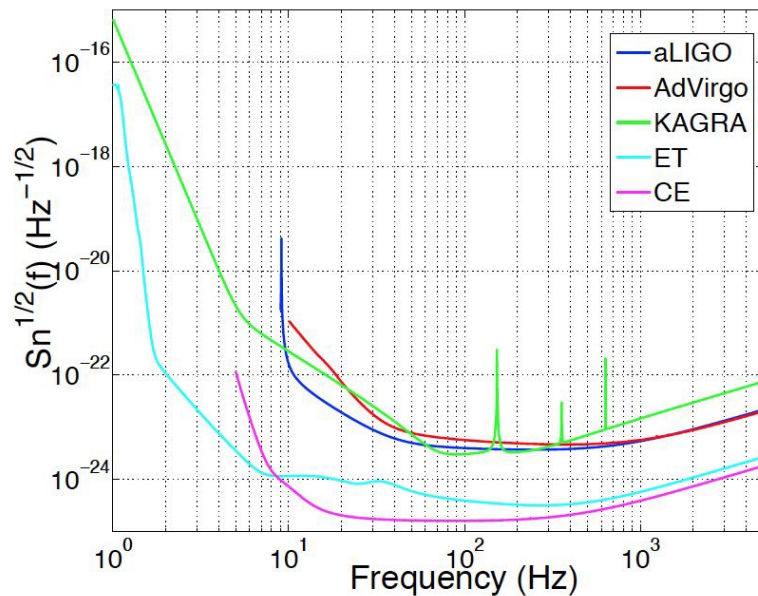
Low-latency alerts & Data analysis for Multi-messenger Astrophysics

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Paris – Jan. 13th, 2022

Einstein Telescope is the project aiming to realize the European 3rd generation ground-based GW observatory:

- A huge improvement in sensitivity compared to nominal sensitivity of 2G interferometers, especially at low frequencies (few Hz – 10Hz)
- High reliability and improved observation capability



ASTROPHYSICS

Black hole properties

origin (stellar vs. primordial)
evolution, demography

Neutron star properties

interior structure, equation of state
demography

Multi-band and –messenger astronomy

joint GW/EM observations (GRB, kilonova,...)
multiband GW detection (LISA)
neutrinos

Detection of new astrophysical sources

core collapse supernovae
isolated neutron stars
stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS AND COSMOLOGY

The nature of compact objects

near-horizon physics, tests of no-hair theorem
exotic compact objects

Tests of General Relativity

post-Newtonian expansion, strong field regime

Dark matter

primordial BHs
axions, dark matter accreting on compact objects

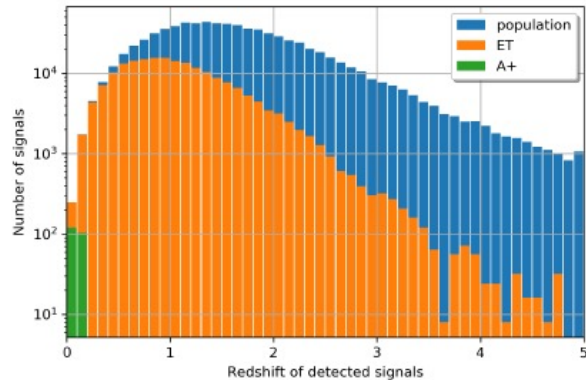
Dark energy and modifications of gravity on cosmological scales

dark energy equation of state,
modified GW propagation

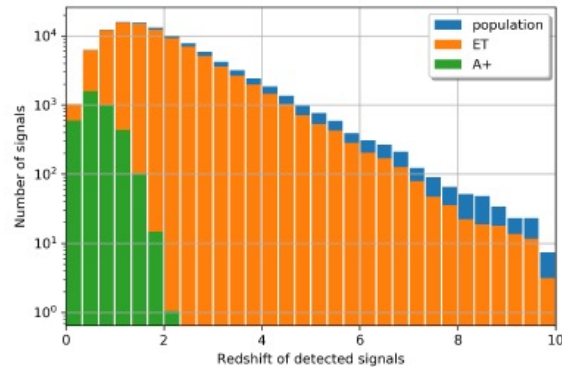
Stochastic backgrounds of cosmological origin inflation, phase transitions, cosmic strings

The “unexpected” ?

BINARY NEUTRON-STAR MERGERS

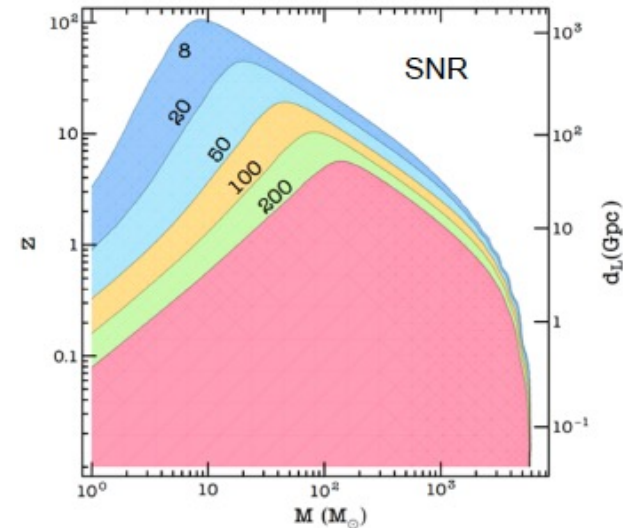


BINARY BLACK-HOLE MERGERS

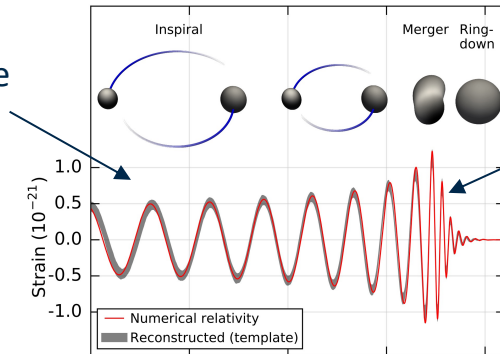
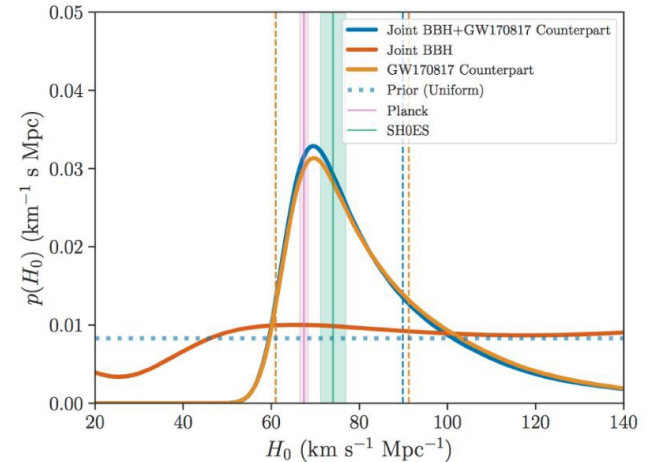
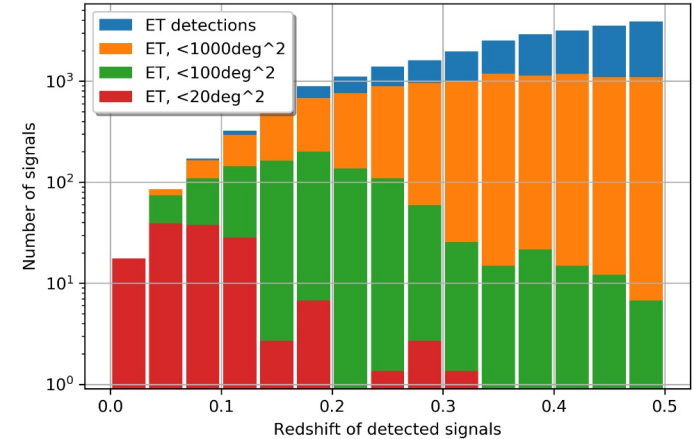


- 10^5 - 10^6 BBH detections per year
- 10^5 BNS detections per year among which ~ 100 - 1000 with EM counterparts
- High SNR events
- Overlapping events

~ 1 detection every 30s



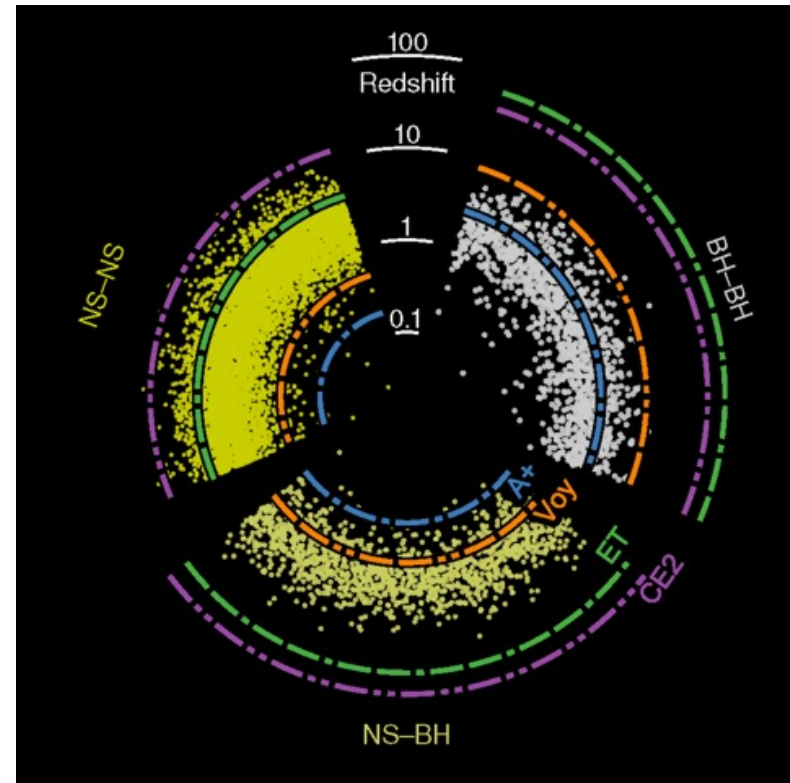
- **BNS detection with EM counterparts and localization precision $< 20 \text{ deg}^2$: ~ 100 per year**
- Overlap with many BBH signals
- Potentially, very long signals
- ET will be able to provide alerts few hours before the merger



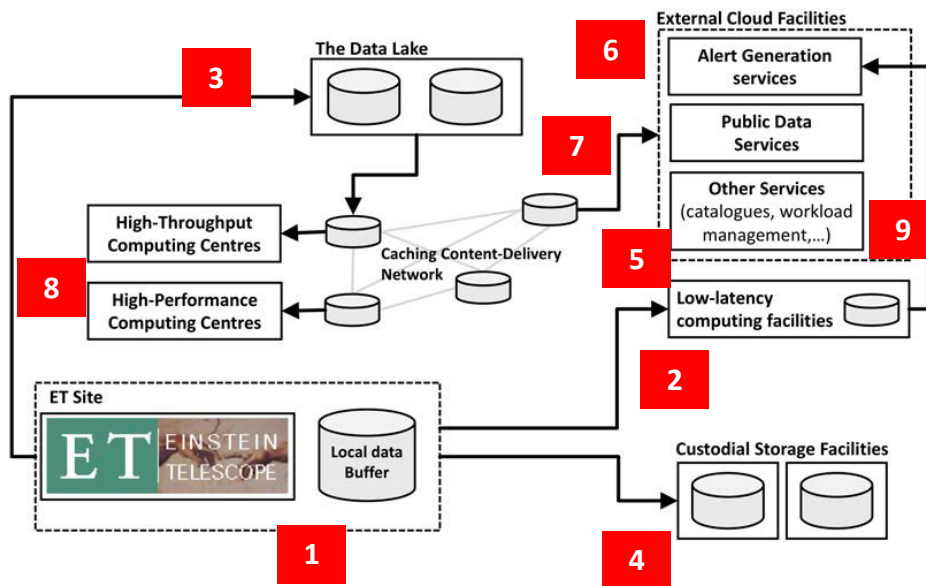
- And with ~ 600 BNS-EM detection, we can reach Planck resolution on H_0 measurement

- Despite the large increase in the expected number of events (10^5 - 10^6 events/year) compare to 2G interferometers, ET raw data will represent **only few tens of PB per year**. ET data will however need to be distributed to a much larger number of users
- Data processing in ET is the highest challenge, **especially parameter estimation of CBC** (ET CPU will represent $\sim 10\%$ of ATLAS in the HL-LHC era) : plenty of margin for improvements with R&D !

=> ET will use a **distributed computing infrastructure largely based on existing infrastructures**: network and national computing centers, mainly HTC, but also HPC (GPU, FPGA) for numerical relativity simulations & Deep Learning techniques



ET will use a distributed computing infrastructure largely based on existing infrastructures: most of the computing (data processing and services) might run off-site



1. Data collection in a local circular data buffer. A local computing infrastructure is used to pre-process and reduce the data to the format used for low-latency and offline analyses

2. Data are transferred to the low-latency search facilities, where search pipelines are automatically run

3. Data are also shipped to the Data Lake for subsequent offline analyses
[It may be possible for the low-latency processing sites to exploit the data lake, reducing the complexity of the computing infrastructure]

4. A reduced version of raw data are transferred to archival sites for safekeeping

5. All data (raw, processed, public) is registered in a general catalogue database that functions as a single front-end both for data discovery and access

6. Low-latency processing facilities run search pipelines and send triggers and candidate information to the low-latency alert generation and distribution services

7. Candidate event alerts are generated and distributed by the relevant services. Data segments to be distributed with the alert are not copied again but tagged in the database as "public"

8. Offline analyses (parameter estimation, deep searches etc.) and all scientific computing (numerical relativity simulation, Machine Learning model training, etc.) are run on available HTC, HPC or even "Big Data" facilities optimised for Machine Learning, depending upon the optimal type of technology

9. Publicly released data are not copied again, but tagged in the database and made available through public discovery and access services.

ET data policy and computing model definition: ET will follow the path created by LIGO and Virgo (c.f. today's talk by Franco Carbognani)

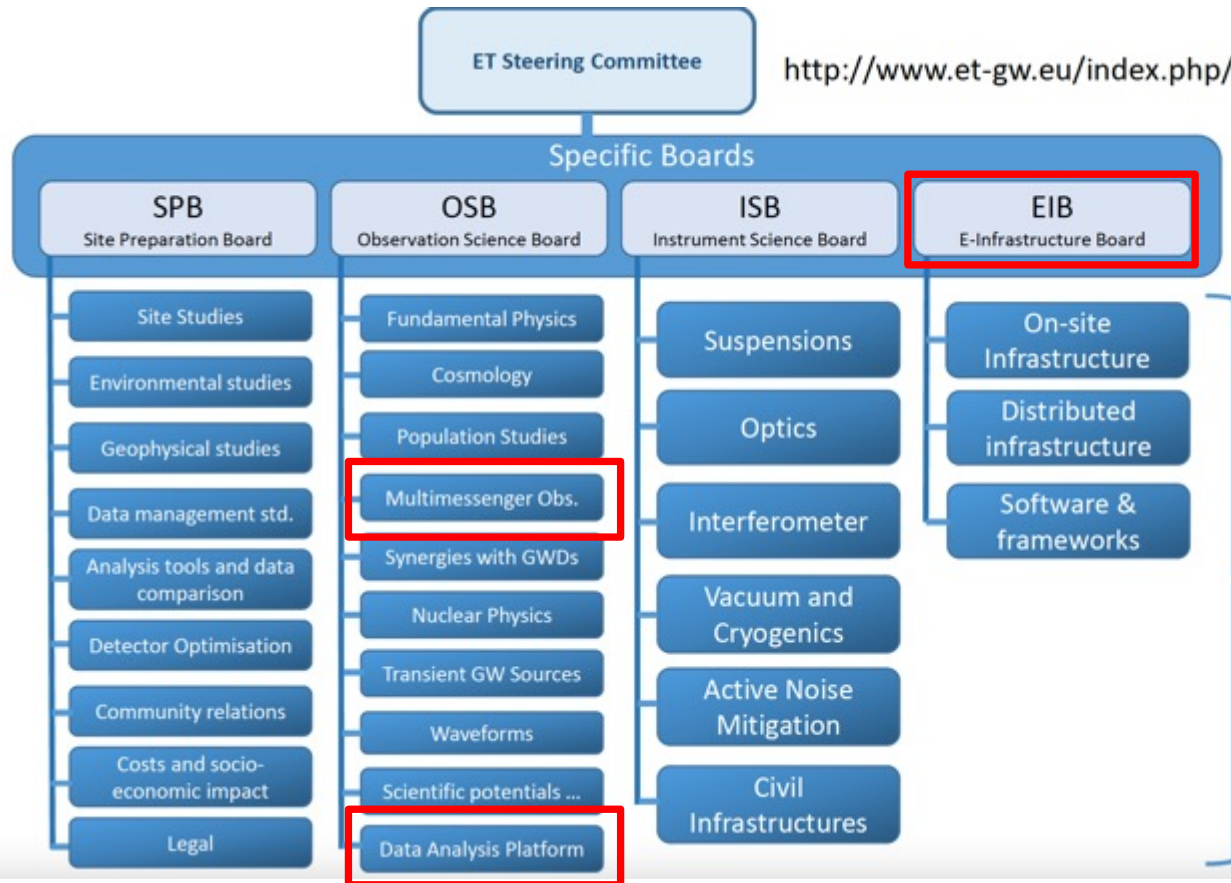
- Open and Public Access to alerts
- Limited period of property data (18 months)
 - Calibration, data quality, internal analysis
- Releasing short chunk of data around published gold events
- Open Access to data implementing the F.A.I.R. indications

And when ET will be taking data:



- EOSC will be operational
 - Infrastructures, services and tools for Low Latency Alerts and multi-messenger analysis will be available
 - And several experiments will be already using these : CTA, Vera Rubin Observatory, DUNE, Hyperkamiokande, KM3Net, SKA ...
-
- **ET is willing to contribute from the beginning**
 - **Possibilities to develop next generation solutions using advanced technologies**

- **Handling ET data volume (~10 PB/year) should be under control, but what will grow compared to 2G GW detectors is**
 - the amount of scientific information encoded in the data
 - the complexity of this information
 - the number of users accessing this data (including for MMA)
- Huge work and improvements are expected from **using ML/AI and new techniques** which will be developed during the next ~10 years
- Most ET needs can be addressed with High-Throughput Computing, however **the role of HPC is expected to increase** (numerical relativity, templates production, parameter estimation) : the **use of GPU and FPGA architectures** will also be considered (for online/offline)
- Most of the computing aspects of ET will have to be organized in order to be able to run on various computing centres and in an automated way
- ET foresees technology tracking of leading-edge computing technologies
- ET computing model will be tested with early data challenges



ET is now an ESFRI project:



Renewed interests and sharp increase in participation

The ET proto-collaboration is currently in construction

Works towards the definition of the Infrastructure and Project governance is starting

- **Einstein Telescope** will provide enhanced sensitivities to GW detection compared to 2G experiments, enabling a very rich scientific program in astrophysics and fundamental physics
- ET has to tackle many challenges in the fields of computing and algorithms development in order to meet the needs for analyses, in particular multi-messengers
- ET is willing to contribute to current developments of tools and services for Low Latency Alerts & Multi-Messenger Analysis
- ET project timescale also allows to start innovative R&D to develop advanced technologies for the 2030's