R&D challenges and global progress

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Network of GW detectors

LIGO Scientific Collaboration:

- 1263 collaborators (including GEO)
- 20 countries
- 9 computing centres
- ~1.5 G$ of total investment

Virgo Collaboration:

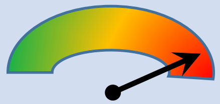
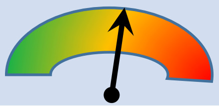
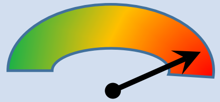
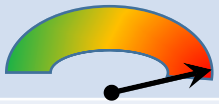
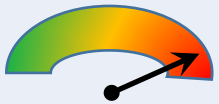
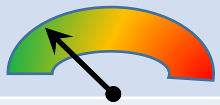
- 343 collaborators
- 6 countries
- 6 computing centres
- ~0.42 G€ of total investment

KAGRA Collaboration:

- 260 collaborators
- 12 countries
- 5 computing centres
- ~16.4 G¥ of construction costs

2029 outlook

- In 2029 we will have a really heterogeneous 2.xG network
  - The concepts of “obsolescence” and “limit of the infrastructure”, that are driving the quest for new research infrastructures (rather more than a new detector) apply differently to the different continents

Continent	Detector	Obsolescence	Limits	
America	LIGO H1			
	LIGO L1			
Europe	GEO600			
	Virgo			
Asia	KAGRA			
	LIGO India			

Current scenario

- That outlook was evident already many years ago and it pushed, in 2004, the first steps of the 3G idea and then (in 2007) of the “Einstein Telescope” (ET) project proposal
- Now, thanks to the work done in the past and to the amazing discoveries in 2015-2017, 3G idea has been boosted and we can depict the following possible scenario:
  - ET project in Europe O(2030+)
  - CE concept in US O(203x+)
  - ?? idea somewhere else O(20xx+)
- What are the readiness levels?

Project steps (time)

Name	Idea	CDR	Project Roadmap	Initial funds	Enabling Technologies, Site	TDR	Bulk Funds	Construction
ET								
CE								
??								

GWIC-3G discussion

- Beside to this global scenario, there is the global coordination effort actuated by the GWIC-3G committee
  - Science
  - R&D
  - Governance
  - Networking
  - Agencies interfacing

Gary's talk at the DAWN 3 and then at the latest GWIG drafted possible evolution schemes and stimulated a lot of discussion

From my DAWN III talk (but amended)

Options for Global Project Governance

- Intergovernmental (treaty) organization (strongest)
- International Research Infrastructure Consortium (added)
- International partnership of existing executive organizations via legal member corporation
- International collaboration of existing executives via single nonbinding member association
- International collaboration with multiple nonbinding agreements with multiple existing executive organizations
- International coordination of separate, but related, existing executive organizations
- Non-coordinated separate, but related, existing executive organizations (least strong)

Starting Points/Initial Conditions

- 2G: LIGO, Virgo, KAGRA, LIGO-India in motion
  - A powerful ad hoc global network
- LIGO and Virgo function in an MOU-driven collaboration, mostly on data analysis
  - LIGO-India will join this
  - KAGRA will ultimately collaborate as well
- Upgrades to these 2G systems are planned
- Pre-conceptual work has begun on candidate regionally envisioned 3G designs
- GWIC, GWAC, APIF, ApPEC, ApPIC, and others already playing roles considering the future
- We felt that our deliberations should be informed by these starting points, but not constrained by them

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Governance <--> Successful Global Proposals

- 3G detectors/sites will be billion dollar/euro class investments
- As 3 or more are needed this leads to 3G as a CERN LHC/SKA/ITER class investment for the sponsors
  - With corresponding long term operating costs
- Strong planning, management, control of risks is needed to assure confidence of sponsors/agencies
  - This argues against ad hoc heterogeneous 3G implementations

4-P

How to get to the envisioned governance?

- Though we work from prior models, one size does not fit all
  - 3G GW will be a unique global scientific enterprise and community
- Needed:
  - Community road mapping
  - R&D, generic → design specific → precursor efforts
  - Funding agency engagement, consensus and confidence
  - Science/technical lifestyle in the transitional and final organizations
- Phased approach has been used by other global projects

How to Evolve?

- We could compare the two antithetical approaches:
  - (a) Fully integrated project, since the beginning
  - (b) Fully independent projects, collaboration of collaborations when operative

(a) Fully integrated project, since the beginning

- We form a single global project, with single timeline, design and governance
  - PRO:
    - Minimisation of the human and conceptual efforts and of the global costs
      - Unified R&D effort
      - Single design
    - Single global management for design/operations
  - CONTRA:
    - Unlinked to the current status and of the 2029 outlook
      - Inefficient use of the energies already invested unless we are globally converging on the ET design and roadmap
    - Sub-optimal use of the opportunities
      - Different calendar in the different continents (ESFRI, Horizon Europe, Decadal survey, …)
      - Different funding schemes (for example ERIC in Europe)
    - Sub-optimal use of the potential/constrains of the different continents
      - Underground vs surface, 10km vs 40km
    - Inefficient from the point of view of the timing

(b) Fully independent projects

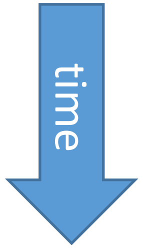
- The different projects evolve independently until they are operative, then a collaboration of collaborations is set up (like the current global situation)
  - PRO:
    - Time efficient: each project can optimally benefit of the continental opportunities
    - Better matching with the continental/regional constrains
    - Probably easier to be funded
  - CONTRA:
    - Duplication of the design and R&D efforts
    - Inefficient from human resources and financial point of view
    - Cumbersome collaboration

How to Evolve?

- We could oppose two antithetical approaches:
  - (a) Fully integrated project, since the beginning
  - (b) Fully independent projects, collaboration of collaborations when operative
- OK, let us try a synthesis between the two approaches:
  - (c) dynamical integration (parallel convergences)

(c) Dynamical integration

- Start from the current scenario:
  - Keep pushing with high priority on the ET project development
    - The ET project is in an advanced phase of its roadmap
    - The ET design is compliant with a heterogeneous 2.xG-3G network configuration that could be the (temporary) effective scenario in early 2030s
    - ET needs several and complex steps at EU level for its approval and for the definition of the financial scheme
  - Keep pushing with high priority on the CE concept development
    - The CE CDR should be realised in short time, considering the global scenario
    - A clear CE project roadmap needs to be defined
    - A financial scheme needs to be defined
- Converge as much as possible when projects will have compliant readiness level
  - (i) Enabling technology through joint R&D
  - (ii) Design options
  - (iii) Global governance



(i) Enabling Technologies 1/5

- The enabling technologies (e.t.) are the key technologies that make the project possible
  - Many e.t. could be in common both to ET and CE (or have at least common requirements)
    - **Cryogenics**
      - ET-LF target temperature is 10K
      - If CE adopts the “Voyager technology”, it should work at 110K
      - Different choices and different specifications, but several common challenging requirements are present:
        - Low noise, reduced cooling time, no pollution on the mirror

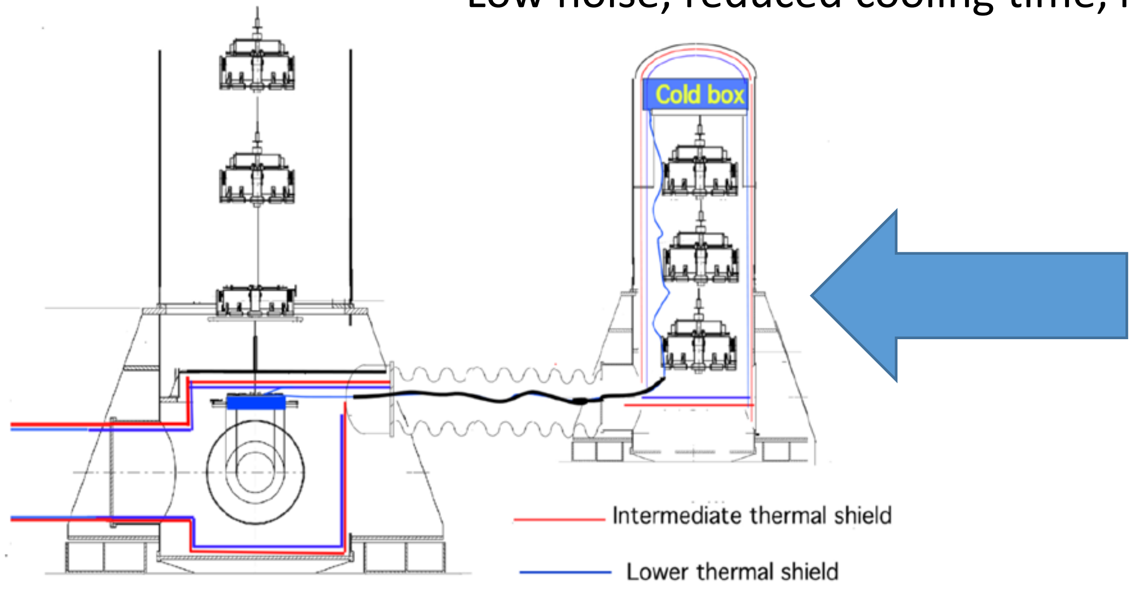
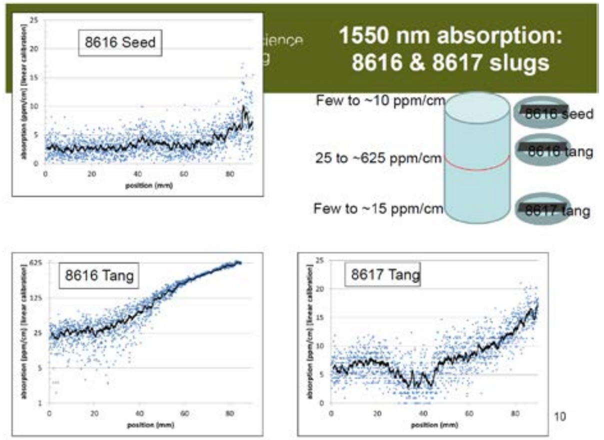


Figure 96: Scheme of the cryostats needed for cooling a test-mass of the LF-interferometer.

Cryogenics is a crucial technology for ET and the solutions proposed in the ET CDR need to be deeply reviewed before to arrive to the TDR: a global R&D and design effort, involving “external” (CERN, for example) experts, is mandatory

(i) Enabling Technologies 2/5

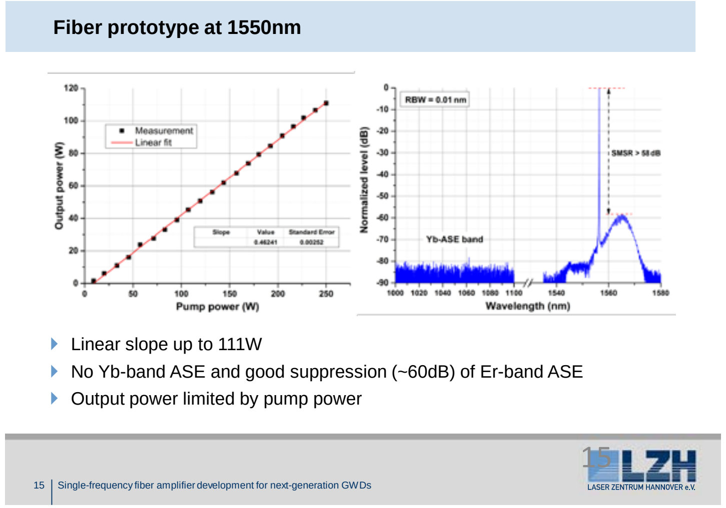
- The enabling technologies (e.t.) are the key technologies that make the project possible
  - Many e.t. could be in common both to ET and CE (or have at least common requirements)
    - **Silicon test masses**
      - Both ET-LF and CE (using Voyager technologies) want to use heavy silicon test masses
      - Thermal noise requirements are quite similar, optical absorption requirement should be more stringent in CE thanks to the Xylophone design in ET
      - Similar difficulties:
        - Czochralski method produced Silicon: large samples, high optical absorption
        - Float Zone method produced Silicon: small sample, low optical absorption
        - Magnetic-Czochralski method produced Silicon: is it the solution?
    - **Silicon fibers/ribbons:**
      - How to produce long (1-2m) suspension fibres in Silicon?
      - Is a monolithic design feasible?
      - Are Si-ribbons a feasible option?
    - **Silicate bonding:**
      - Is silicate bonding a reliable technology for heavy (300kg) silicon masses?



Angus Bell
8th ET symposium, 2017

(i) Enabling Technologies 3/5

- The enabling technologies (e.t.) are the key technologies that make the project possible
  - Many e.t. could be in common both to ET and CE (or have at least common requirements)
    - **Different wavelength**
      - The use of Silicon test masses force to adopt a different wavelength for the laser light
      - In ET λ=1550nm has been identified and tested up to more than 110W (Michael Steinke, 8th ET symposium 2017)
      - The λ=2μm wavelength investigated in CE seems to have some advantage for the thermal noise in the coatings
      - We need to develop all the opto-electronics produced for the advanced detectors
        - A convergence to a common wavelength is mandatory
        - Common R&D and shared decisions are needed



(i) Enabling Technologies 4/5

- The enabling technologies (e.t.) are the key technologies that make the project possible
  - Many e.t. could be in common both to ET and CE (or have at least common requirements)
    - **New coatings**
      - Coatings thermal noise will be the limiting factor in a wide frequency range
      - We need to develop new coatings both for cryogenic temperatures (ET-LF, CE) and for room temperature (ET-HF)
      - Crystalline coatings represent a new possibility, but amorphous dielectric coatings still are the most robust option. Because of the cost of the R&D and of the cost of the production plants, we MUST develop with a global effort the 3G coatings.
    - **New seismic filtering system**
      - ET needs to reduce the seismic noise at few hertz to achieve the nominal sensitivity.
      - ET CDR solution has a large cost impact on the infrastructure:
        - Size of the caverns
      - It is possible that using and hybrid solution using both the passive suspensions “à la Virgo” and active suspensions “à la LIGO/CE” we can reduce the infrastructural costs:
        - collaboration is mandatory!
    - **Newtonian Noise noise subtraction**
      - In the ET CDR NN is not subtracted, but it is an e.t. for CE
      - Requirements are different, but joint developments are recommended

(i) Enabling Technologies 5/5

- The enabling technologies (e.t.) are the key technologies that make the project possible
  - Many e.t. could be in common both to ET and CE (or have at least common requirements)
    - **Vacuum**
      - A large fraction of the cost of both ET and CE will be generated by the vacuum plants.
      - A large engineering effort, involving also private companies, is mandatory to reduce the production and maintenance cost of multi-km installation of vacuum systems
      - Common solutions will generate a reduction of cost.
- GWIC-3G started a global survey of the enabling technologies and of the involved team
  - A global coordination of the efforts need to be set up
    - We need to start from what already exists:
      - GWIC-3G
      - LVC+KAGRA: 3G activities **MUST** be in the core business of Virgo and LIGO
  - Funding agencies should prepare "coordinated/common funding schemes"
    - In EU we had the APPEC common initiatives (but, it has been a positive experience?)
    - USA-EU-XX common initiatives are possible under the NSF PIRE tool (is it appropriate?)
    - Other schemes?

(ii) Design Options 1/2

- ET has been designed in 2008-2011 as pioneering effort in the community:
  - We required the capability to work alone or embedded in a 2.xG network of smaller brothers:
    - This is a “winning” characteristic also in a 3G network scenario, if the other infrastructures will arrive later
  - ET science case has been realised before the 2015-2017 detections
    - It is under review considering the network scenario
    - It is worth to note that in the CDR the ET sensitivity has been particularly addressed to stellar mass BHs, thanks to the low frequency sensitivity:
      - This is a “winning” characteristic, considering the unexpected detections of 10-60 M_{Θ} BH made by LIGO and Virgo
- CE is entering in its conceptual design phase, assuming that ET exists
- In case of a **confirmed** 3G network scenario a trade-off between cost and capabilities can be evaluated in ET, if it fits with the its roadmap (<2023)
  - ET Design complexity can be reduced in a 3G global network scenario?
    - Xylophone approach
    - Geometry
      - The triangle is mandatory if ET is alone
      - It is useful if ET is in a 3G network, but maybe not mandatory
    - Redundancy and null stream

(ii) Design Options 2/2

- ET has a clearly defined roadmap, presented to APPEC:
  - 2018 Form the ET collaboration
  - 2019 ESFRI roadmap
    - In Nov 2018 ET and the GW GRI (Global Research Infrastructure) will be presented as case study to the G7 body GSO (Group of Senior Officer)
    - We need to define the site selection parameters before to submit the proposal
      - The requirement to be compliant with alternative design options (Δ vs L) could be a crucial point
  - 2021-2022 Site Selection
    - Technical/political activity
    - Requirements need to be compared with the site characteristics through an intense experimental activity in the next 3 years
  - 2023 Full Technical Design Report ← Here, the design options are frozen
  - Cost definition
  - 2025 Infrastructure realization start (excavation, ….)
  - 2030 -2031 end of infrastructure construction, beginning of installation
  - 2032+: installation / commissioning / operation

(iii) Governance evolution

- Governance is a hot topic in GWIC-3G
- We need to find a strategy that:
  - Is compliant in the short term with the current scenario
  - Is allowing in the medium term (4-6 years) the access to the funding and support possibilities differently available in US, EU, Asia, Australia
  - Is promoting a joint governance of the 3G network in the long term

Conclusions and Discussion

- The realisation of a network of 3G GW observatories is a global affair
- But it is started through “continental” efforts
- The convergence path passes through a
  - Common science case
  - Joint R&D developments and common Enabling Technologies
  - Compliant design options
  - Converging governance model
- How that convergence is implemented depends upon:
  - The bottom-up self-organisation and willing of the GW community
  - The top-down set of opportunities and tools offered by the funding agencies

END