DIPARTIMENTO DI FISICA

SAPIENZA UNIVERSITÀ DI ROMA

AMALDI RESEARCH CENTER

INFN ROMA Istituto Nazionale di Fisica Nucleare Sezione di Roma

ET EINSTEIN TELESCOPE

NEWS
NEw WindowS on the universe and technological advancements from trilateral EU-US-Japan collaboration

Einstein Telescope and the future of ground-based GW detection

E. Majorana

experience - motivations and R&D need

XXIII SIGRAV Conference, Urbino 7-9 Sept 2021

SIGRAV X Conf, Bardonecchia 1992

Proceedings of the X Italian Conference on General Relativity and Gravitational Physics Bardonecchia (TO, Italy), Sept. 1–5, 1992

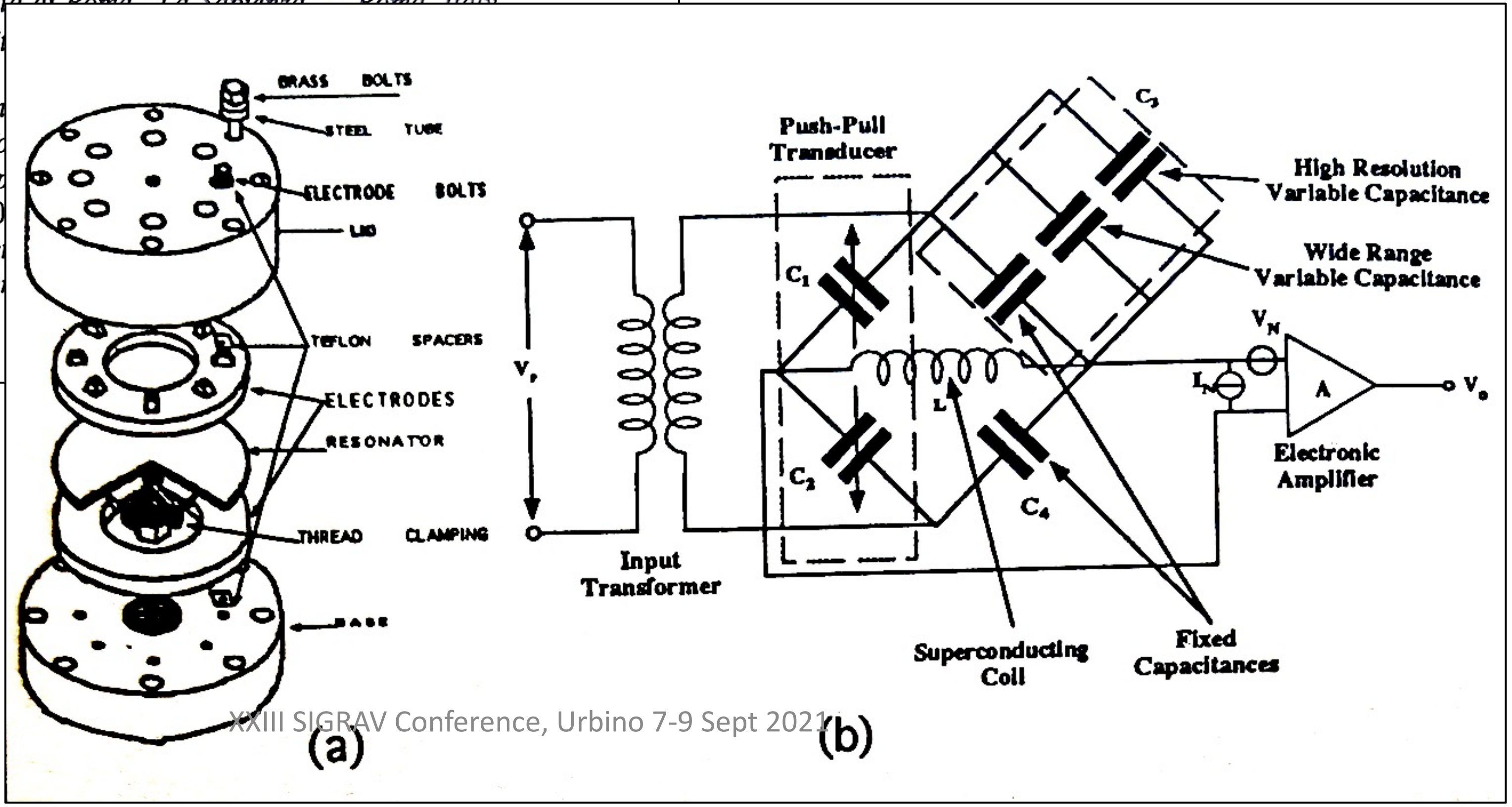
Developmentof a Back Action Evading Transducing Scheme for Cryogenic Gravitational Wave Antennas

Ettore MAJORANA[1,3], Piero RAPAGNANI[1,2] and Fulvio RICCI[1,2]

[1]*Istituto Nazionale di Fisica Nucleare – P.le A. Moro 2 00185 Roma, Italy*
[2]*Dipartimento di Fisica, Università di Roma "La Sapienza" – Roma, Italy*
[3]*Dipartimento di Fisica, Universi*

Summary: *We present the design*
wave antennas (g.w.a.) suitable fo
results of some tests at low temp
mechanical merit factor (2.8 · 10
ppm and an electrical quality fac
the system is in satisfactory agree

Talk given by Ettore MAJORANA



A worldwide community, a prosperous future, why ?

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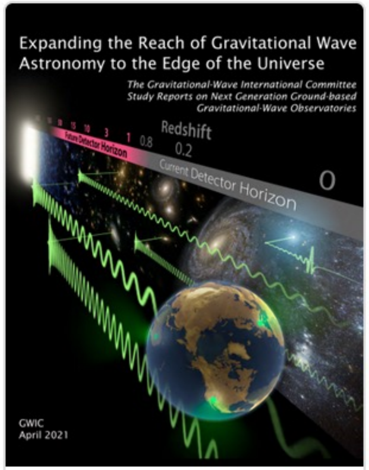
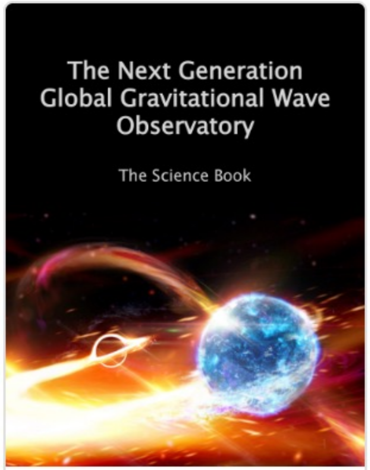
GWIC-3G Home Charge Committee Subcommittees Documents Meetings

GWIC Releases the GWIC-3G Subcommittee Reports on Next Generation Ground-based Observatories

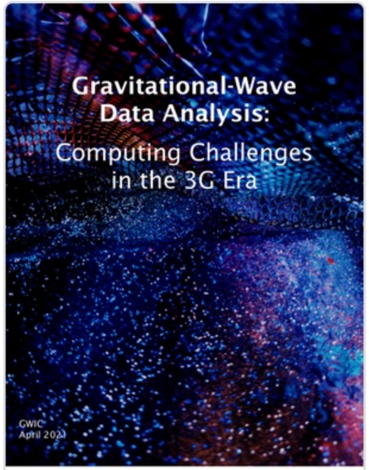


Introduction

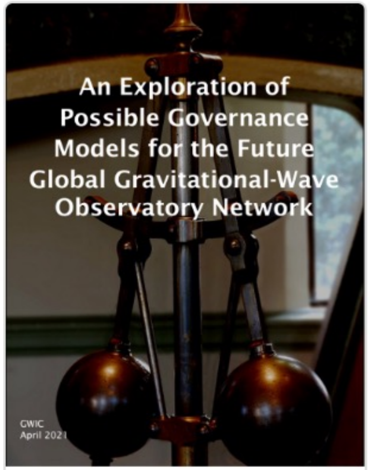


Science

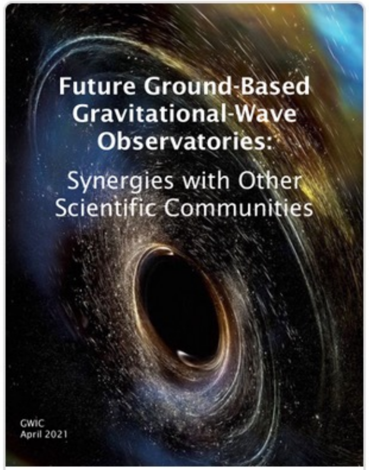
R&D



Computing



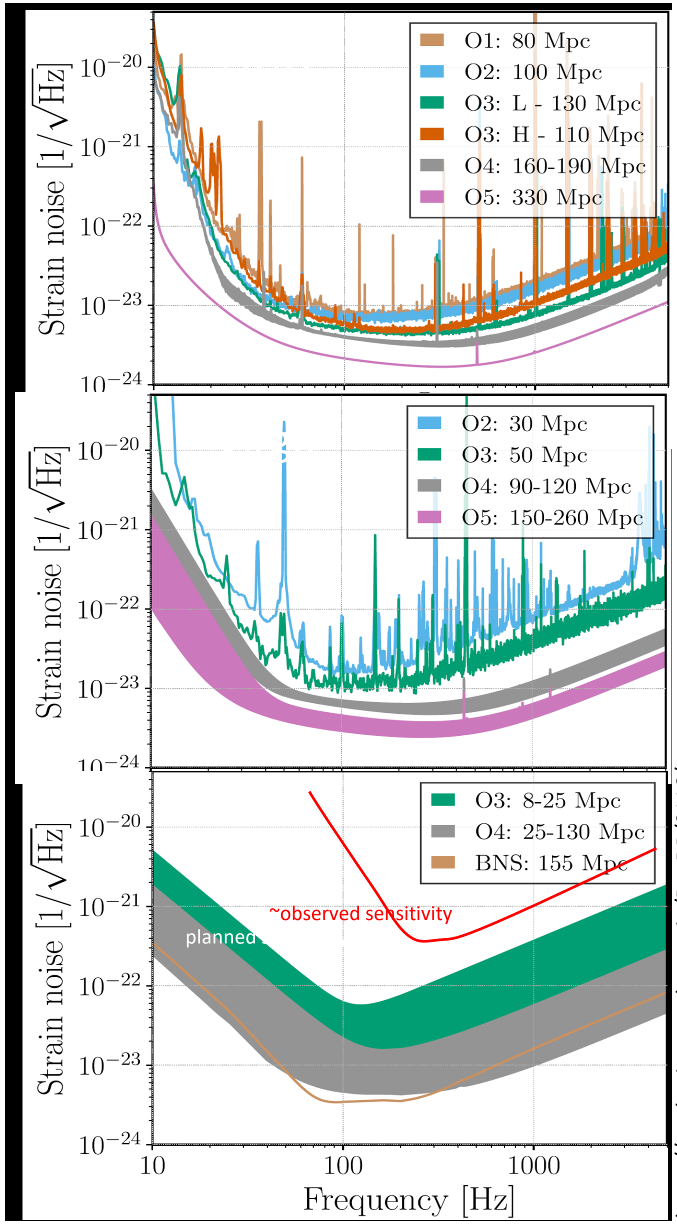
Governance



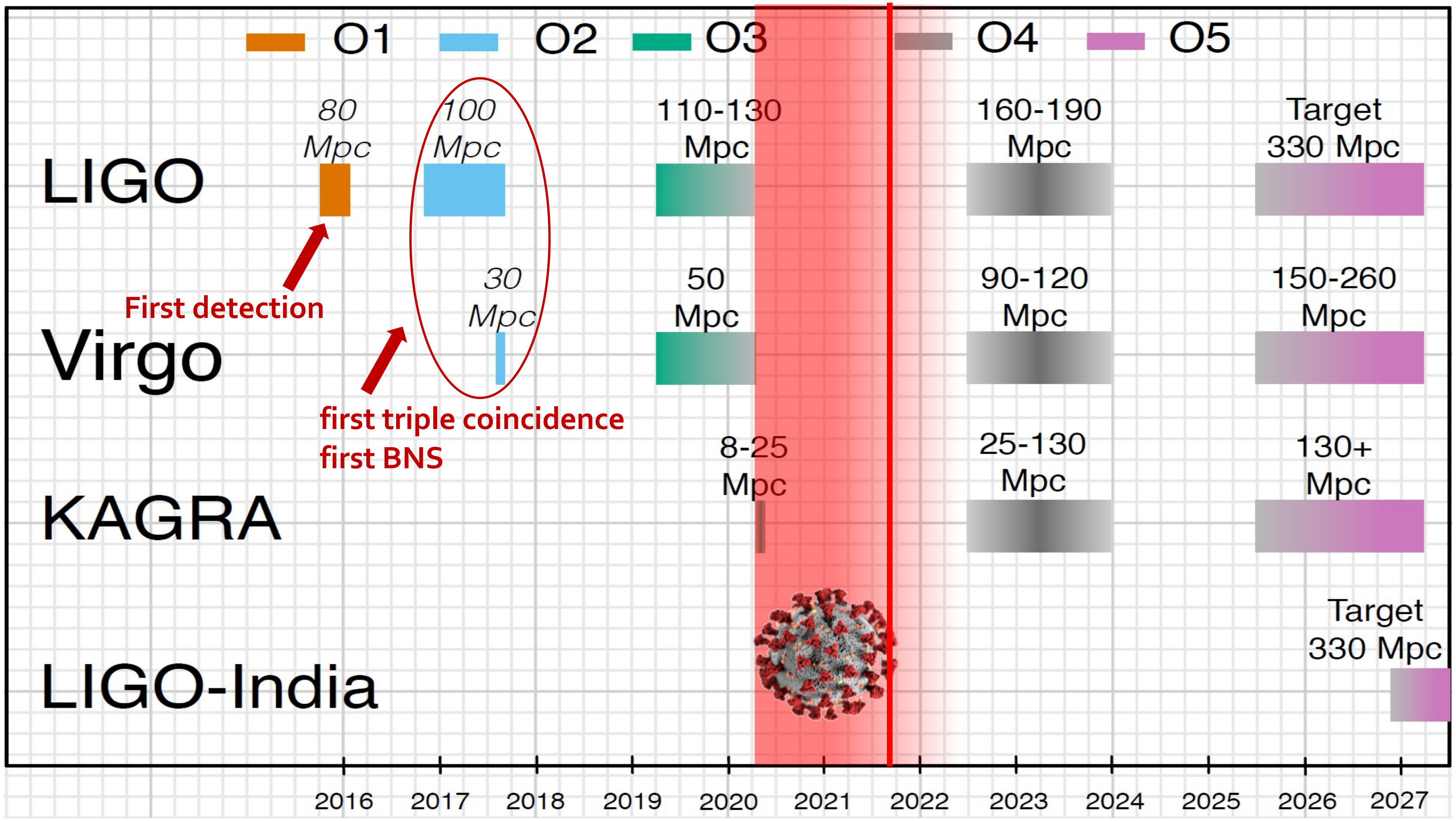
Communities

https://gwic.ligo.org/3Gsubcomm/

LVK Observation runs

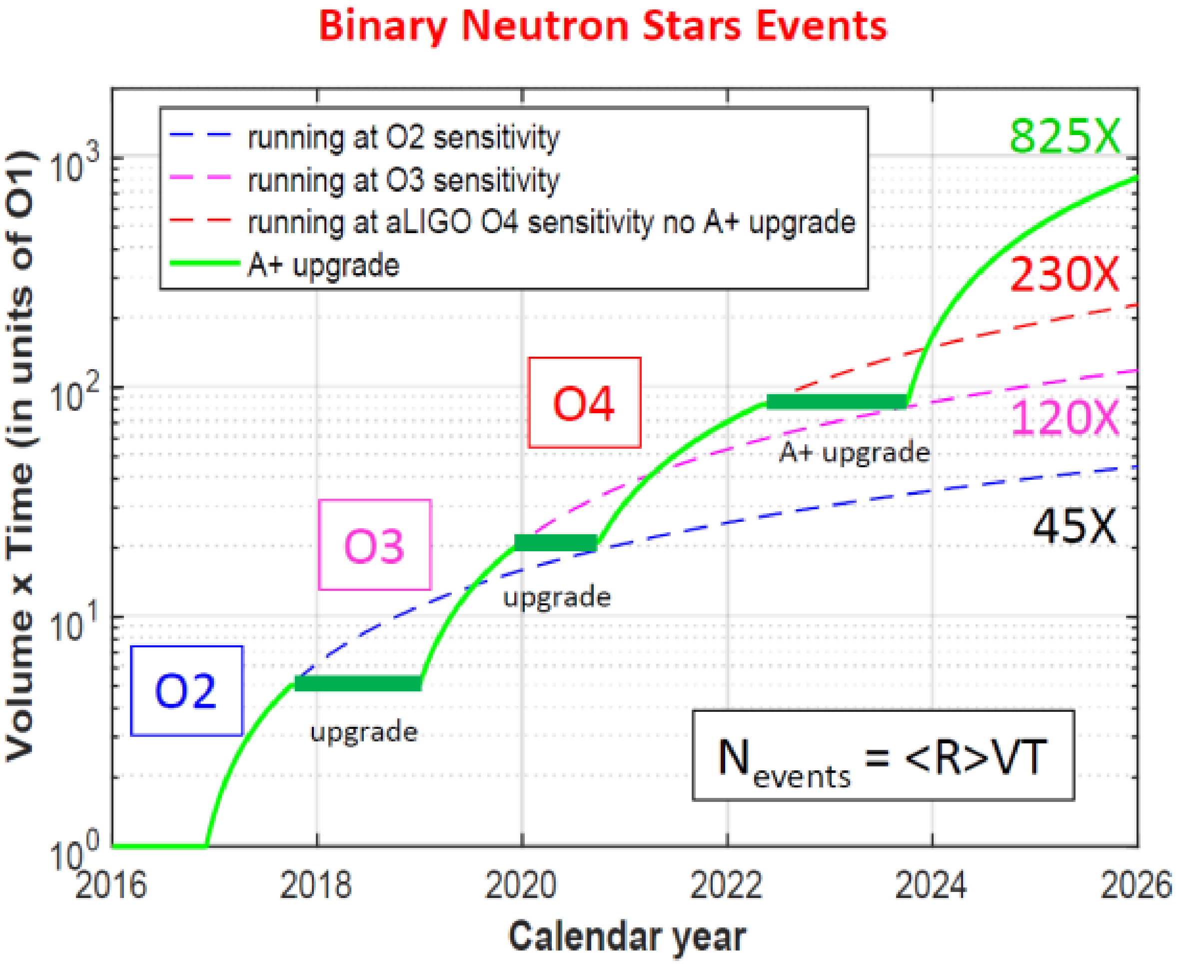


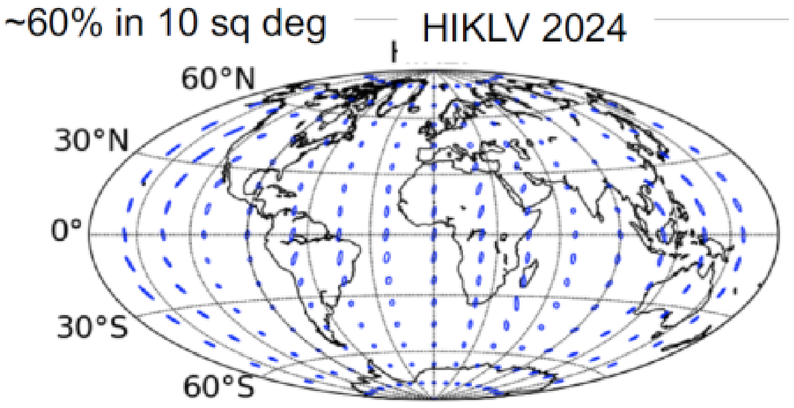
https://gwdoc.icrr.u-tokyo.ac.jp/DocDB/0116/L2011619/003/KSCnewsletter_202004H.pdf

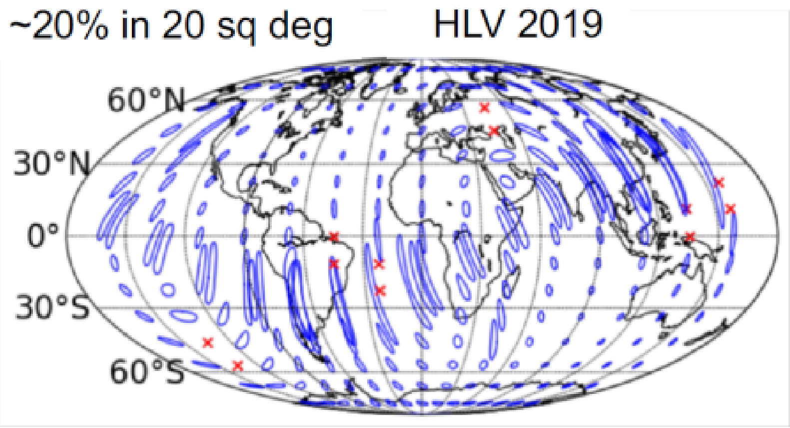


Post O5 planning
= **just started**

Plans for LIGO-KAGRA-Virgo runs



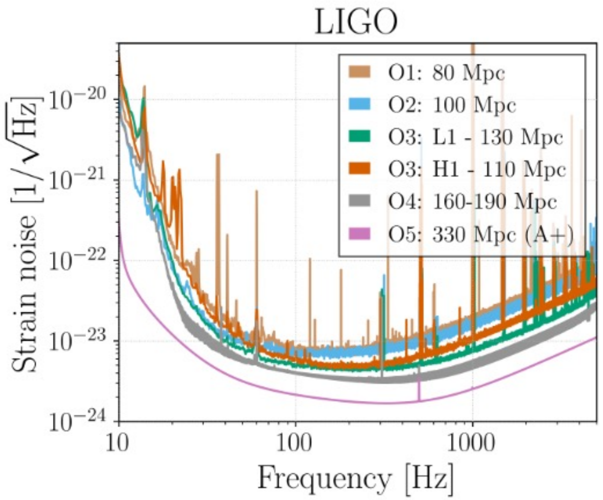


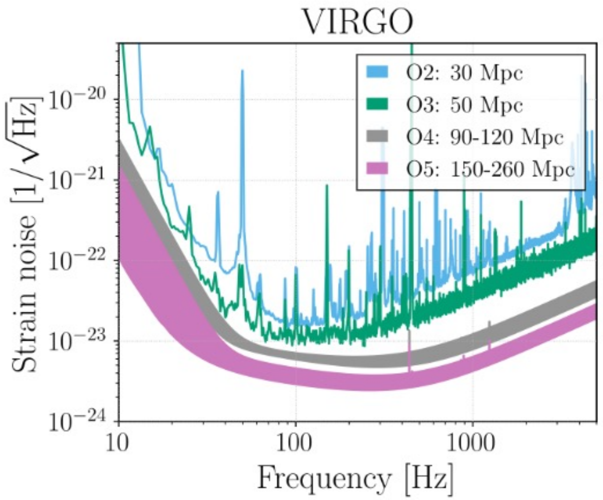


- <R> average astrophysical rate
- V volume of the universe probed → (Range)^3
- T coincident observing time

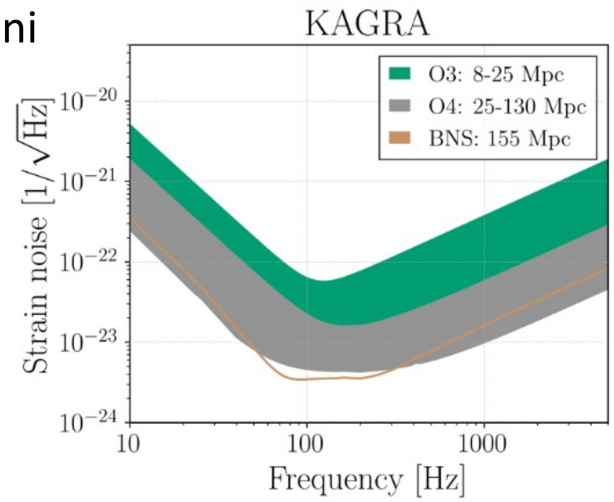
What‘s next ?

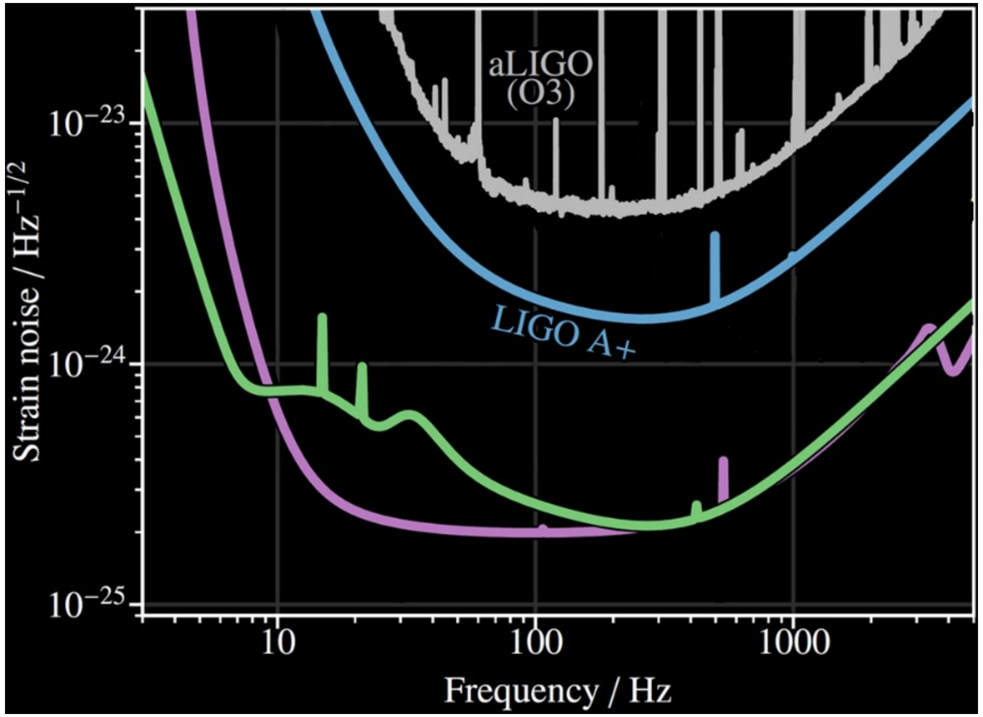
Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA https://doi.org/10.1007/s41114-020-00026-9



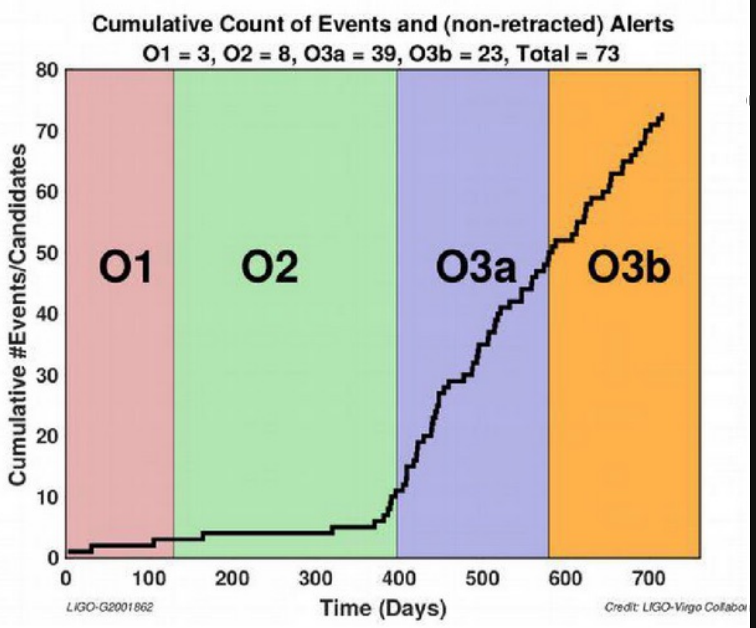


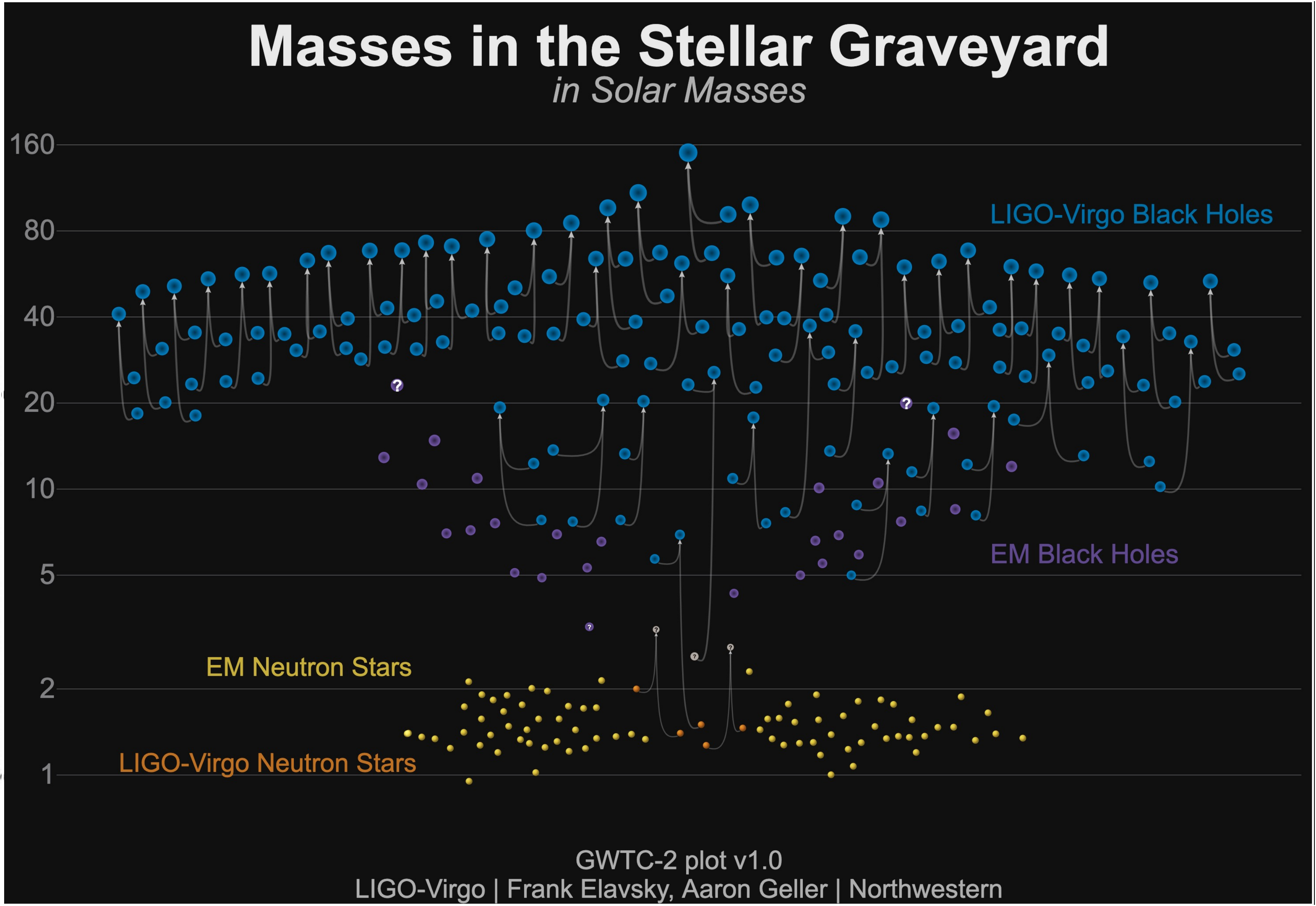
Talk by F. Piergiovanni





Routinely observing compact binary systems !

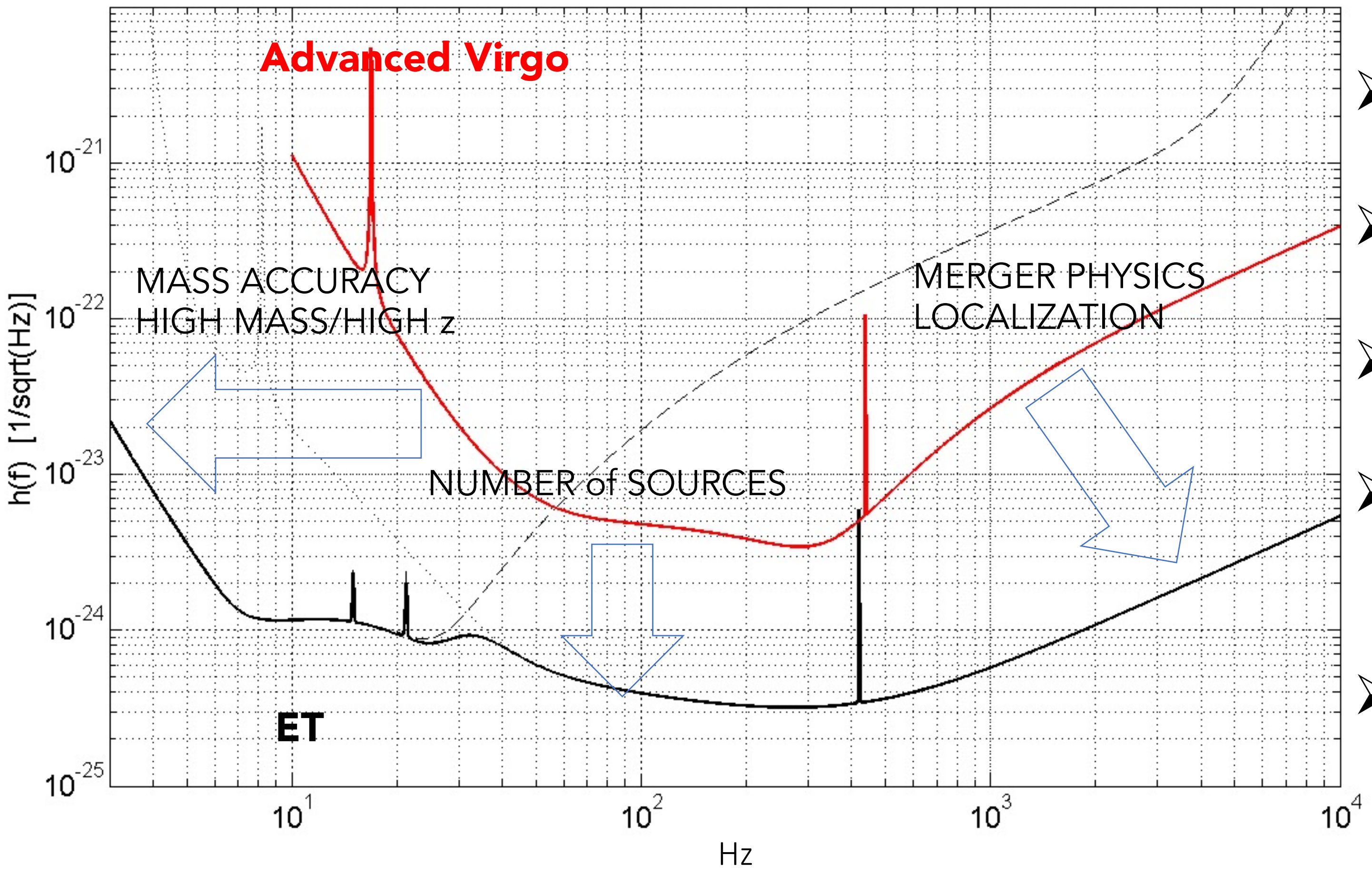




LSC LIGO Scientific Collaboration VIRGO

Slide credit: S.Hild

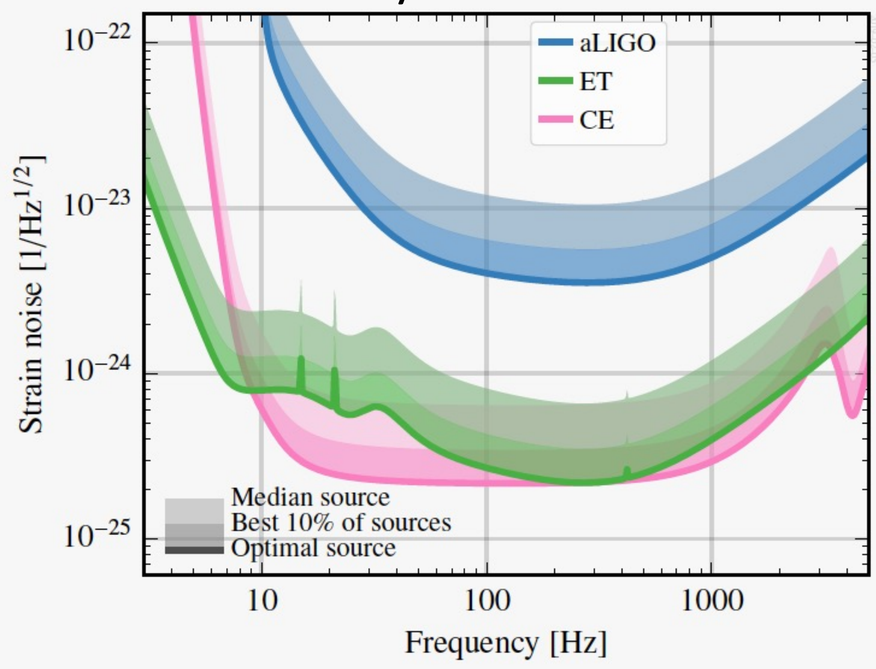
SENSITIVITY GOAL: ~×10-20 better



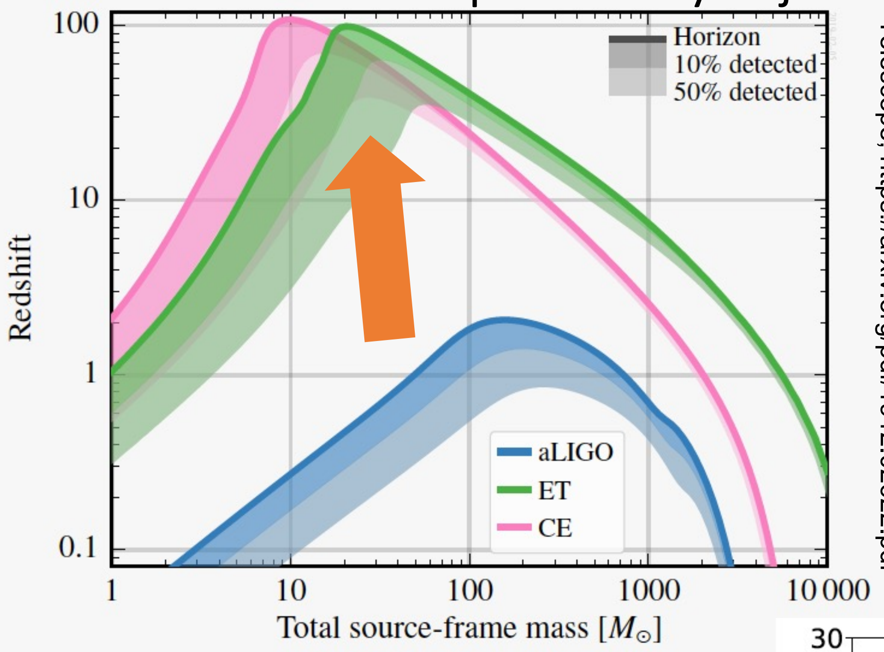
- *Merging Black Holes* ***throughout the whole universe*** and reconstruct BH demography
- Explore *new physics in gravity* and fundamental properties of compact objects
- Study the properties of the *hottest matter* in the universe
- Investigate connection between high *energy processes in radiation/particle VS gravitation*
- *Investigate primeval universe* and connections with particle physics

CBS 10^5 to 10^6 events/year

Strain sensitivity



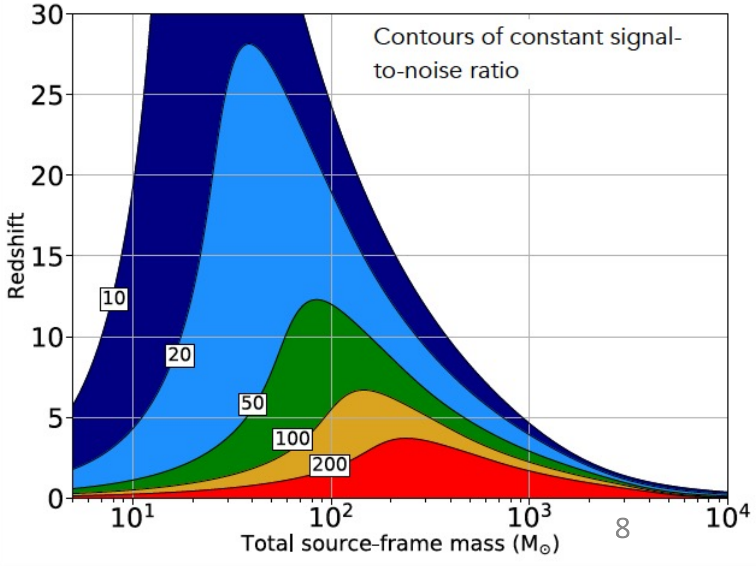
Coalescence of compact binary objects



M. Maggiore et Al. Science Case for the Einstein Telescope, https://arxiv.org/pdf/1912.02622.pdf

Binary Coalescences Overview:

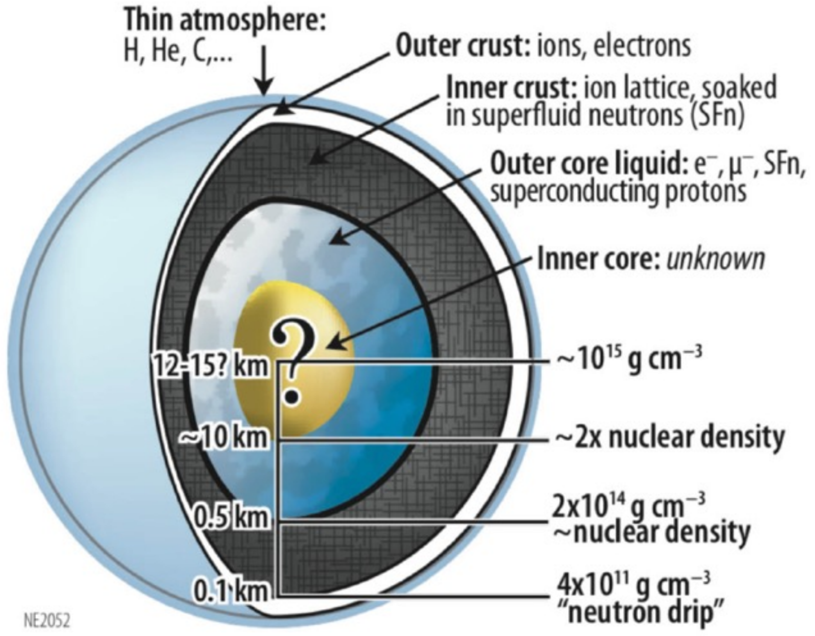
- Demography of stellar and intermediate-mass BBH population over full Universe,
- High SNR events will provide excellent precision to do accurate test of GR, nature of the BH, strong-field dynamics, black hole no-hair theorem etc;
- Observe several 10,000 binary neutron star mergers per year.
- ET will determine NS EOS.

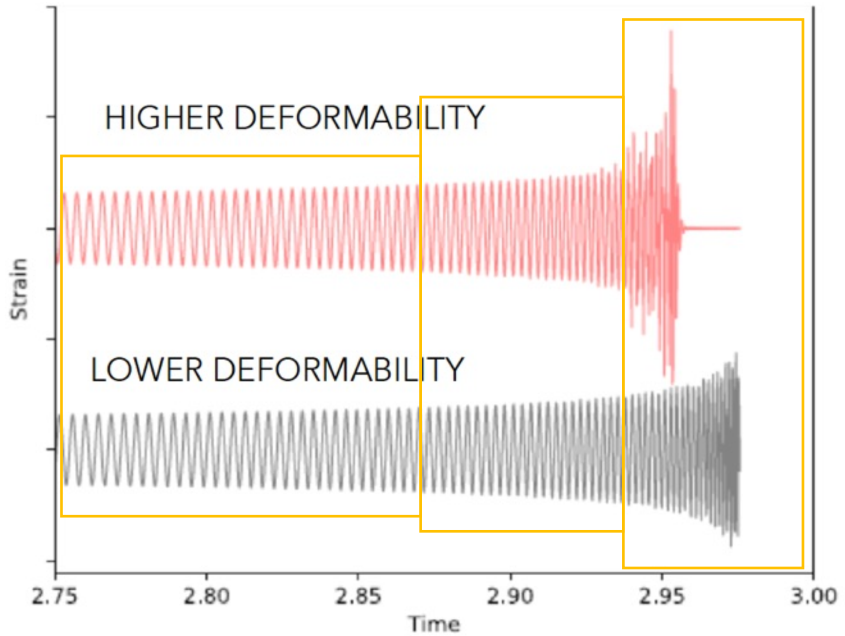


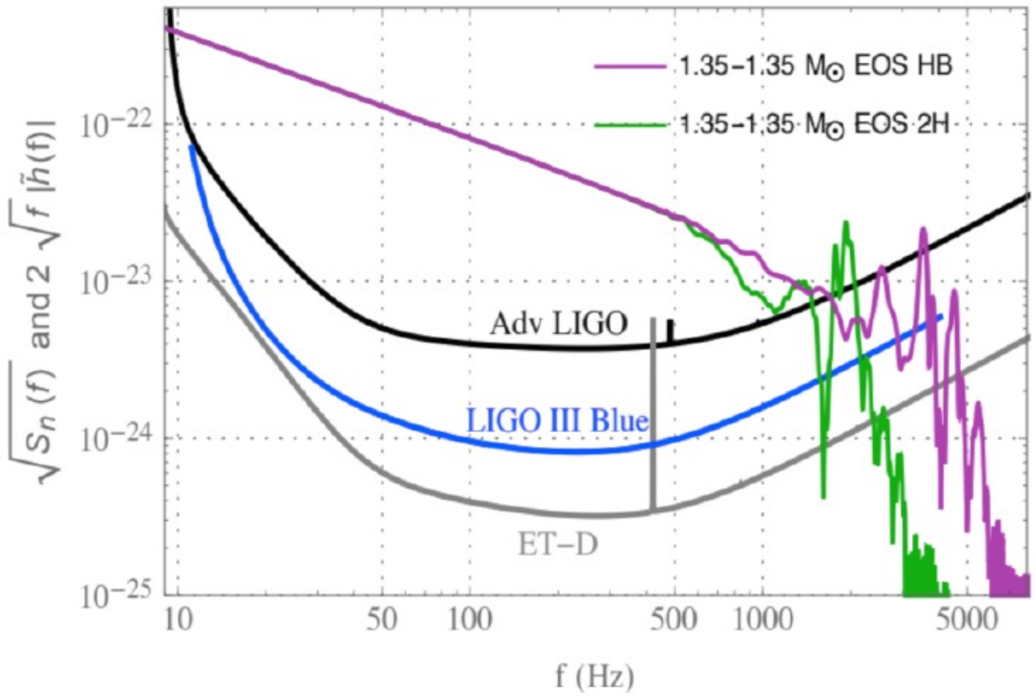
A network of 3 detectors (ET+CENorth+CESouth)

We really need much more to reconstruct NS composition through EOS

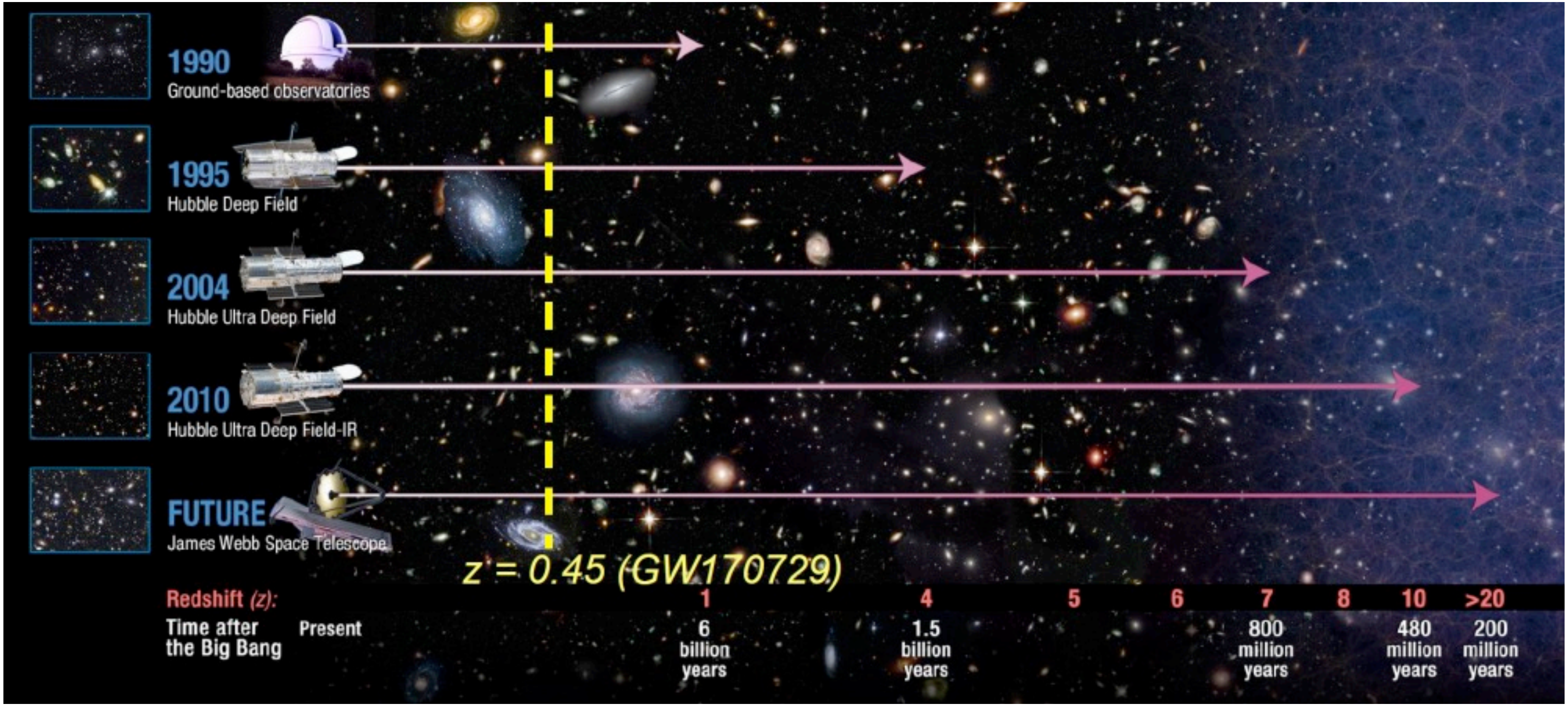
More events, higher sensitivity !







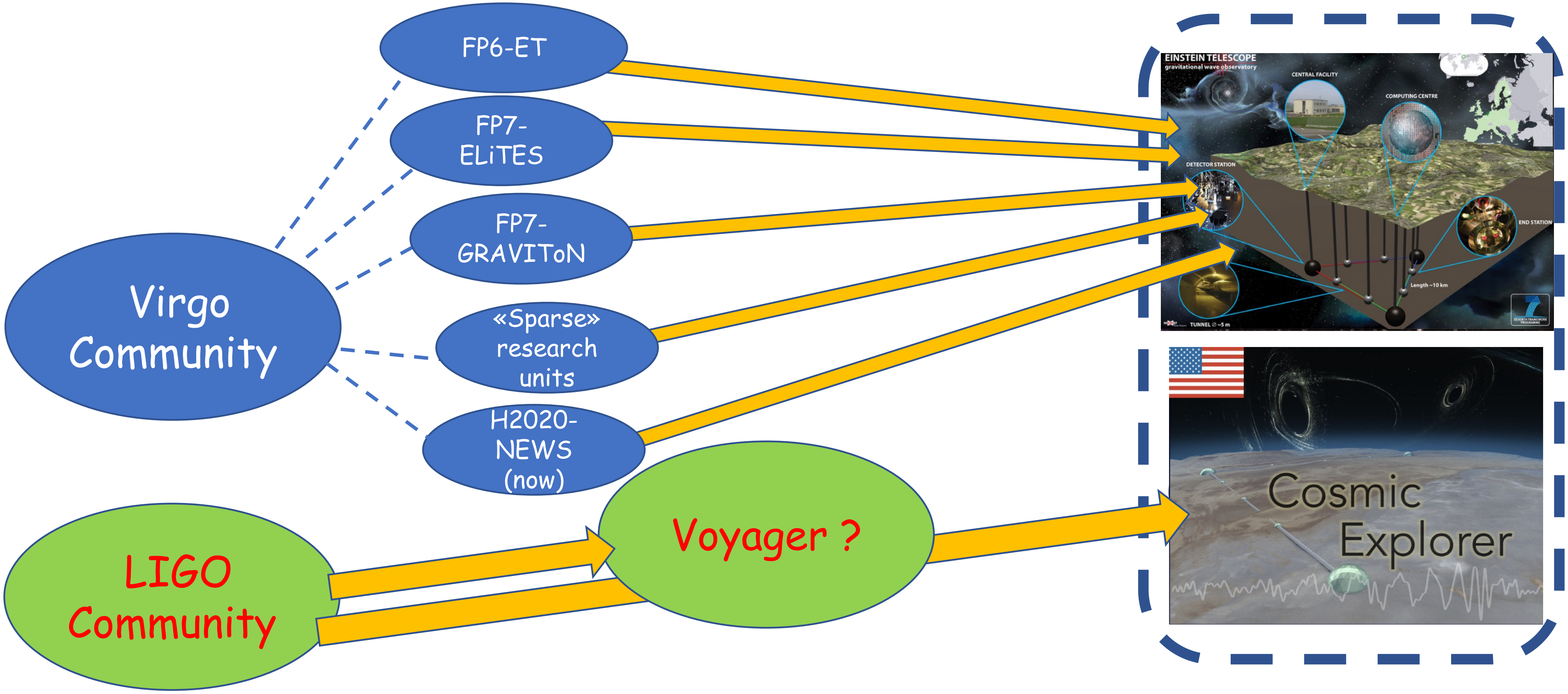
Gravitational Waves ... vs EM telescopes



Can we dare to embrace the whole Universe through GW observations ?

How to: 3G ideas, very different paths in US and in Europe

2nd generation detectors evolution and 3G roadmap: different scenarios in US vs Europe in the last decade

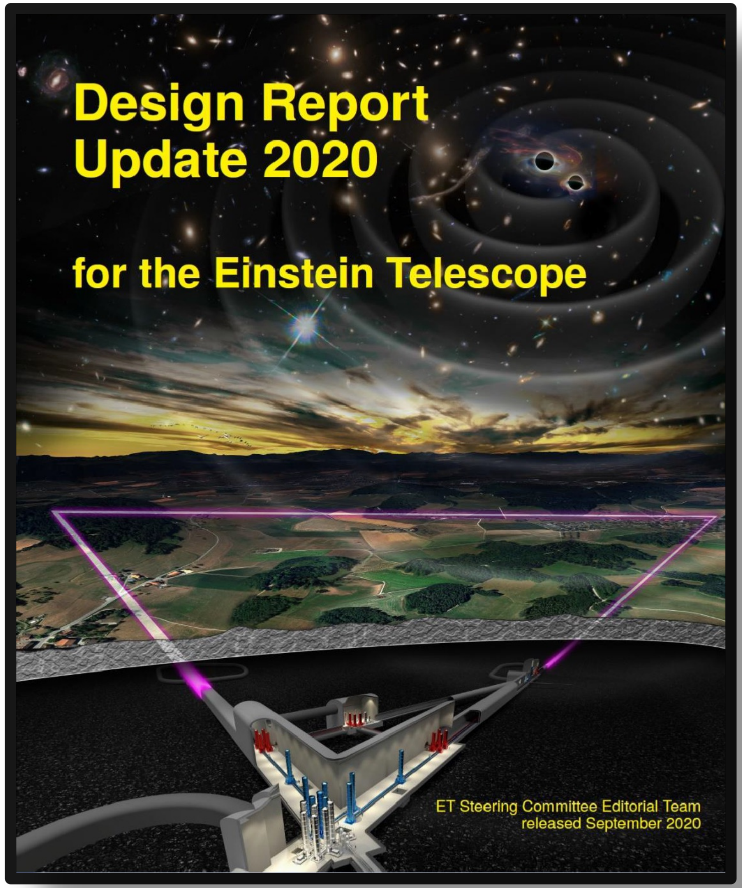


Conceptual Design Studies

https://tds.virgo-gw.eu/?call_file=ET-0106C-10.pdf

https://apps.et-gw.eu/tds/?content=3&r=17245

ESFRI



- In 2020 governments of 5 EU countries (Italy, the Netherlands, Belgium, Spain and Poland) submitted the ET application to ESFRI (European Strategy Forum on Research Infrastructure).
- July 2021 ET obtained ESFRI status, as the highest value project ever to feature on an ESFRI roadmap.

- **Constitution of the ET collaboration**
- **Site definition (2024)**

ET collaboration current organisation

ESFRI

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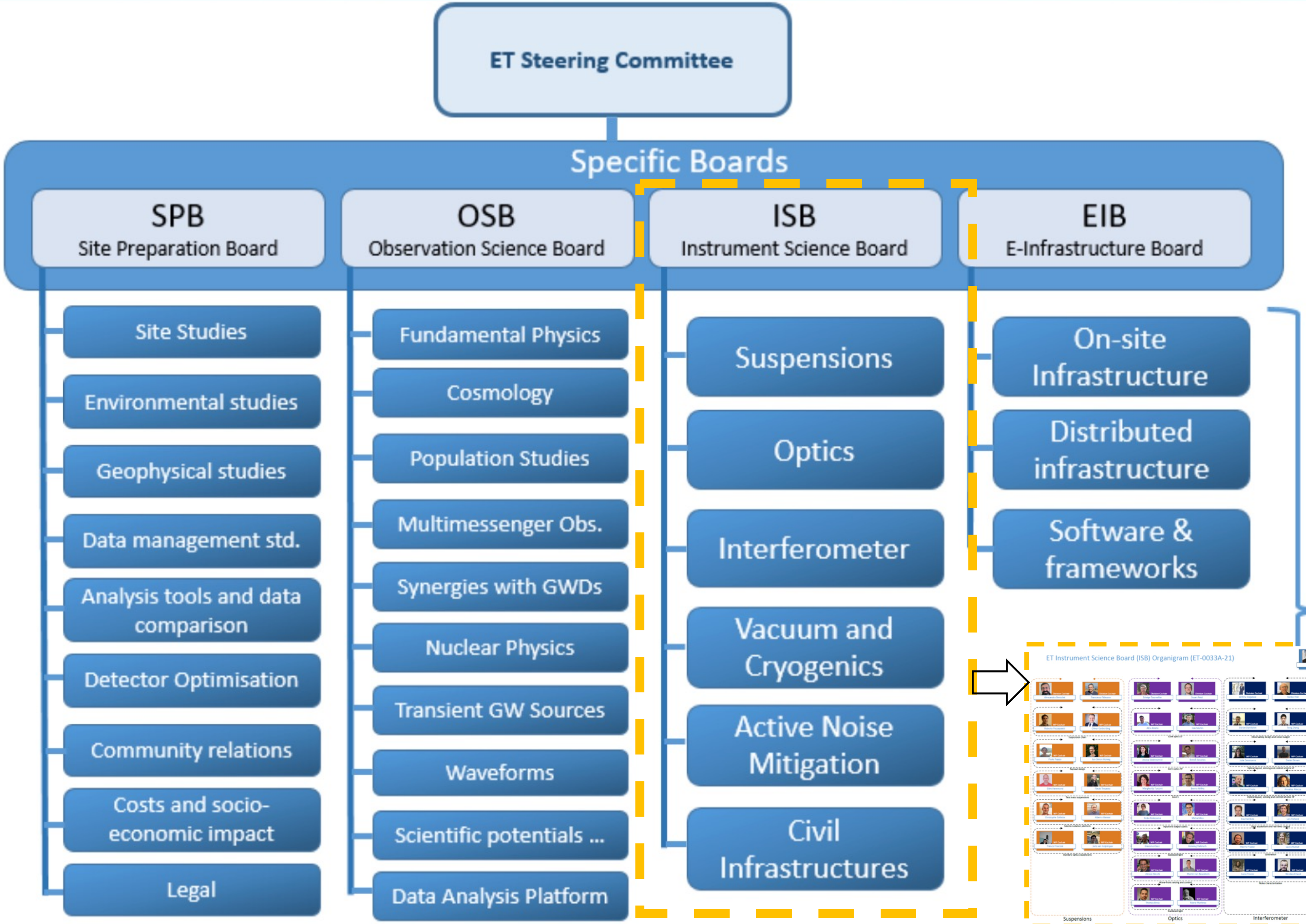


The proto-collaboration is currently the most organised component of the ET project

- All the **four** trees are **pro-active**
- The path from a concept design to a Technical Design is long and treacherous
- Though a mature experience with present detectors most of the main aspects to improve the sensitivity require R&D

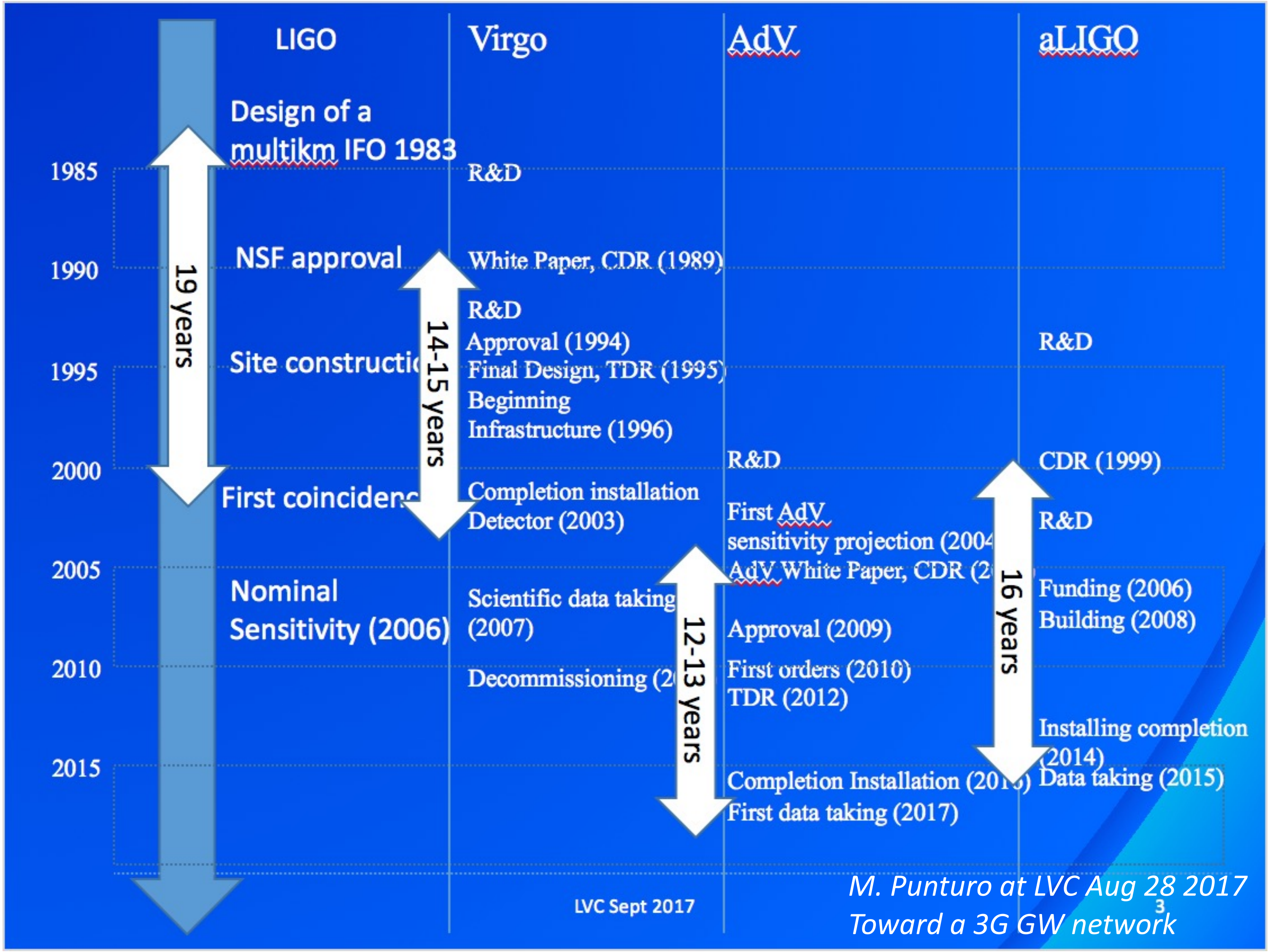
Typical Timelines, an history/disclaimers

- GW detectors are scientific infrastructures with a long “time constant”
  - Ideas in the ’70s
  - Projects in the ‘80
  - 1G integration, end of ‘90s
- The typical time constant (CDR-to-realisation) for a GW detector is about 14-16 years

➔nowadays how long building a 2G detector would it take ? (INDIGO approval 2016)

➔Something has to change !
❖Infrastructure is the main issue
❖Timeline to have the whole ITF in high sensitivity operation

❖Who produces scientific data meanwhile?



ET, the European 3G idea

ET EINSTEIN TELESCOPE

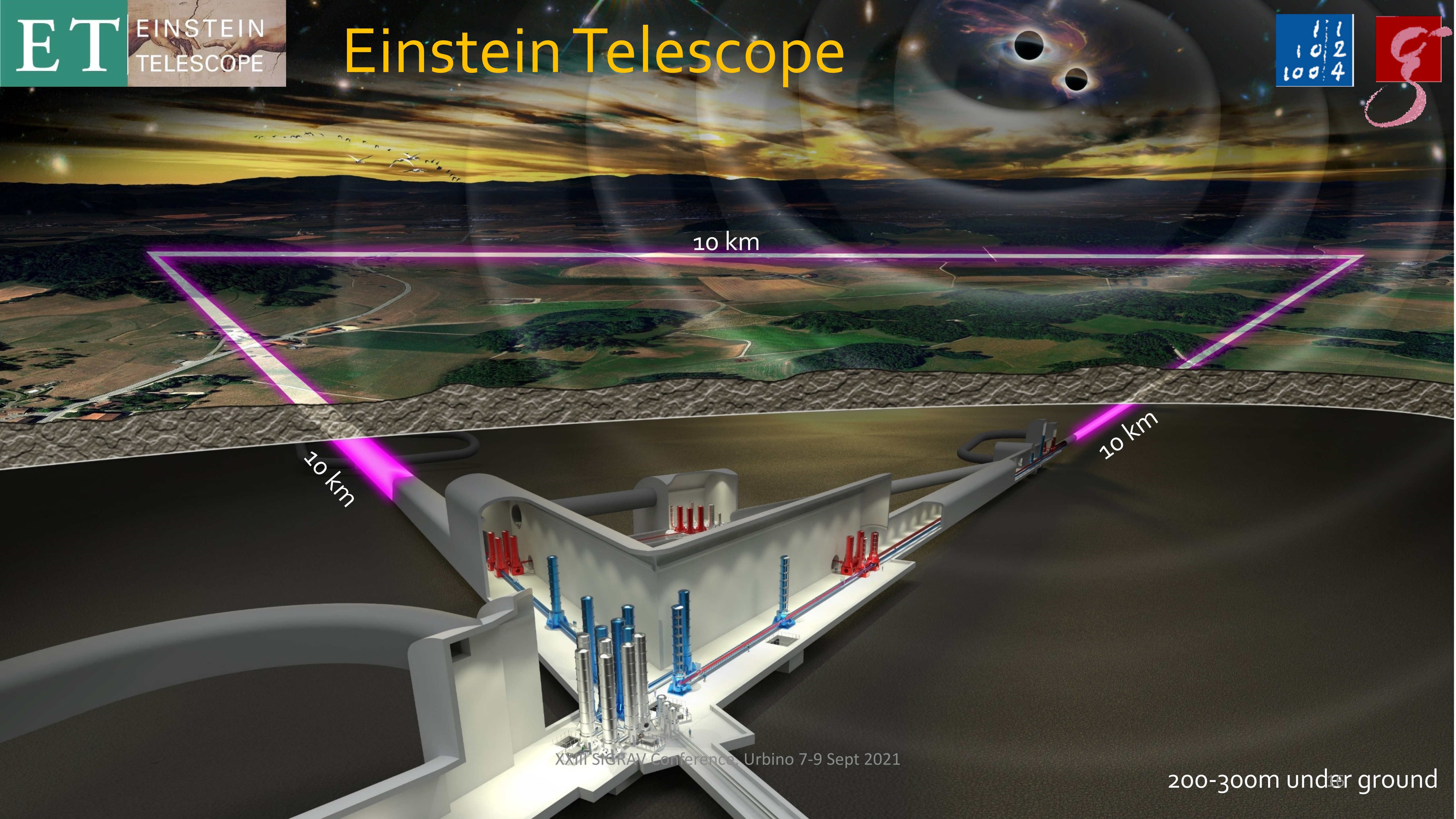
- The 3G detector conceived in Europe is a new GW observatory
  - 3G: Factor 10-20 better than advanced (2G) detectors
  - New:
    - We need a new infrastructures because
      - Current infrastructures will limit the sensitivity of future upgrades
      - In 2030 current infrastructures will be obsolete
  - Observatory:
    - Wide frequency range, with special attention to low frequency (few Hz)
      - LF and HF technologies separated
    - Capable to work alone and produce science results (though aiming to be in a 3G net)
      - (poor) Localization capability
      - Polarizations (triangle)
      - Redundancy
    - 40-50-years lifetime of the infrastructure
      - Compliant with the upgrades (a big-science facility)

Cryo-LF/QNR techniques

Standalone operation for localization is now unconceivable

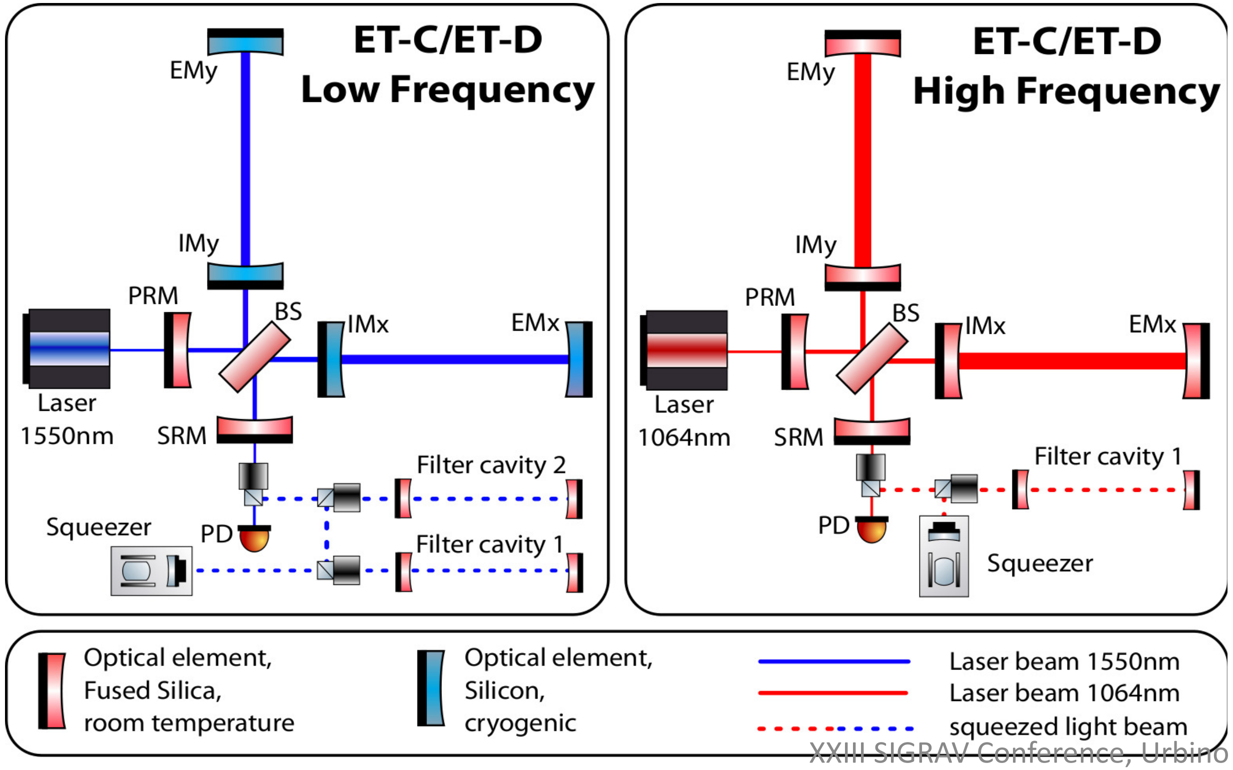
ET was born as a triangle

Einstein Telescope



Concept1 - Detection band widening: two instruments in one

- Improving low and high frequency with a single detector is very challenging
  - HF requires more laser power
  - LF requires cold mirrors (suspension thermal noise)
- 2 "specialized" instruments in one: a very wide detection bandwidth



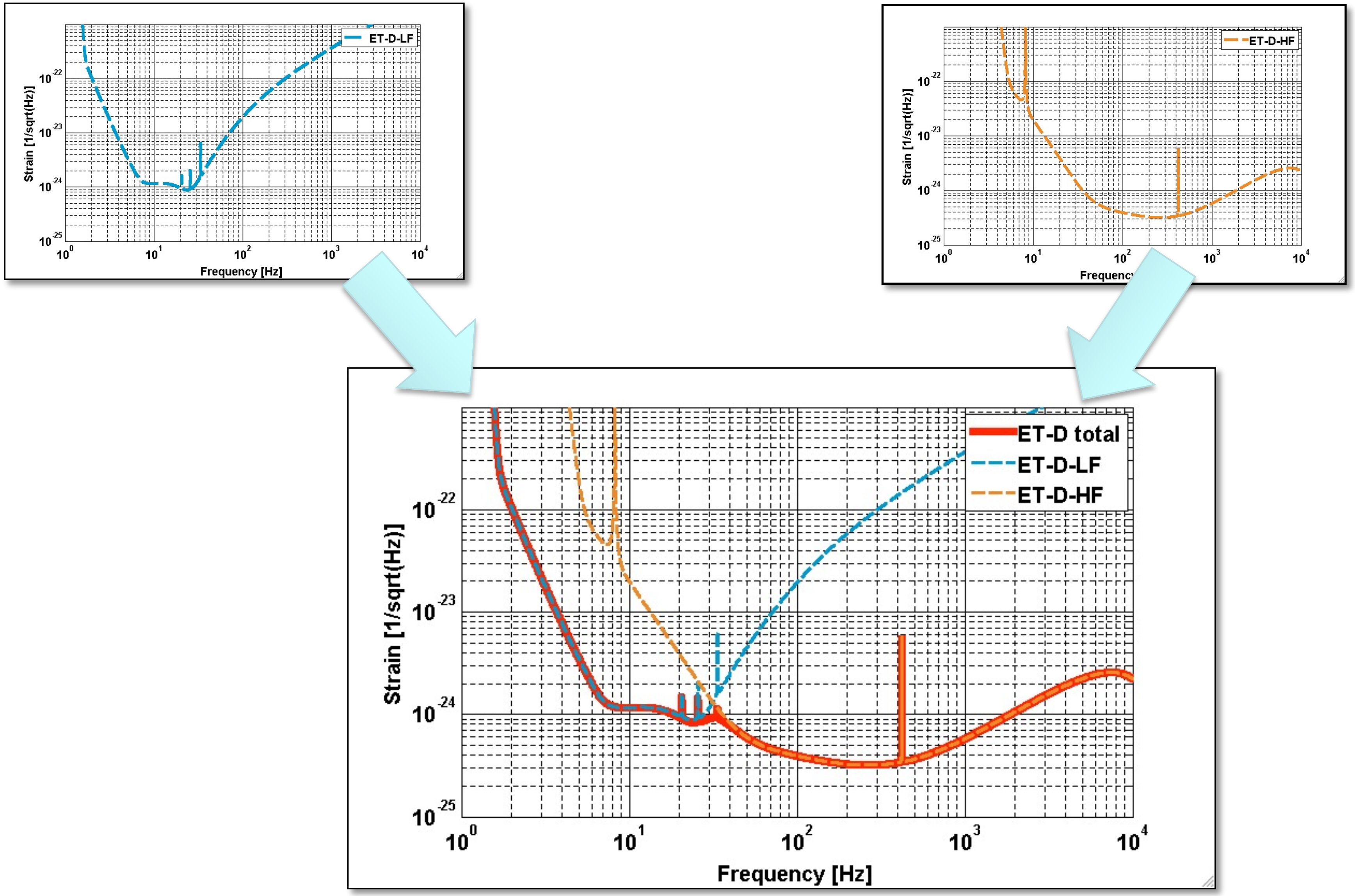
Efforts with one detector imply

- Technical issues
- Constrains on detectable sources

The "too-short-blanket" and optimization of a single detector(excercize done by KAGRA)

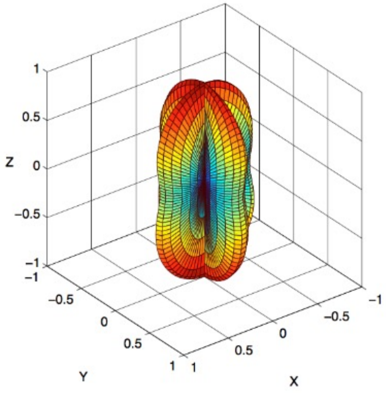
Y. Michimura et al., *Particle swarm optimization of the sensitivity of a cryogenic gravitational wave detector* Phys. Rev. D **97**, 122003 – Published 12 June 2018

"hybrid detector" principle

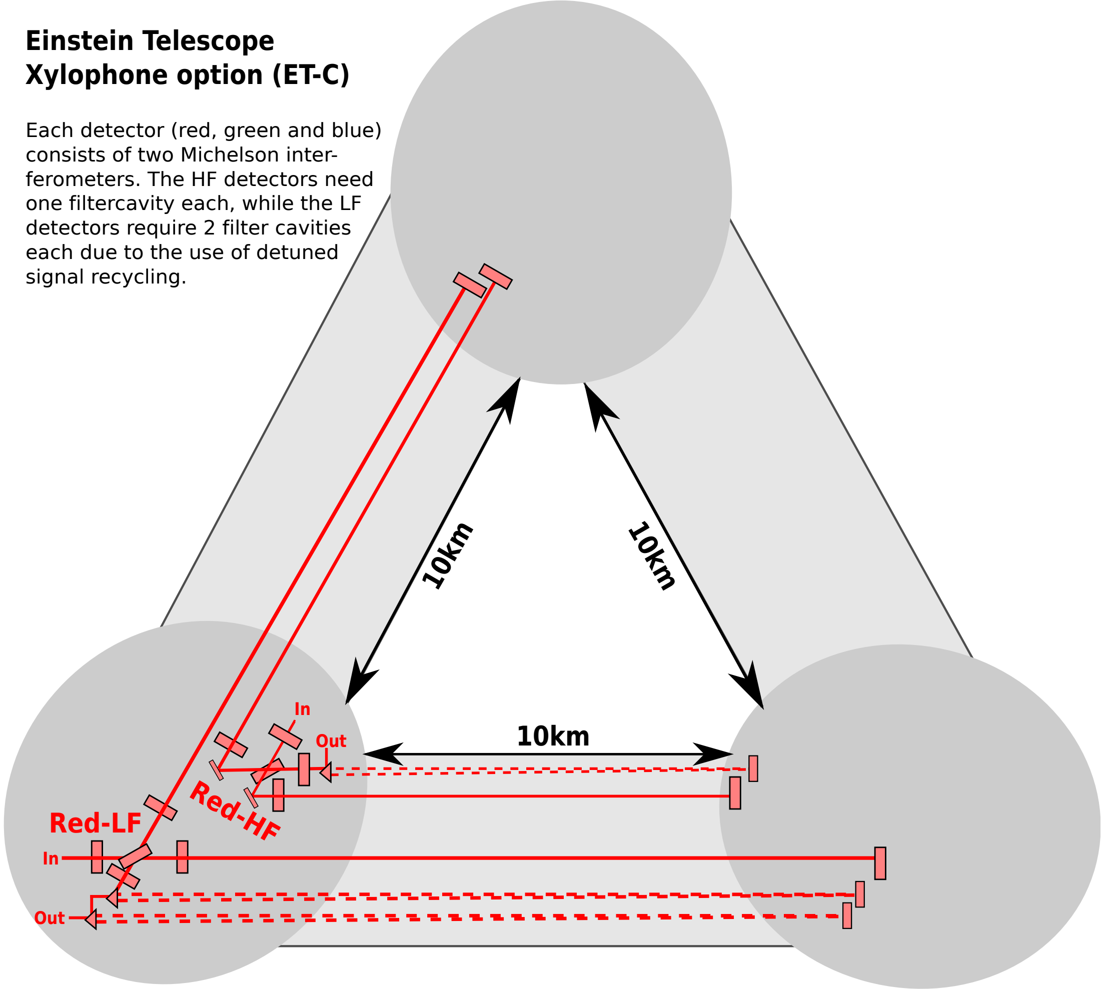


The path towards a "STAND-ALONE OBSERVATORY"

- Start with a "single" hybrid detector

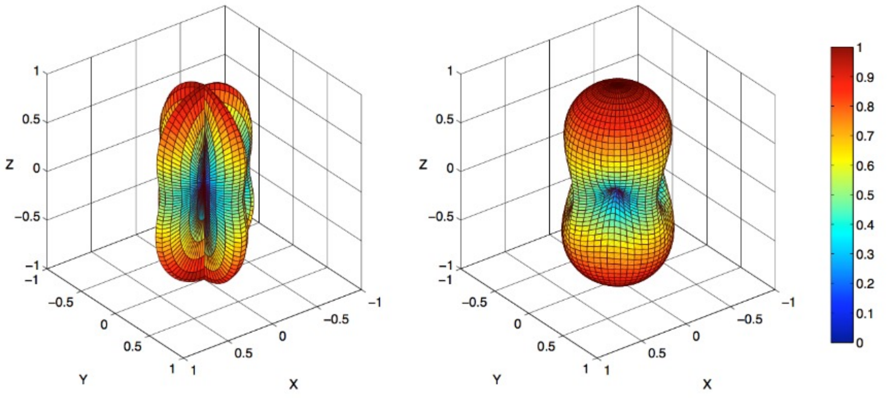


Antenna pattern (*in case of a 90deg L)

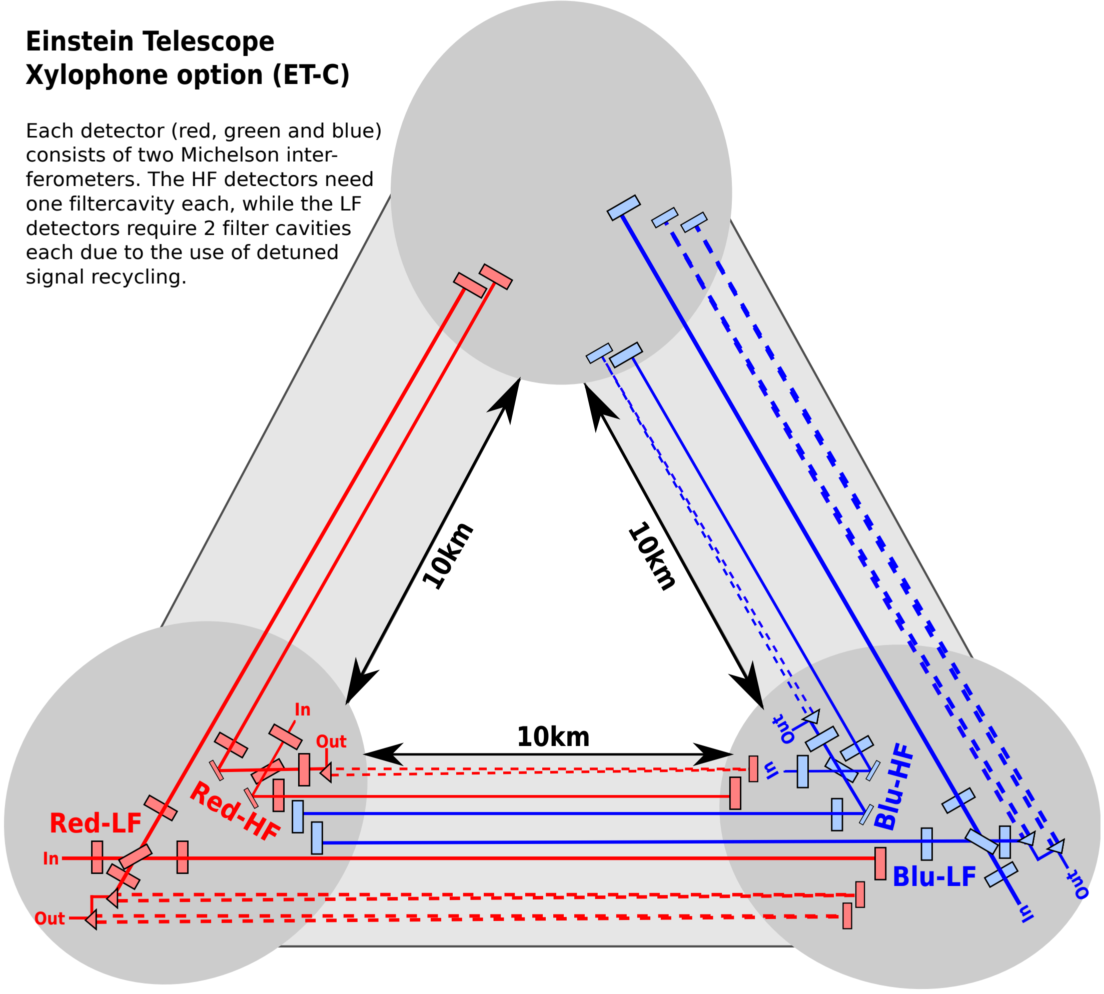


The path towards a “STAND-ALONE OBSERVATORY”

- Start with a “single” hybrid detector
- Add a second one to fully resolve polarizations



Antenna pattern for a polarized GW: simple “L” (left) vs Triangle (right)

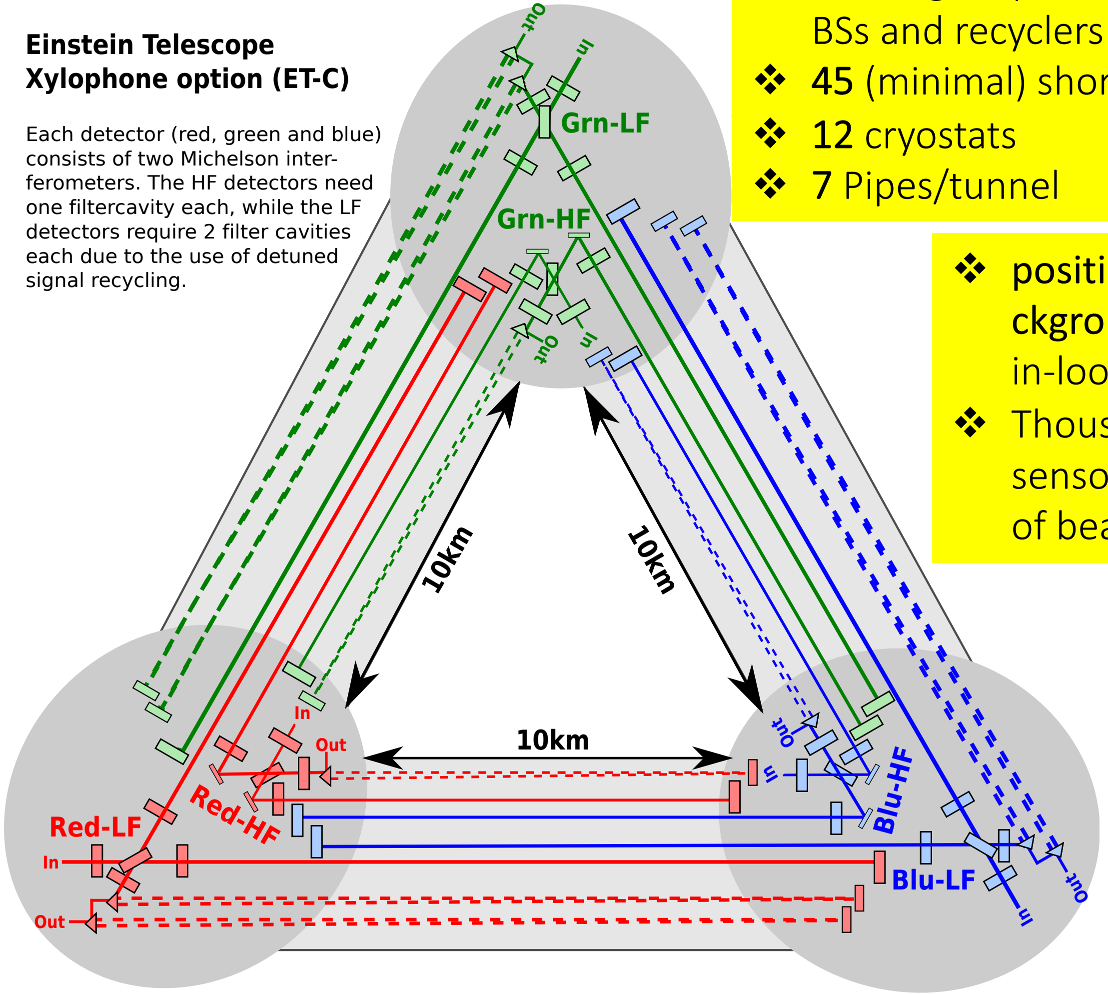


...Finally, “STAND-ALONE OBSERVATORY”

- Start with a “single” hybrid detector
- Add a 2nd one to fully resolve polarization
- Add a 3rd one for null stream (A. Freise et al 2009 Class. Quantum Grav. 26 085012)
- and redundancy

Einstein Telescope Xylophone option (ET-C)

Each detector (red, green and blue) consists of two Michelson interferometers. The HF detectors need one filtercavity each, while the LF detectors require 2 filter cavities each due to the use of detuned signal recycling.



Minimal numbers

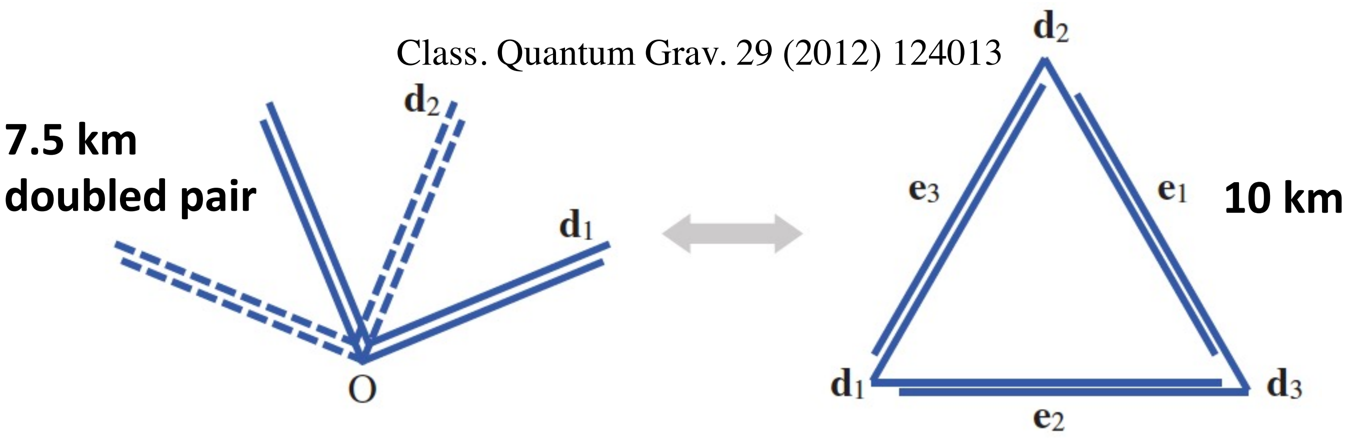
- 21 Long suspensions for Test masses BSs and recyclers (signal and power)
- 45 (minimal) shorter towers
- 12 cryostats
- 7 Pipes/tunnel

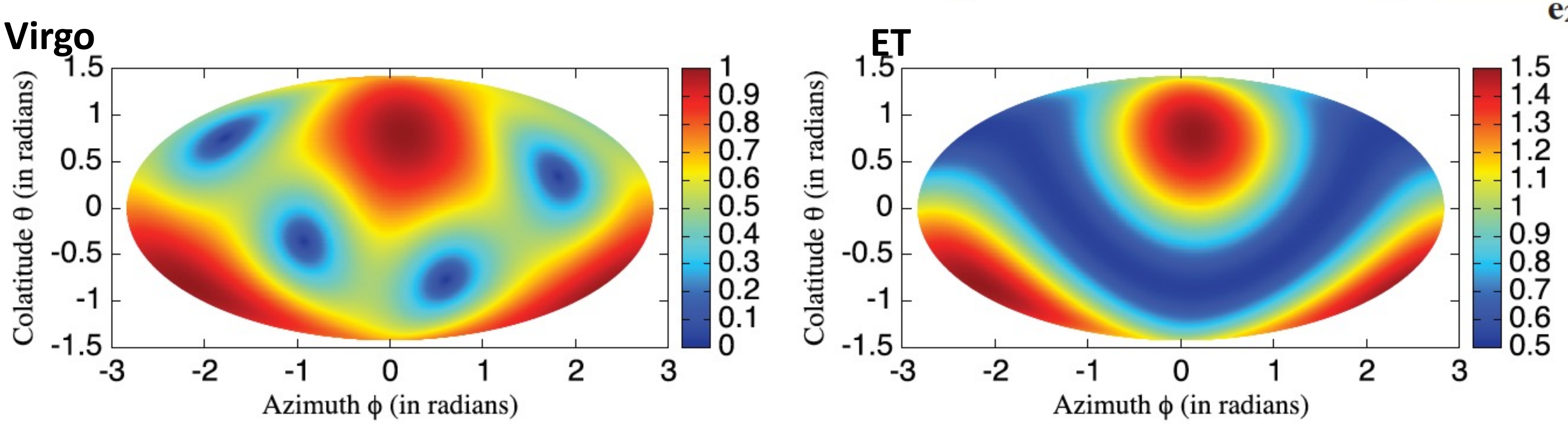
- **position/acceleration/background:** thousands of in-loop sensors for
- Thousands of global sensors for optical D.O.F of beams

3D is not simply a rescaling: the triangle/L debate

Triangular or L ?

Class. Quantum Grav. 29 (2012) 124013

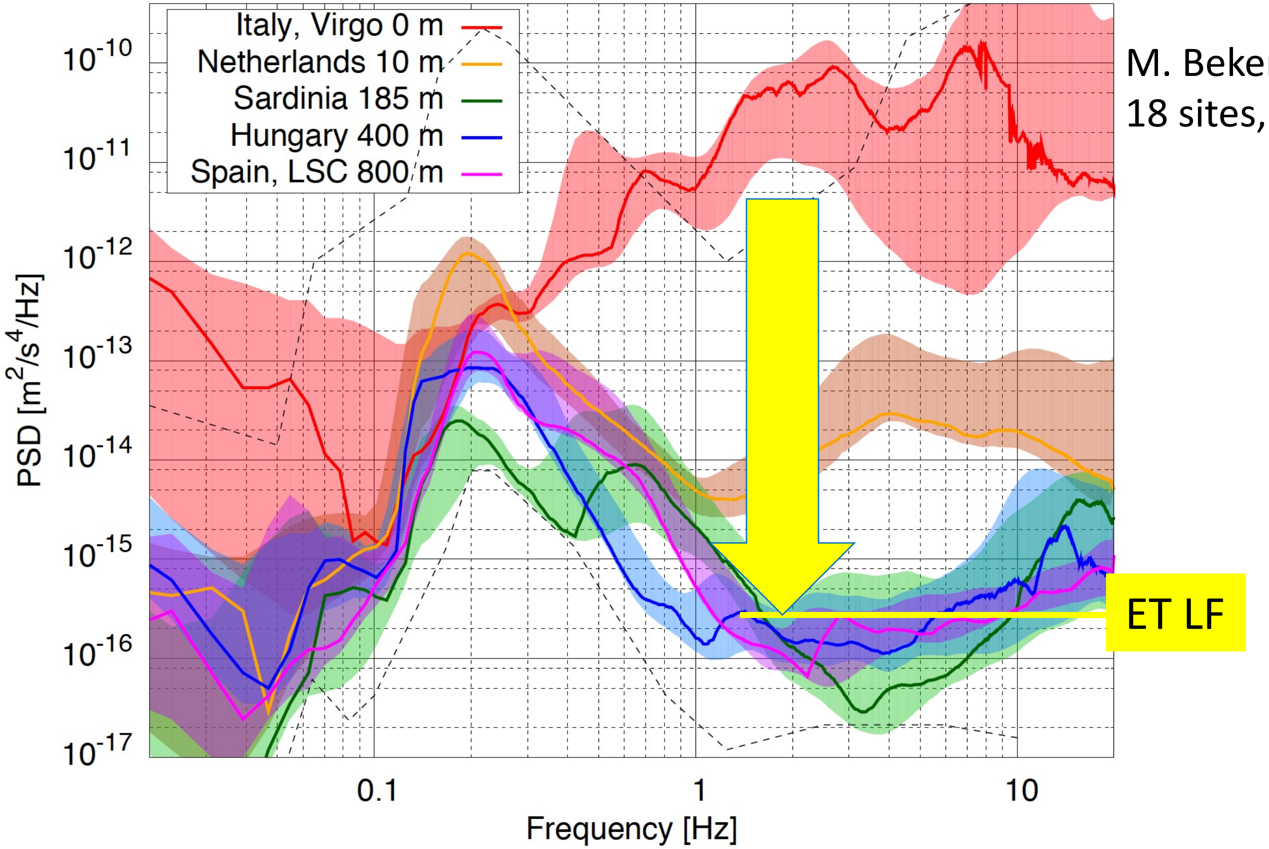




- Characteristics of a triangular array : sum of outputs depends only on background noise
- Reconstruction of signal **polarizations** and **null stream veto**
- Two L shaped arrays (misaligned) **do not provide null stream veto**
- For two L shaped interferometers a wide separation would be essential ➔ localization
- **ET reference solution is a triangle, but** cost/feasibility/network studies still going on.

Concept2 – Where: Underground

The site, an open issue… slowly converging



M. Beker exploration 2013:
18 sites, 12 underground: preliminary selection

Serval possible sites in the world. Site selection started long ago, seismic aspects are not the whole story

Many other ingredients: Anthropogenic vibrational noise, overall cost of the infrastructure, its servicing and operation, national impact of the enterprise, social and economical impact of the area …

SPB: ET sites under characteri

Euregio Meuse-Rhine

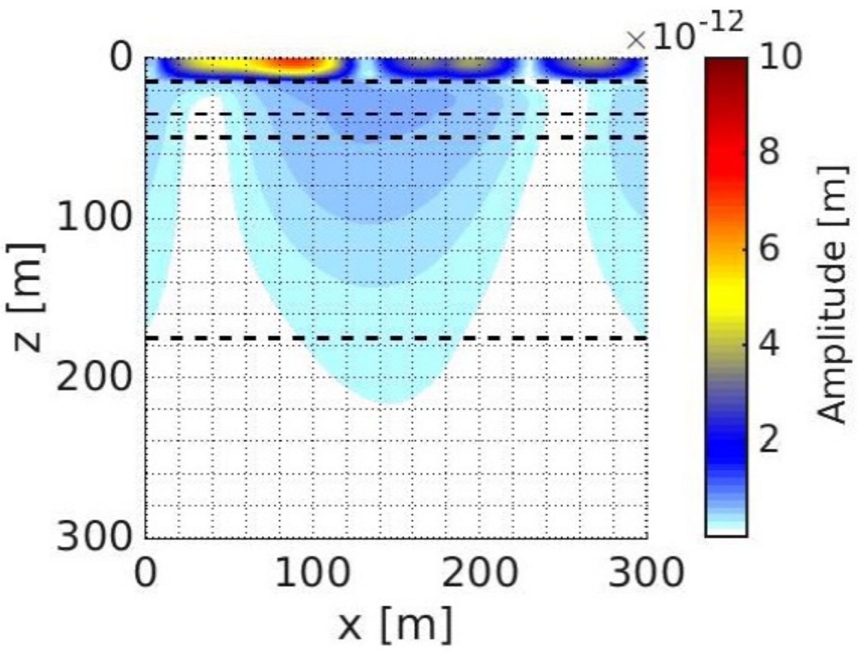
- A 250-m deep borehole has been excavated and equipped
  - Seismic data under acquisition and analysis
- 3-5 other boreholes expected
- Extensive active and passive site characterisation with sensor arrays in 2021
- Good seismic noise attenuation given by the particular geological structure
- ET pathfinder centre under construction
- ~30M€ funding through Interreg grants

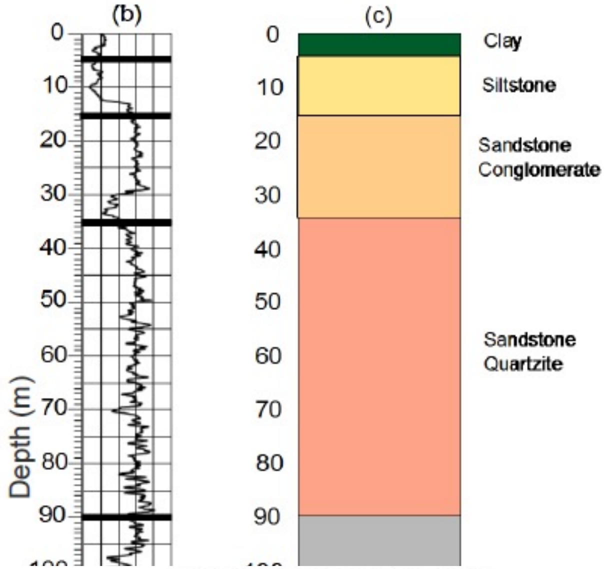
Sardinia

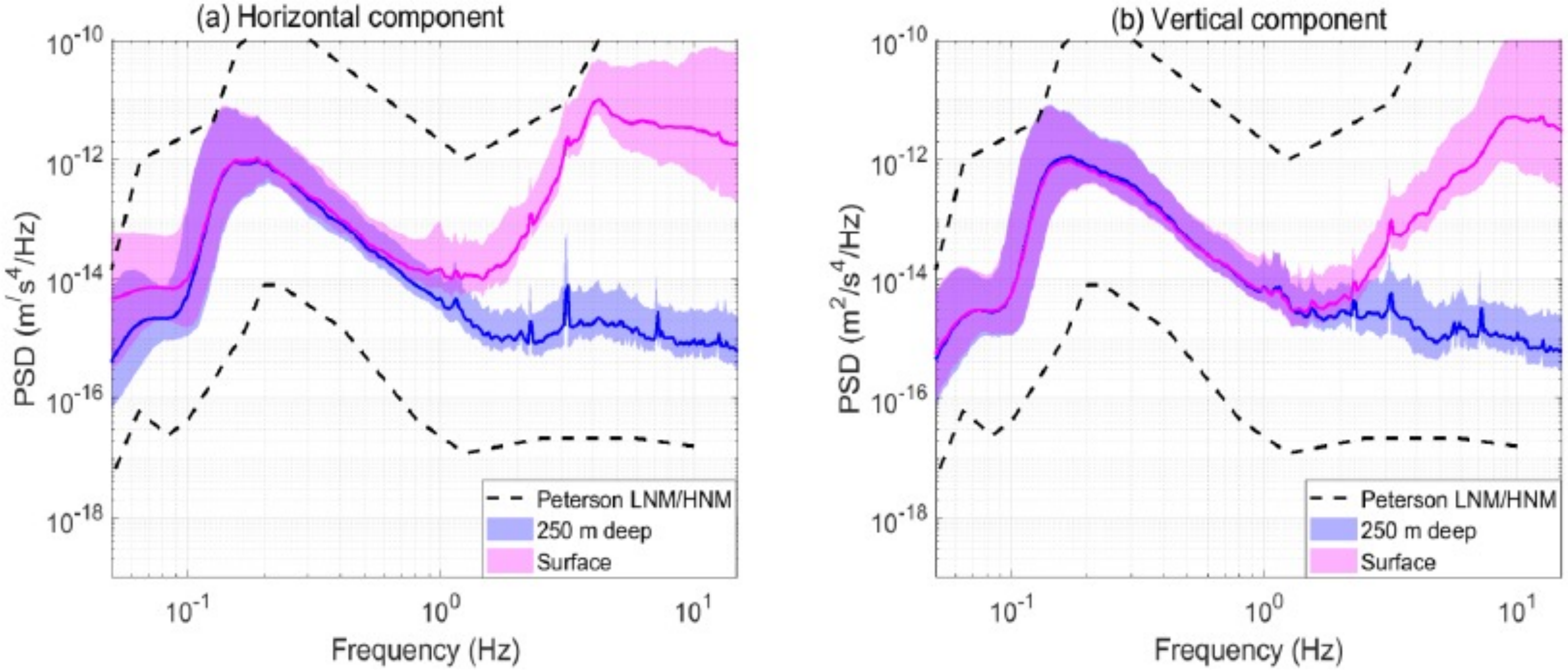
- Long sta
  mine in
  - Seism
    chara
    the m
- Undergr
  construc

- Two ~290m boreholes have been excavated and they will be equipped in the next weeks
- Intense & international surface investigations programme in Summer/Fall 2021
- ~30M€ funding through national and regional funds

Euregio Meuse-Rhine site (Terziet)







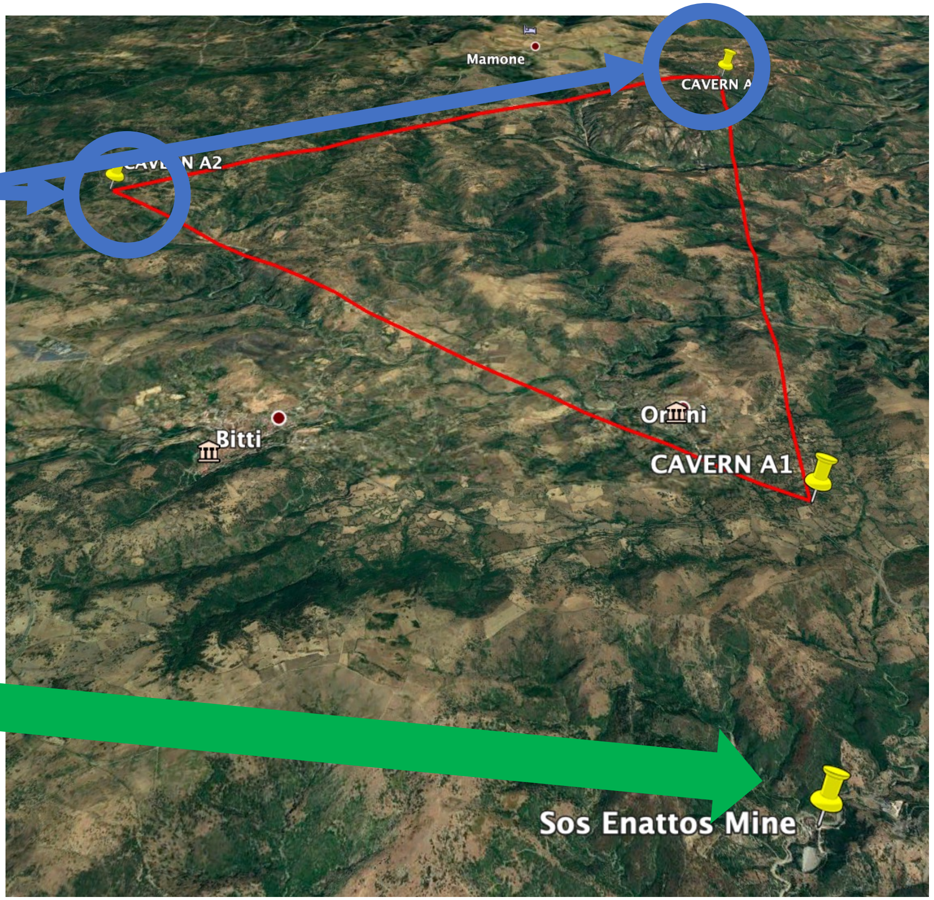
Credit: S. Koley, GWADW 2021

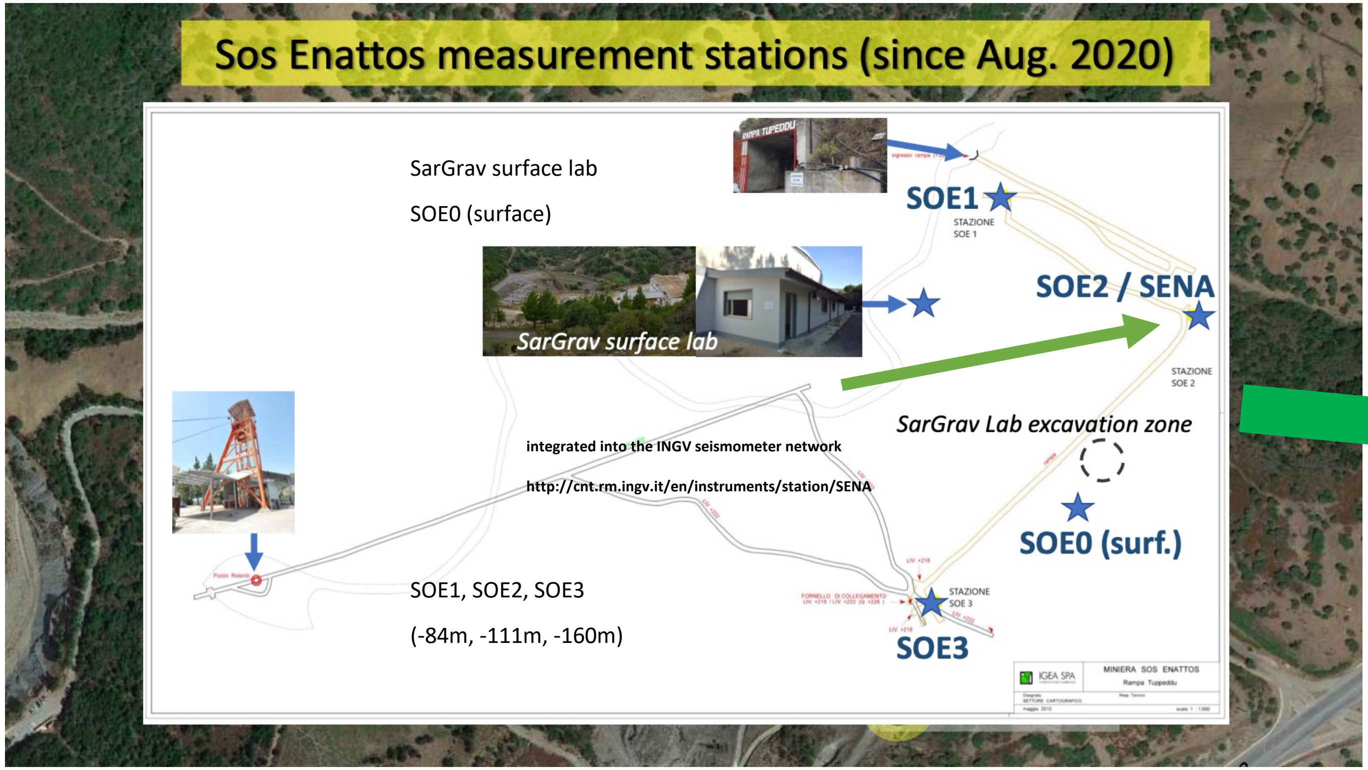
https://www.nikhef.nl/wp-content/uploads/2019/10/Terziet-Drilling-Campaign-Final-NoC.pdf

Sardinia SosEnattos

- **so far measurements done not in the bore holes**
- **very soon exactly the same standard devising as in Terziet**

Bitti and Onanì corners





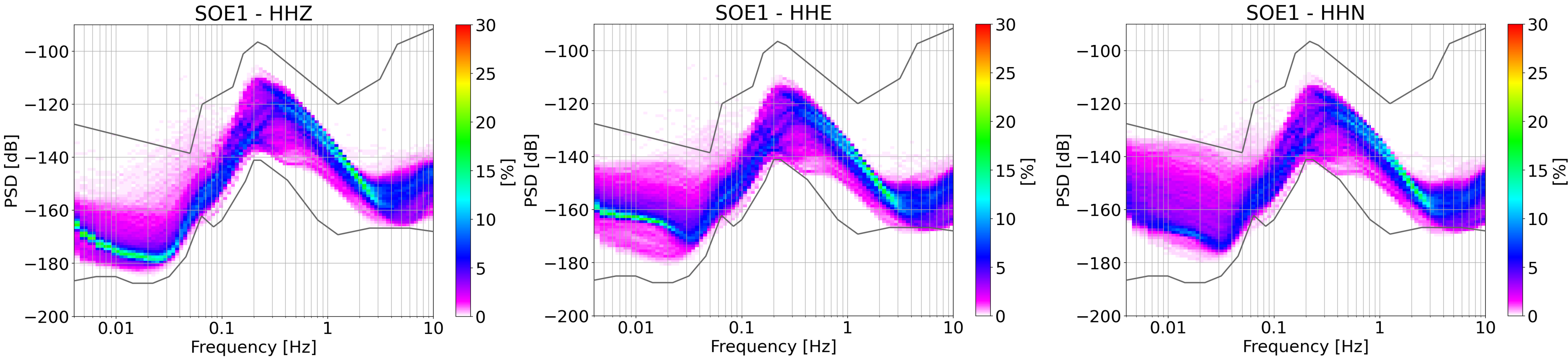
Credits D'Urso, Naticchioni

4 broadband seismometers, 3 short-period seismometers, 2 magnetometers, 1 tiltmeter distributed over underground and surface stations

SOE1 2021 data
-84m January-April

Sardinia Sos Enattos

Vertical Horizontal



- L. Naticchioni et al., ***Characterization of the SosEnattos site for the Einstein Telescope***, **JPCS**1468,2020

Credits L. Naticchioni

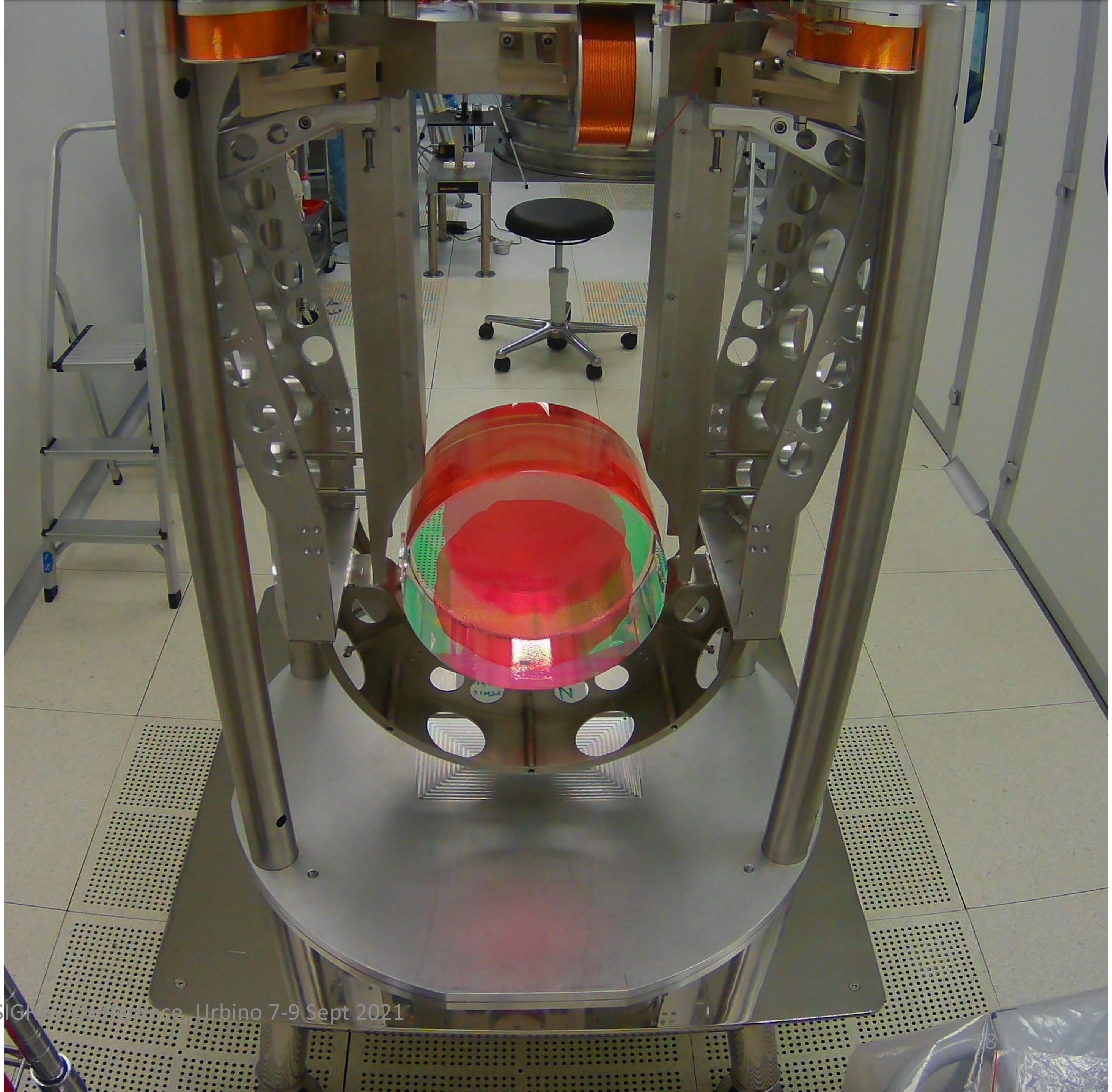
- M. Di Giovanni et al., ***A seismological study of the SosEnattos Area - the Sardinia Candidate Site for the Einstein Telescope***, **SRL**, 2020 https://doi.org/10.1785/0220200186
- A. Allocca et al., ***Seismic glitchness at SosEnattos site: impact on intermediate black hole binaries detection efficiency***, **EPJP**, 2021 https://doi.org/10.1140/epjp/s13360-021-01450-8
- Another report in preparation…

Concept 3 – R&D

- most of the experimental aspects of ET require R&D)
- A factor 20 in sensitivity is not for free !

Just an example (dedicated to Urbino colleagues) : **test masses are mirrors**

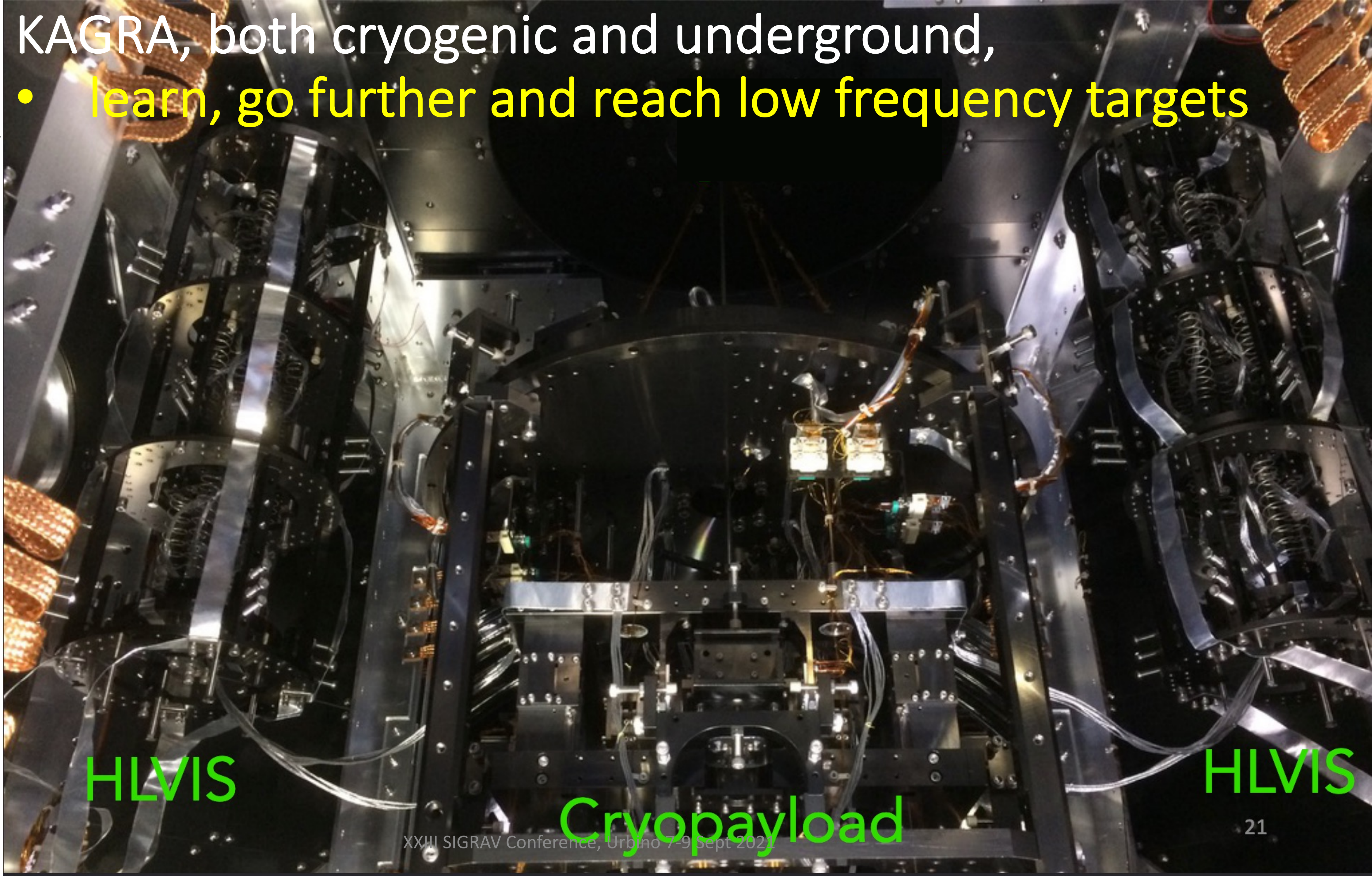
Quasi-inertial, for ET we claimed 2-3 Hz & cryogenic (for Virgo room T and 10 Hz)



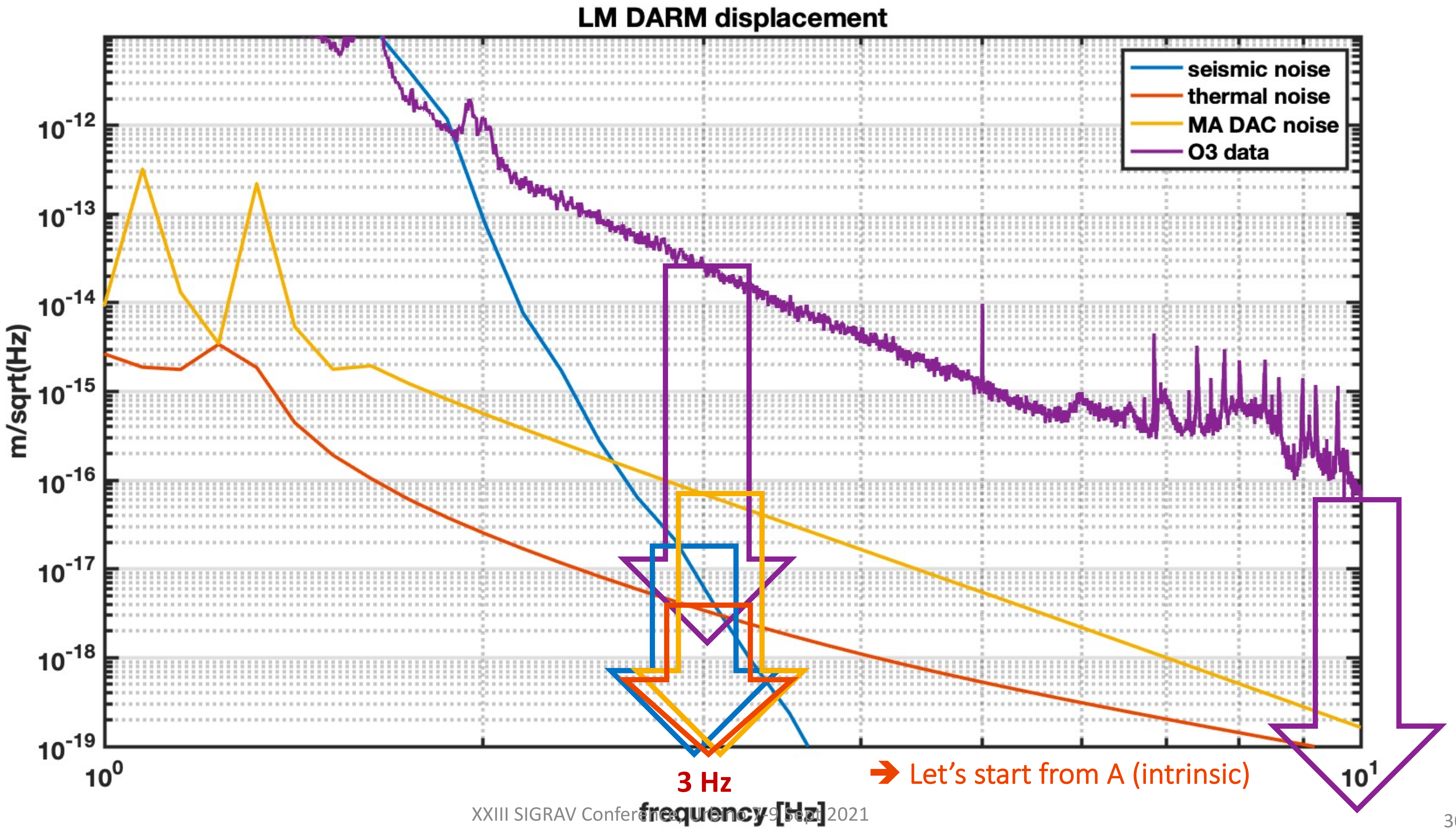
Relevance of Low Frequency sensitivity

KAGRA, both cryogenic and underground,

- learn, go further and reach low frequency targets

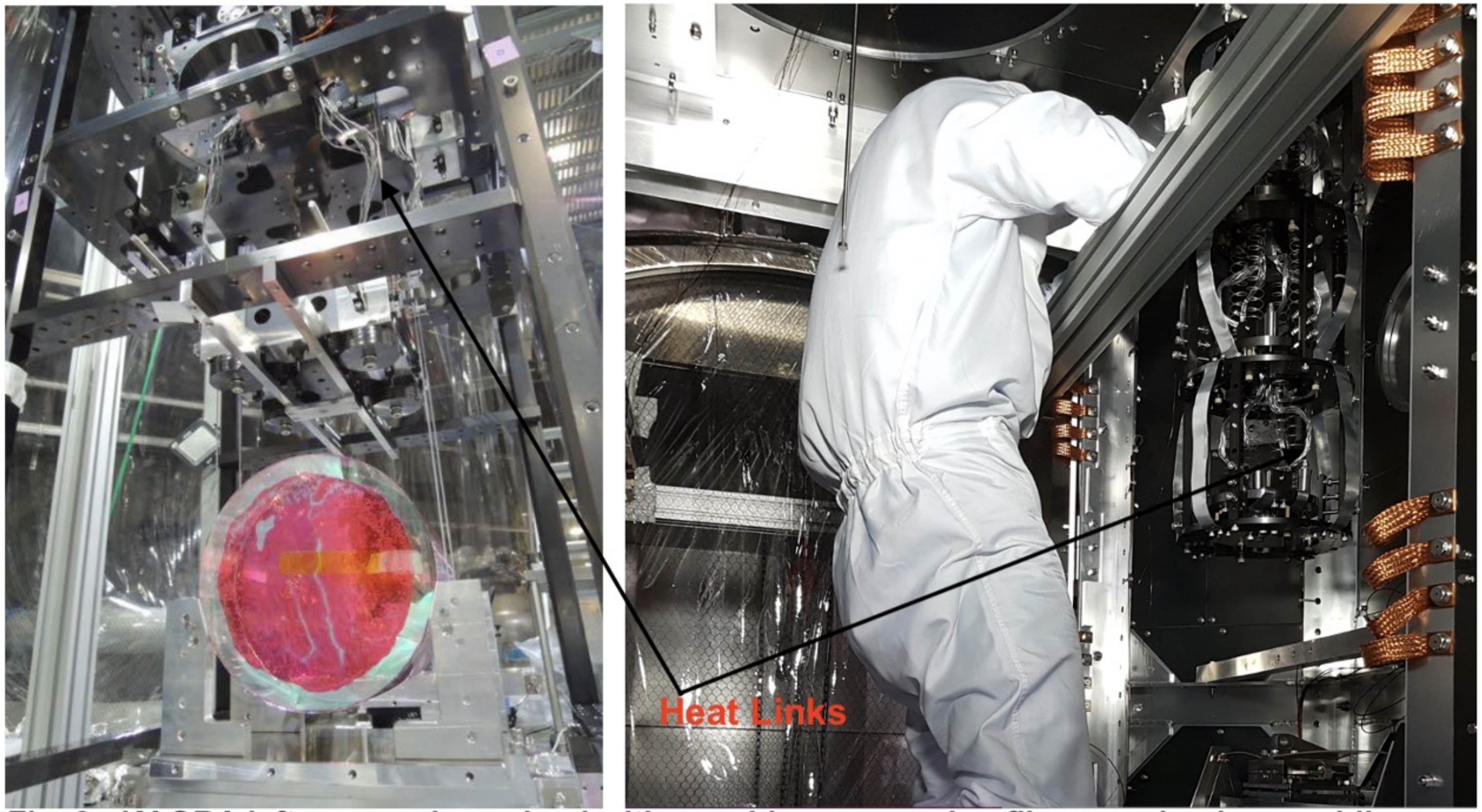


From Room Temperature prospective: A) two issues TN (intrinsic),
B) Driving technical noise (electromechanical design a study is possible at RT)



➔ Let's start from A (intrinsic)

Conductive cooling using heat **link is a working technology suitable for KAGRA**, vibration drag from inner shields for was sufficiently attenuated, **but a deep R&D upon that base must be done for ET (high sensitivity from 3 Hz)**



T. Yamada, “Low-Vibration Conductive Cooling of KAGRA Cryogenic Mirror Suspension”, KAGRA International Workshop 7 Dec. (2020)

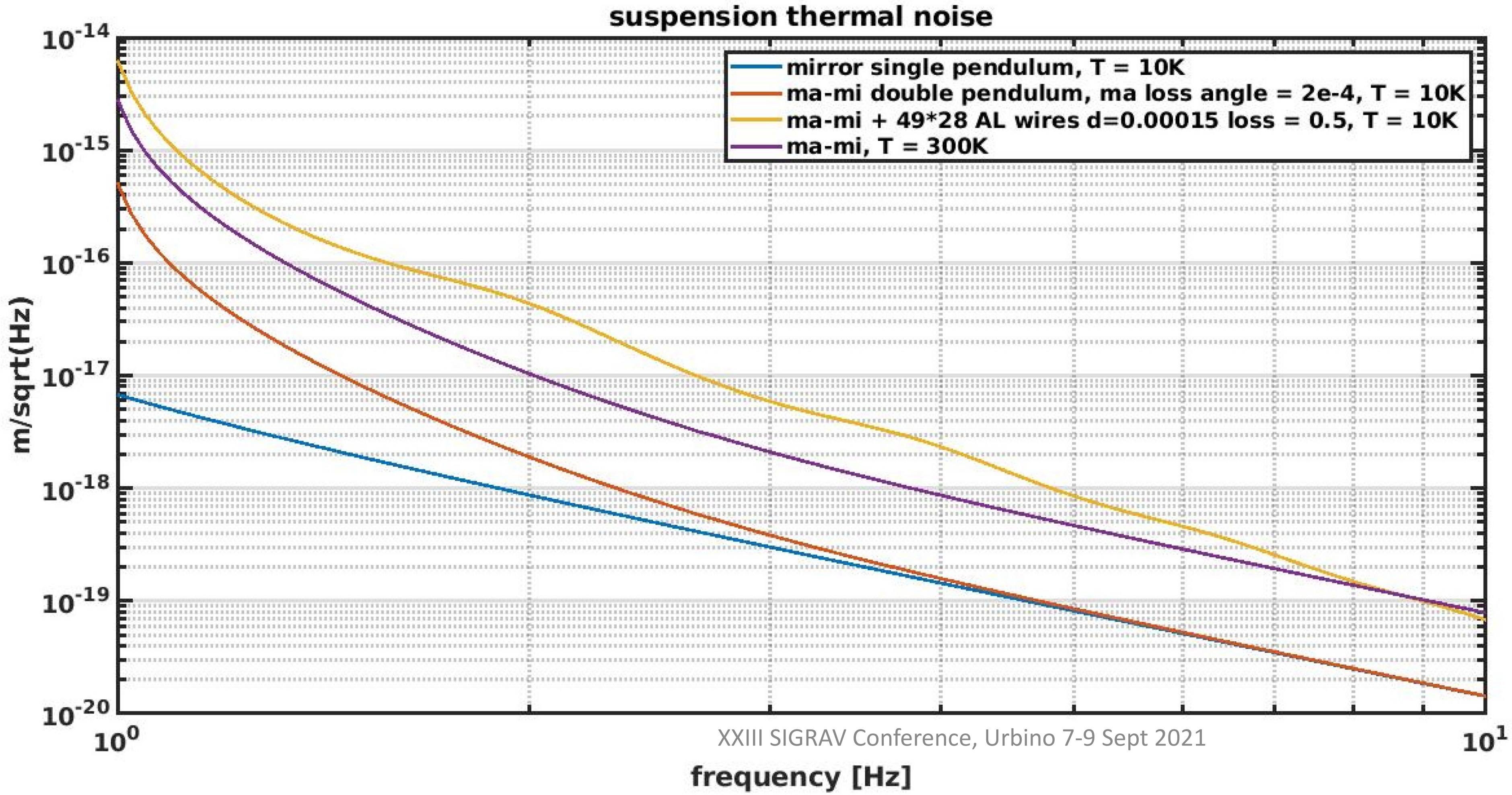
Cryogenics of the TM is achieved, but what about actual mechanical thermal noise ?
We started to consider also that in ET perspective.

Seed modelling for a "good payload"

- Analytical Modelling[1] now includes soft heat Links[2]
- Structural modelling and TN in interfaces requires FEM

- Good to attenuate cryostat vibration injection
- Bad concerning violin modes and related thermal noise

[1]**P. Ruggi**, Thesis VIR-0020A-21 (2003), [2]T. Yamada, "High Performance Heat Conductor with Small Spring Constant for Cryogenic Applications", arXiv:2003.13457 (2020); [2]Gabriela I. Gonzalez and Peter R. Saulson, "Brownian motion of a mass suspended by an anelastic wire", J. Acoust. Soc Am 96 (1) (1994)



- This is the time to start the actual design…

Conclusions

the seeds of present updated R&D/technical/scientific perspective:

- GW observation with 2G detectors,
- 2021 ET concept design considered with prioroty
- KAGRA experience

big science

- infrastructure development is the garden to plant them

Harmony, please