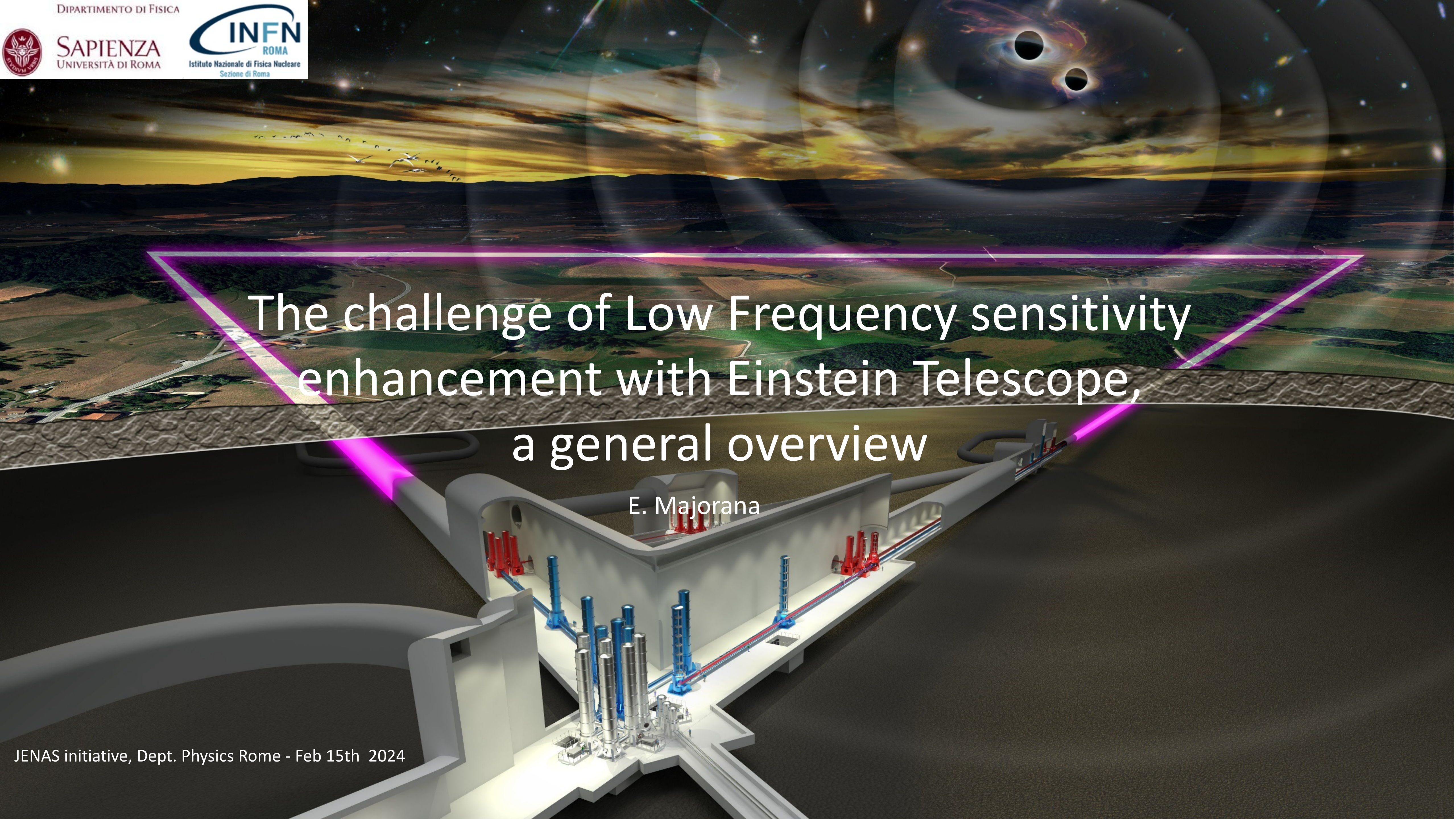
Dipartimento di Fisica
Sapienza Università di Roma
INFN Roma
Istituto Nazionale di Fisica Nucleare
Sezione di Roma

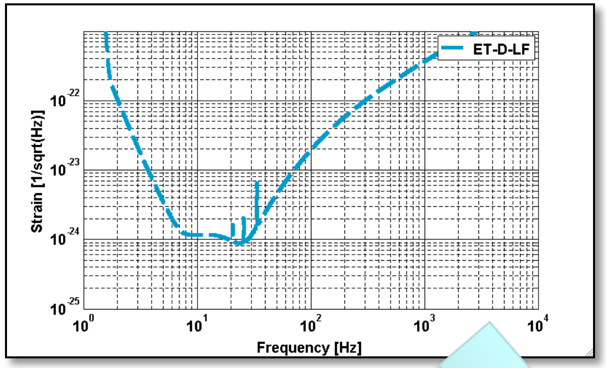


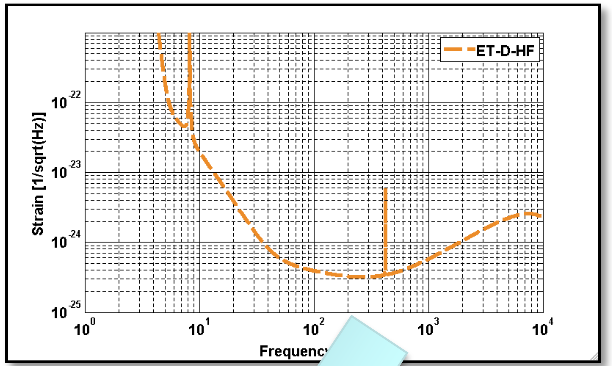
The challenge of Low Frequency sensitivity enhancement with Einstein Telescope, a general overview

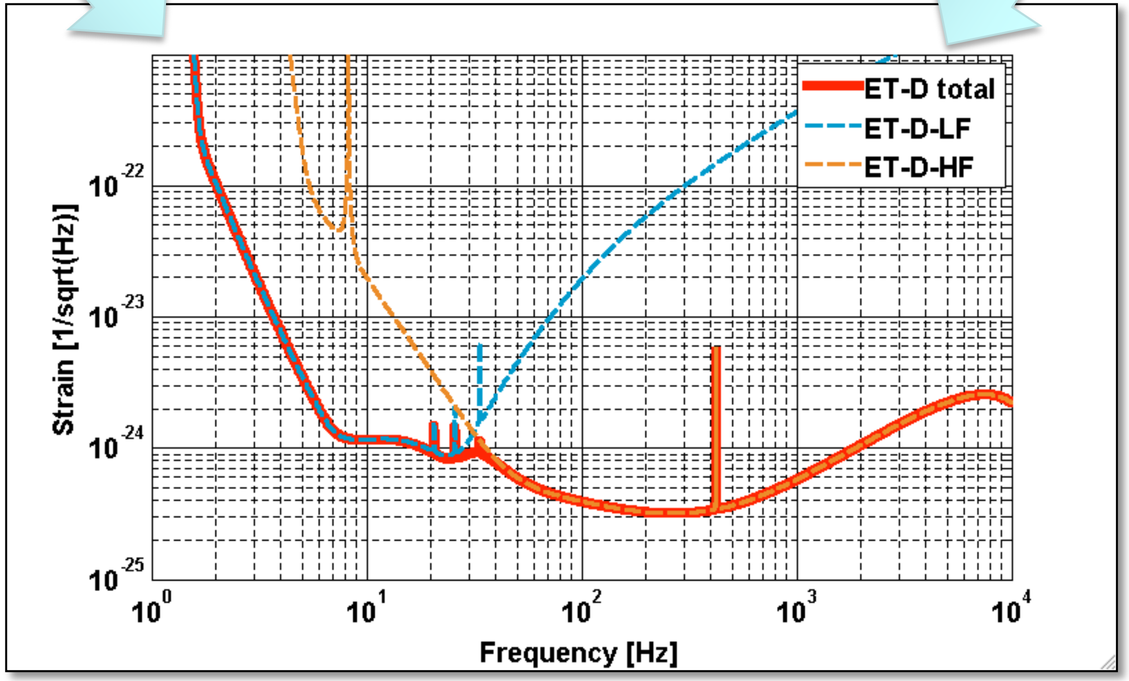
E. Majorana

JENAS initiative, Dept. Physics Rome - Feb 15th 2024

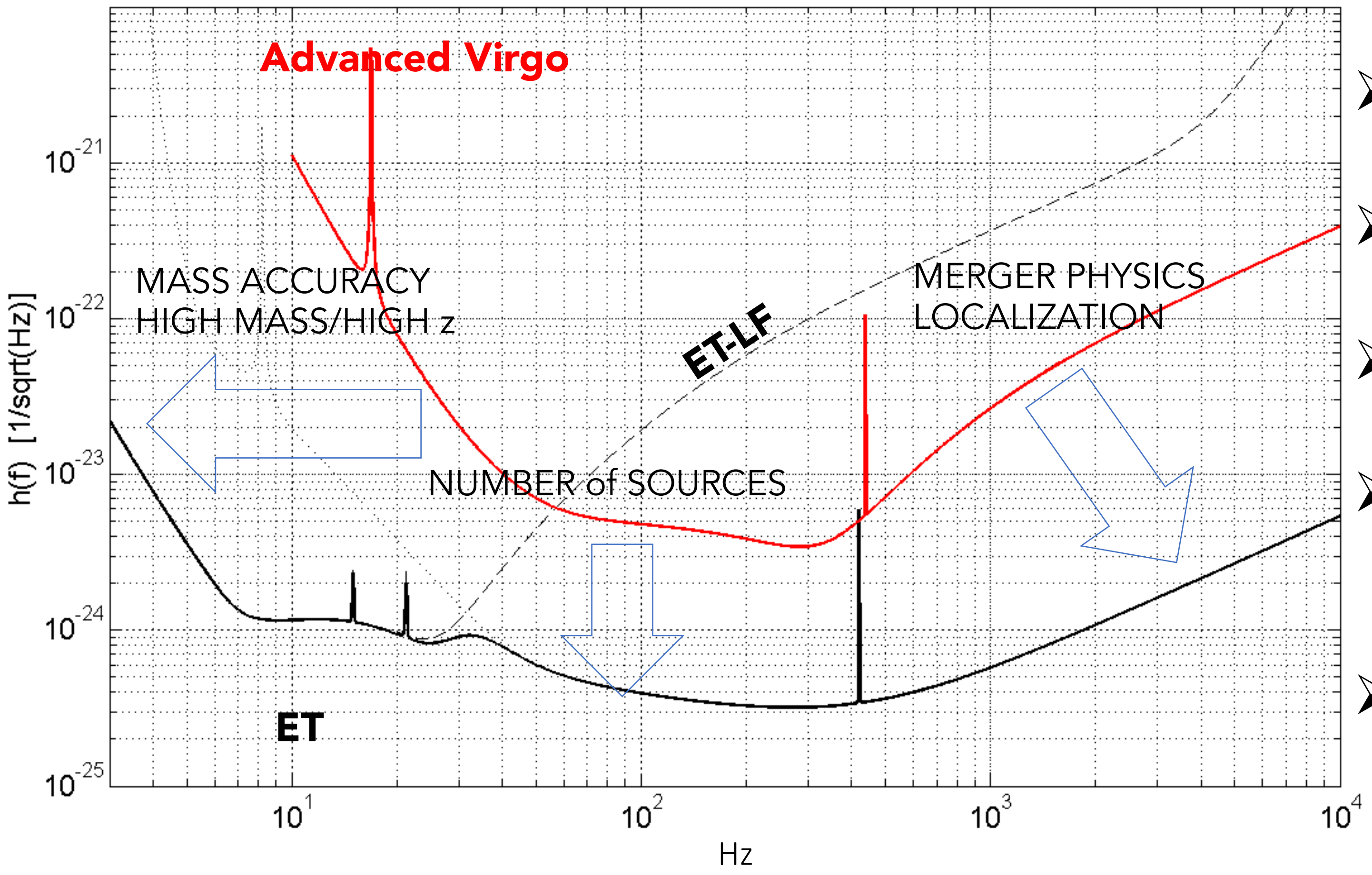
“hybrid detector” principle







SENSITIVITY GOAL: ~×10-20 better than AdV detectors



- *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

ET, the European 3G idea

ET EINSTEIN TELESCOPE

- The 3G detector conceived in Europe is a new GW observatory
  - 3G: Factor 10 better than advanced (2G) detectors
  - New:
    - We need new infrastructures because
      - Current ones are too small and will limit the sensitivity of future upgrades
      - In 2030 current infrastructures will be technologically obsolete or aged
  - 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)
      - Localization capability (if alone)
      - Polarizations (triangle)
      - Redundancy
    - 40-50-years lifetime of the infrastructure
      - Compliant with the upgrades (a big-science facility)

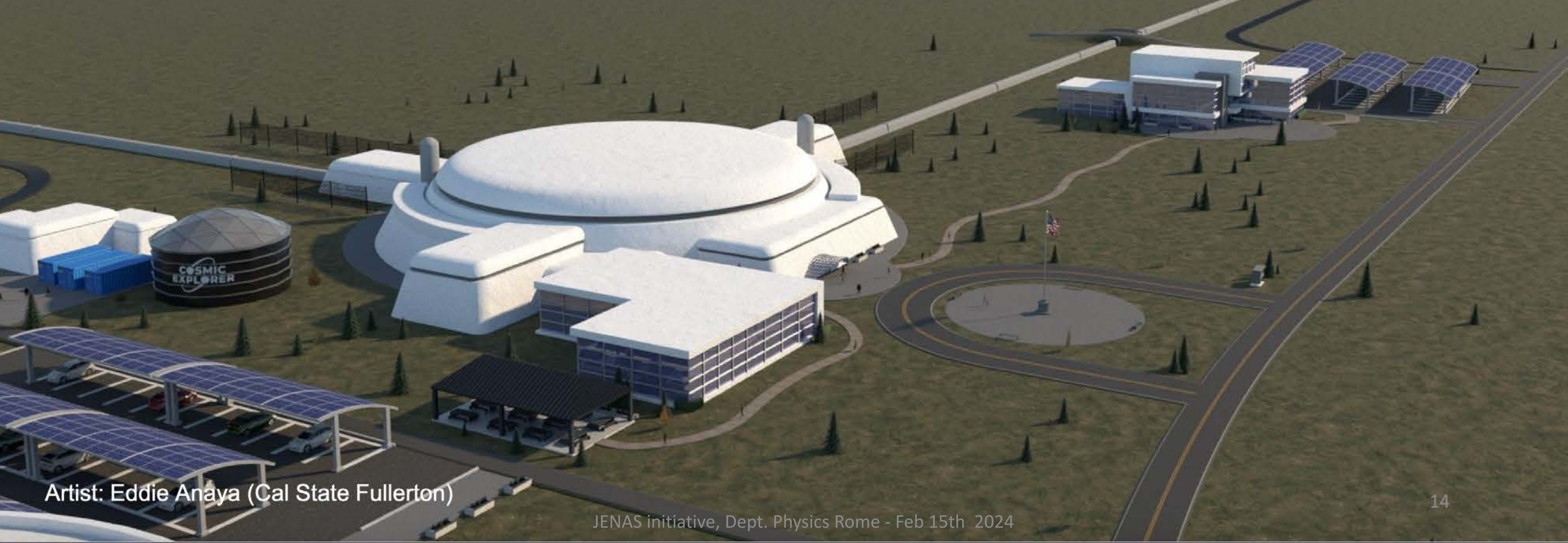
Cryo-LF/QNR techniques

Standalone operation for localization is now unconceivable

ET was born as a triangle

ET will be not alone…

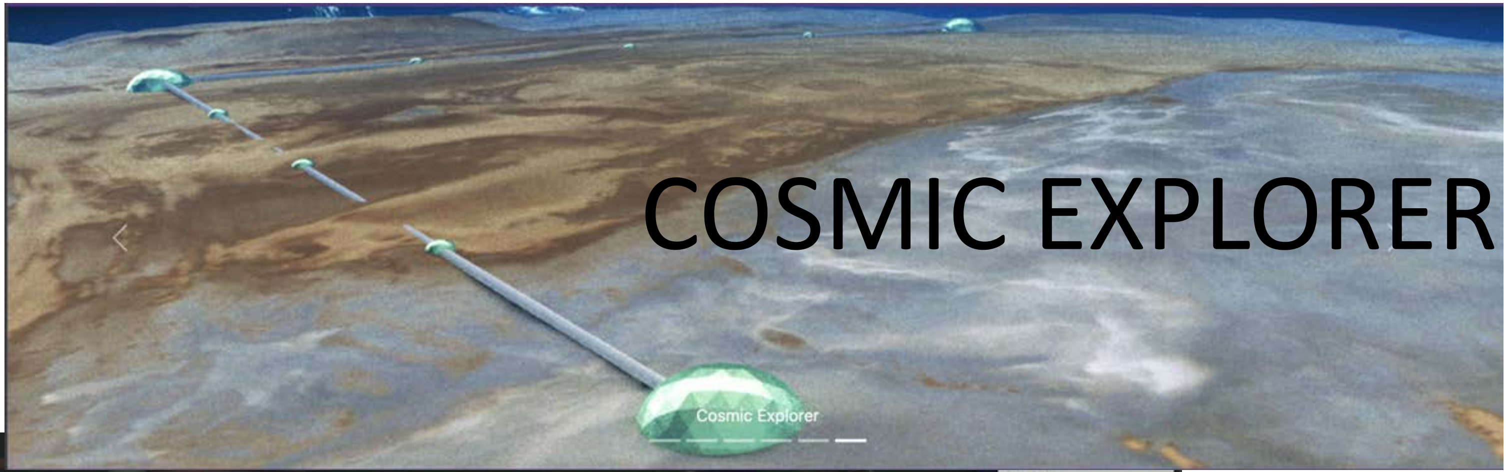
40 km and 20 km **L-shaped** surface observatories
10x sensitivity of today's observatories (Advanced LIGO+)
Global network together with Einstein Telescope

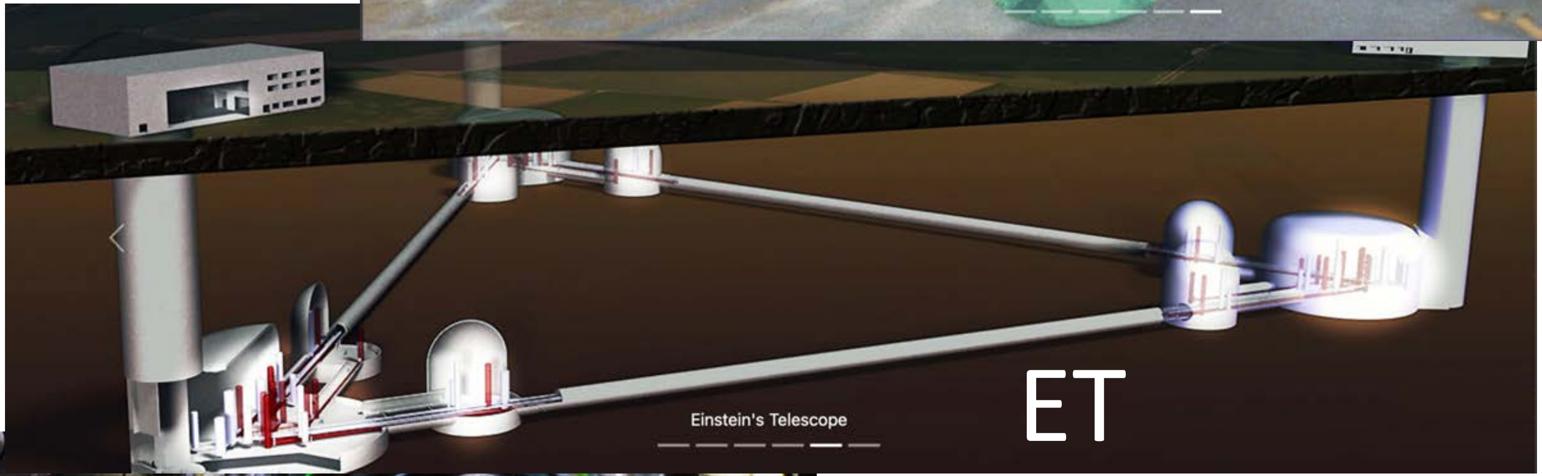


Artist: Eddie Anaya (Cal State Fullerton)

A worldwide community, a prosperous future…

3rd Generation detectors (3G)



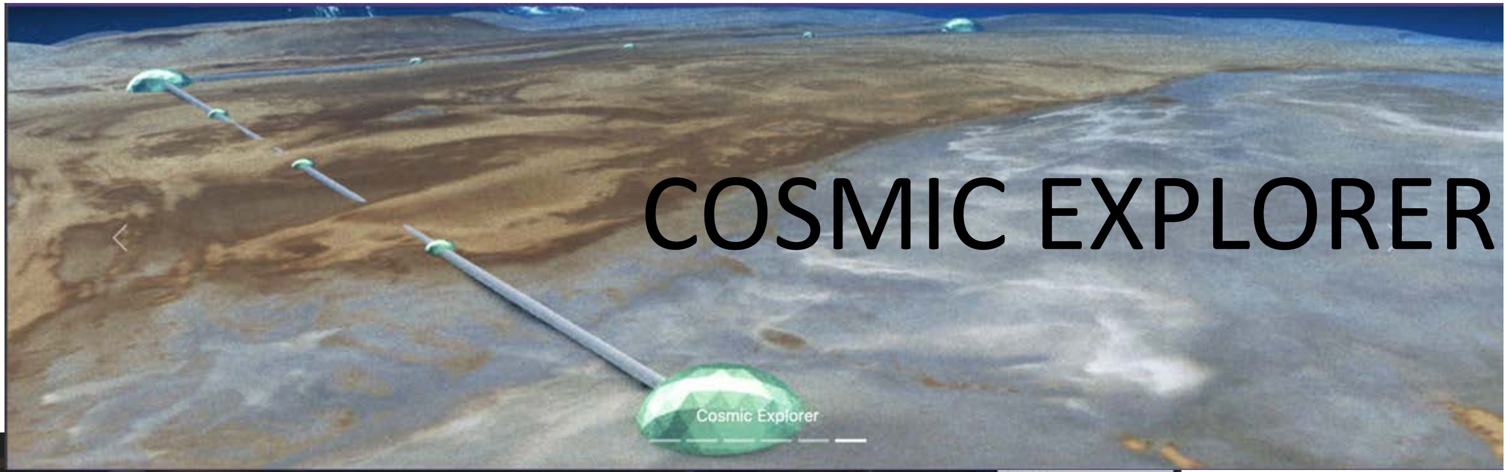


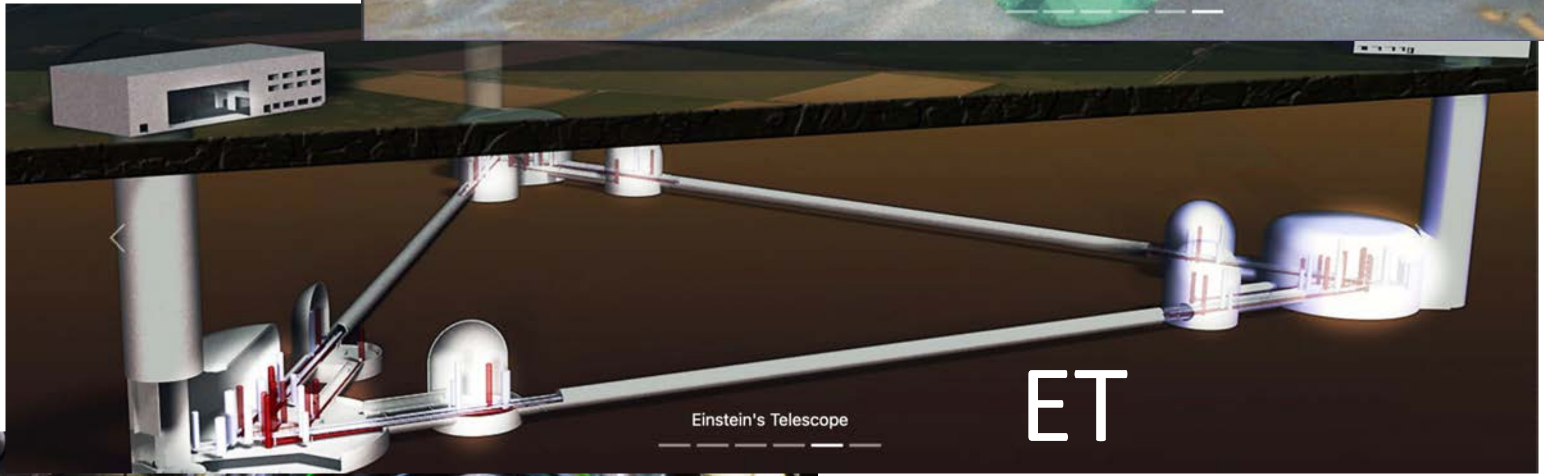
In the path towards 3G detectors KAGRA is usually set close to ET, although it is the less sensitive among the existing detectors

A worldwide community, a prosperous future…

Indeed, KAGRA is a much younger machine (>10 years), which
- implements new features (underground/cryogenics/monocrystalline material for test mass and suspension)

- It is conceived as a detector, it joins the LVK (present sensitivity is very low)
- but is also appealing as a pathfinder for new solutions

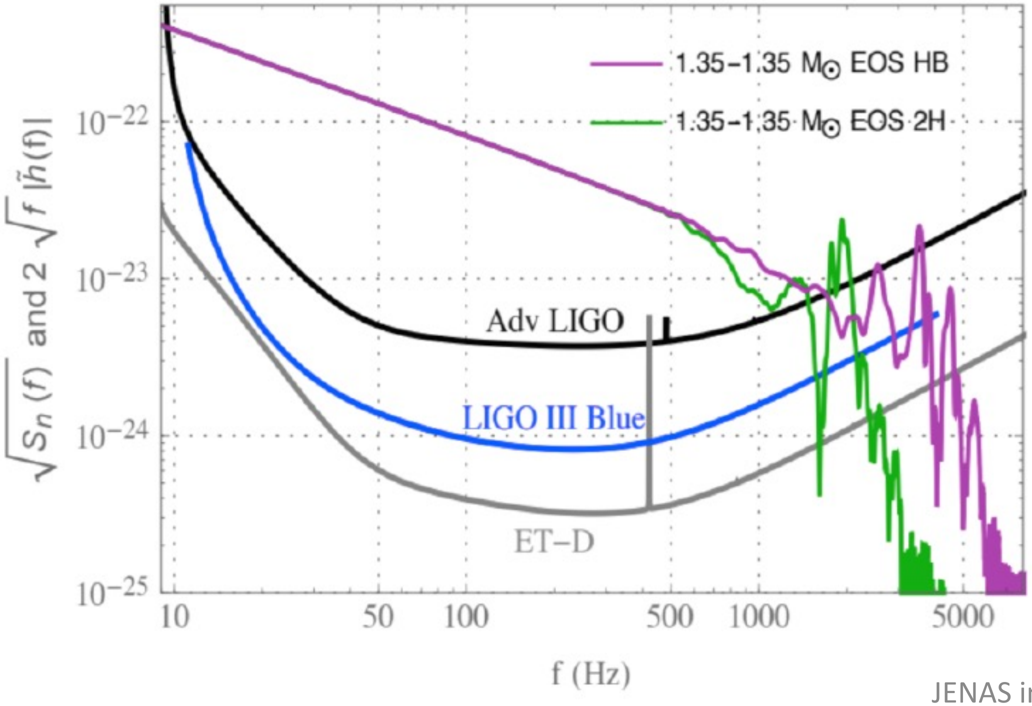


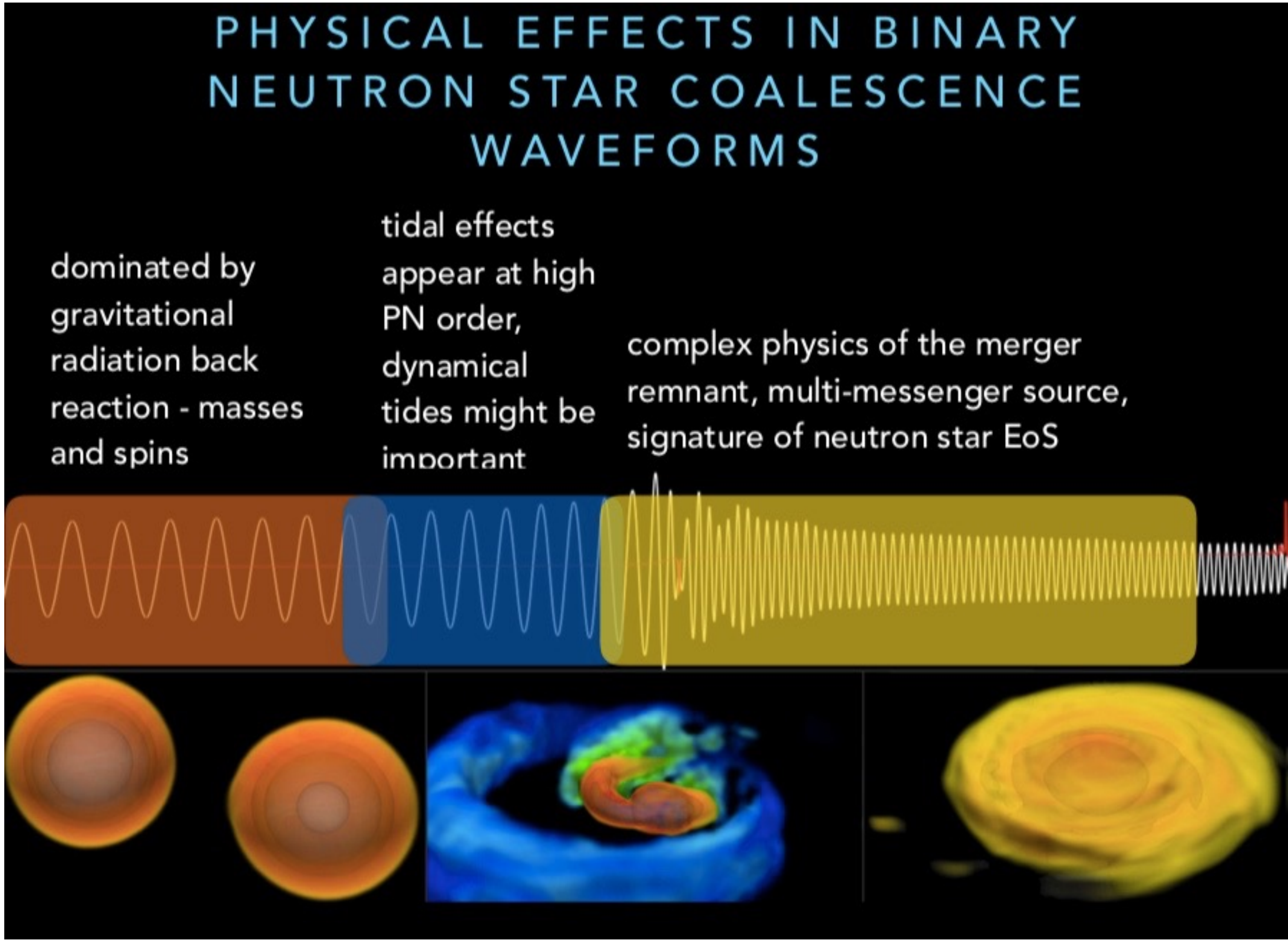


CE was born later, three main guidelines
- **Simpler**
- **Longer**
- **Double**

MULTIMESSENGER NSNS AND NSBH: ultimate density states of matter

NS EOS ~ Unaccessed using present detectors

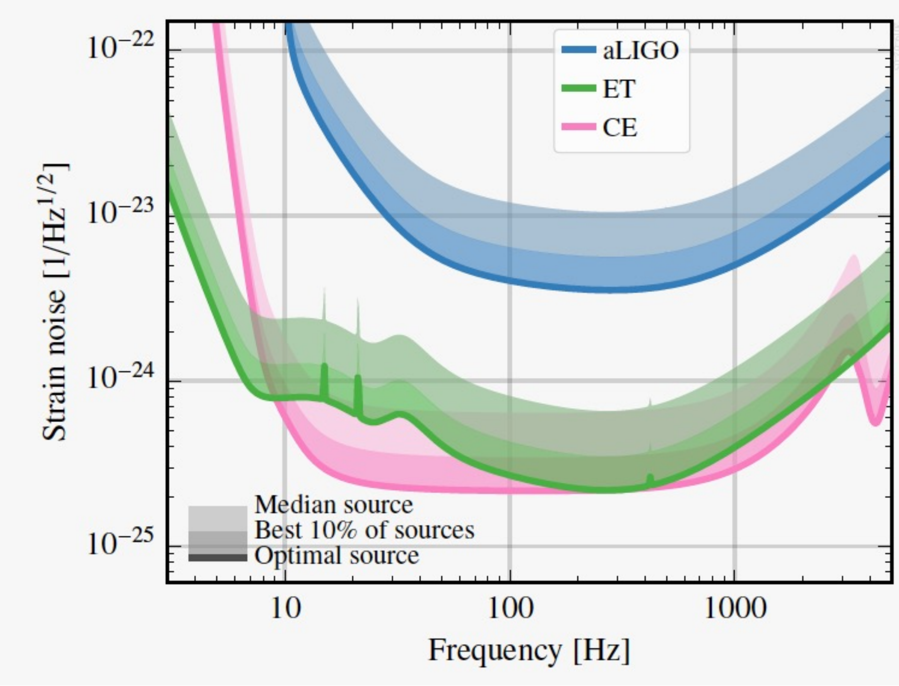




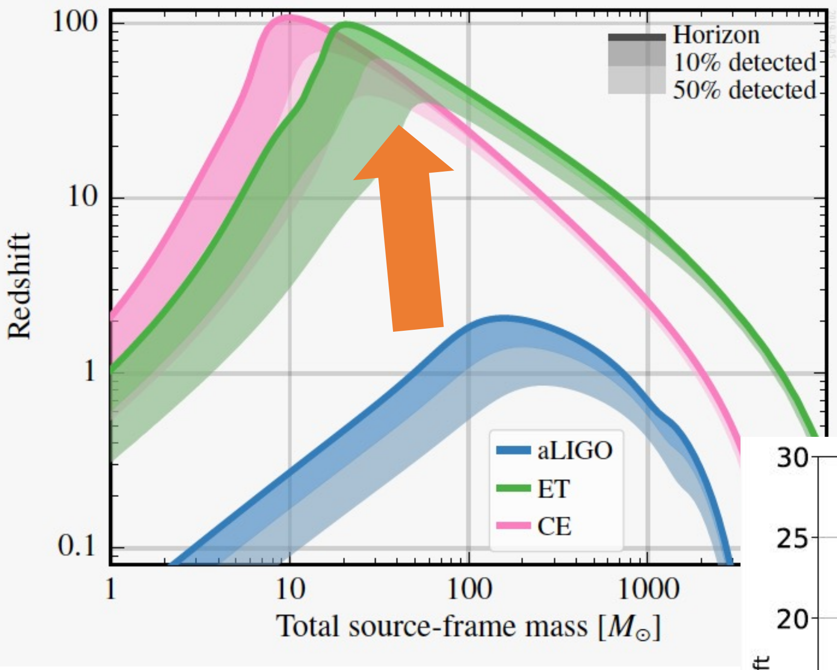
A first study was performed assuming a triangular hybrid detector in a network of three of 3 detectors (ET+CENorth+CESouth)

Target 10^5 to 10^6 events/year

Strain sensitivity



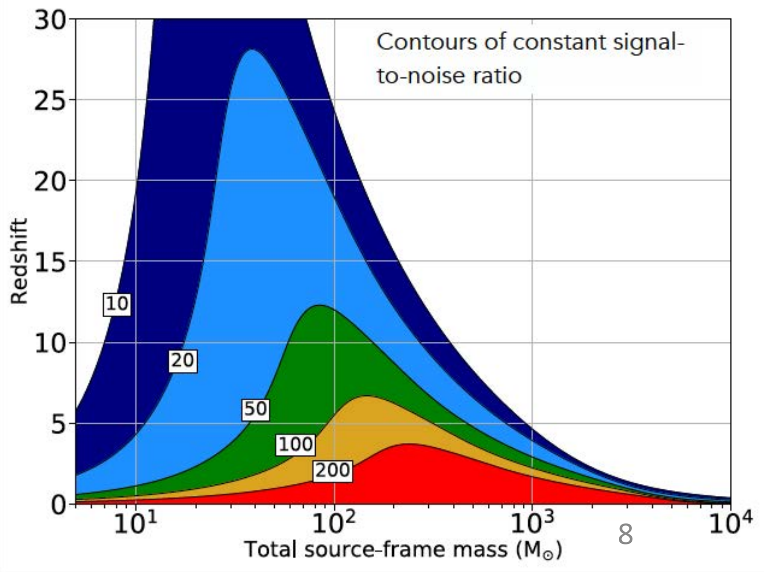
Coalescence of compact binary systems



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

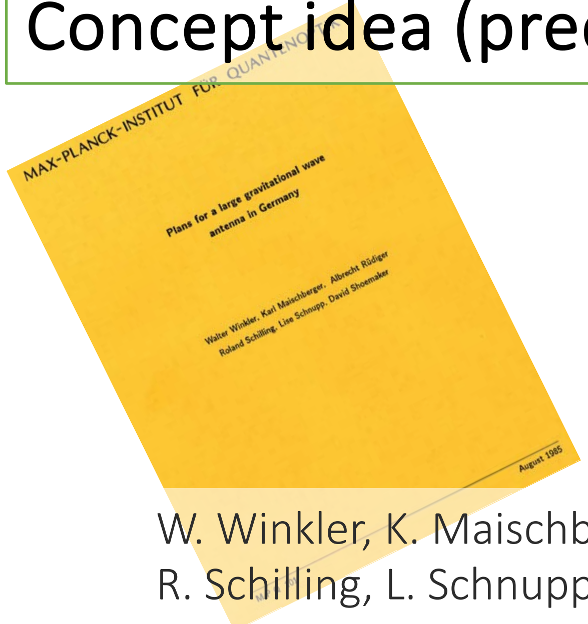
Binary Coalescences Overview:

- Census of stellar and intermediate-mass BBH population over full Universe, 10^5-10^6 events per year;
- 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;
- Extend the range of observed BBH masses towards >1,000M_{sol} and <1M_{sol};
- Observe several 10,000 binary neutron star mergers per year.
- ET will determine NS EOS.



Very promising, but much deeper Cost-Benefit Analysis was need to go ahead and finalize configuration and infrastructure

Concept idea (precursors)



W. Winkler, K. Maischberger, **A. Rüdiger** R. Schilling, L. Schnupp, D. Shoemaker, "Plans for a large gravitational wave antenna in Germany", Fourth Marcel Grossmann Meeting, Rome, June 1985*

- ET inherited several concepts by this proposal !
- ~40 years after this proposal the site location of a new concept interferometer must be assessed.

Abstract

After encouraging progress with the 30 m prototype, the GW group at the Max-Planck-Institut für Quantenoptik are increasing efforts towards a full-sized antenna. A definition phase is being started, in the duration of which (1 to 2 years) various questions are to be clarified.

Size: Arms 3 km in length are proposed, as a trade-off mainly between cost and the influence of thermal mirror motion. Tunnels, completely or partly below the surface, are to house the vacuum tubes.

Configuration: Besides the standard single 90° interferometer, a redundant triangular configuration consisting of three 60° interferometers is also being considered.

Optics: The size of the mirrors will depend on the choice between delay lines and Fabry-Perot cavities. A set of relatively large mirrors is to be manufactured and tested. Components for light modulation and guiding need research.

Techniques: Light power enhancing techniques (injection locking, recycling) are to be investigated. Improved frequency stabilization is to be developed, and phase modulation of the laser light (to reduce noise due to scattered light) is to be tried.

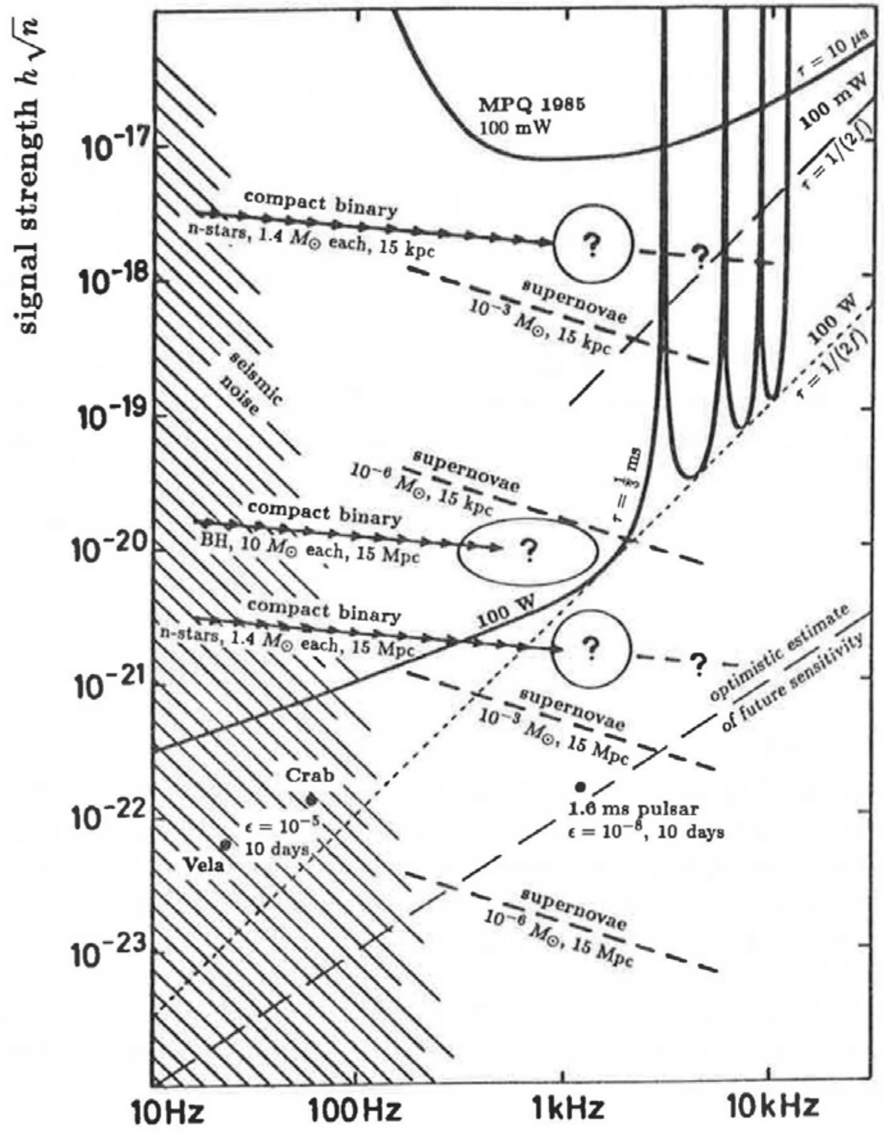
Vacuum: On the basis of given vacuum requirements, the design of the vacuum system (choice of material, pumps) will have to be made by an industrial firm.

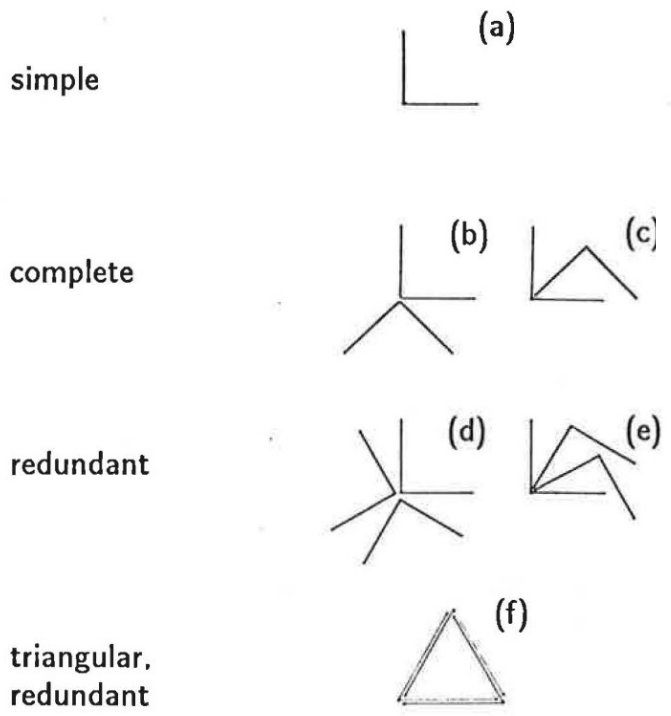
Site: Possible sites found in a topographical survey must be re-assessed in respect of seismic and traffic noise, accessibility, ownership and current use.

Cost: A reliable estimate of the main cost items (construction, vacuum system, and power and cooling water supplies) will come from a design study to be made by an engineering consultant; such a study will also allow an estimate of the time scales in planning and construction.

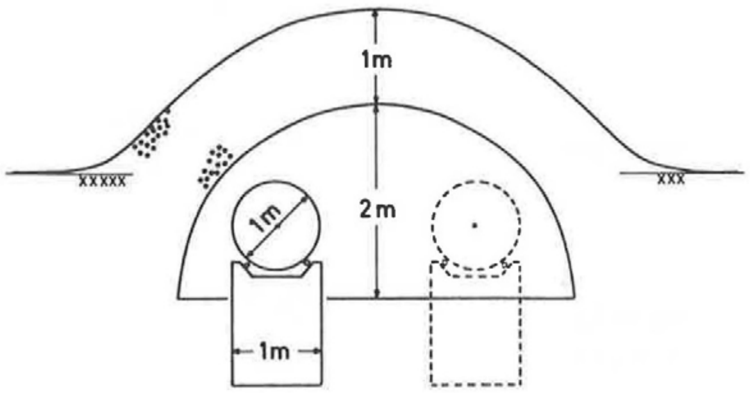
* A. La Rana, "EUROGRAV 1986–1989: the first attempts for a European Interferometric Gravitational Wave Observatory", EPJ H (2022) **47**: 3

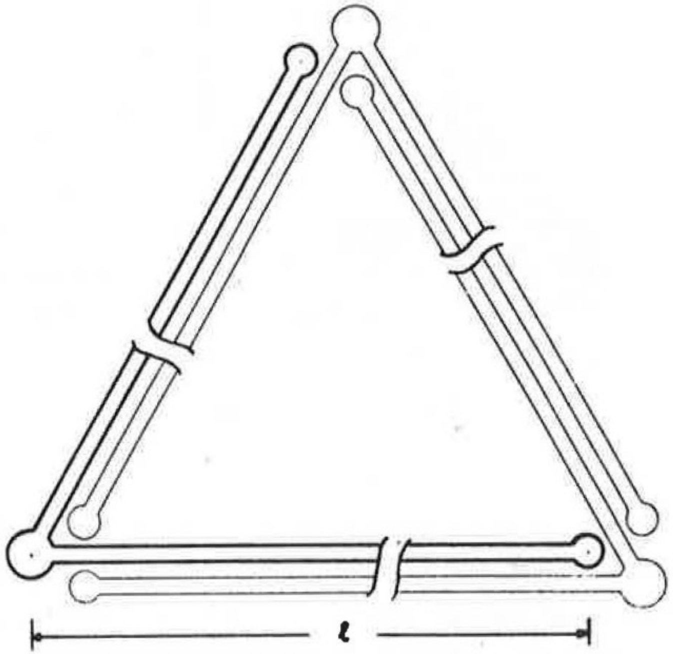
Concept idea (precursors)





Configurations of simple (a), *complete* (b, c), *redundant* (d, e) *triangular redundant* (f) *receiving stations.*





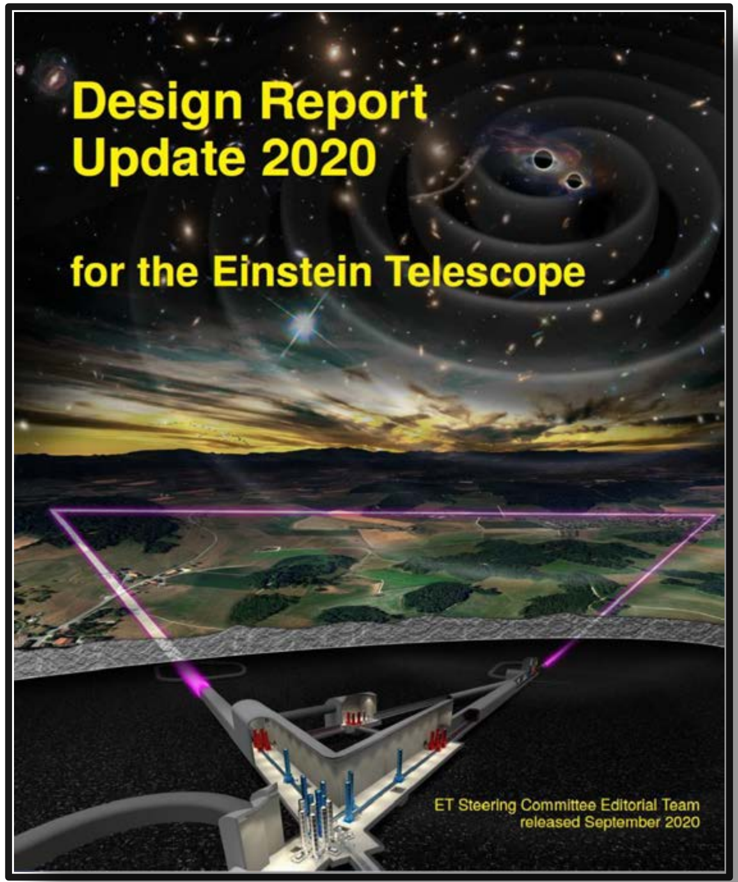
- In 1985 the concept of GW detector network was not fully mature
- The debate on “L” VS “Δ” is still vibrant

Concept idea (of ET)

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

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

ESFRI →

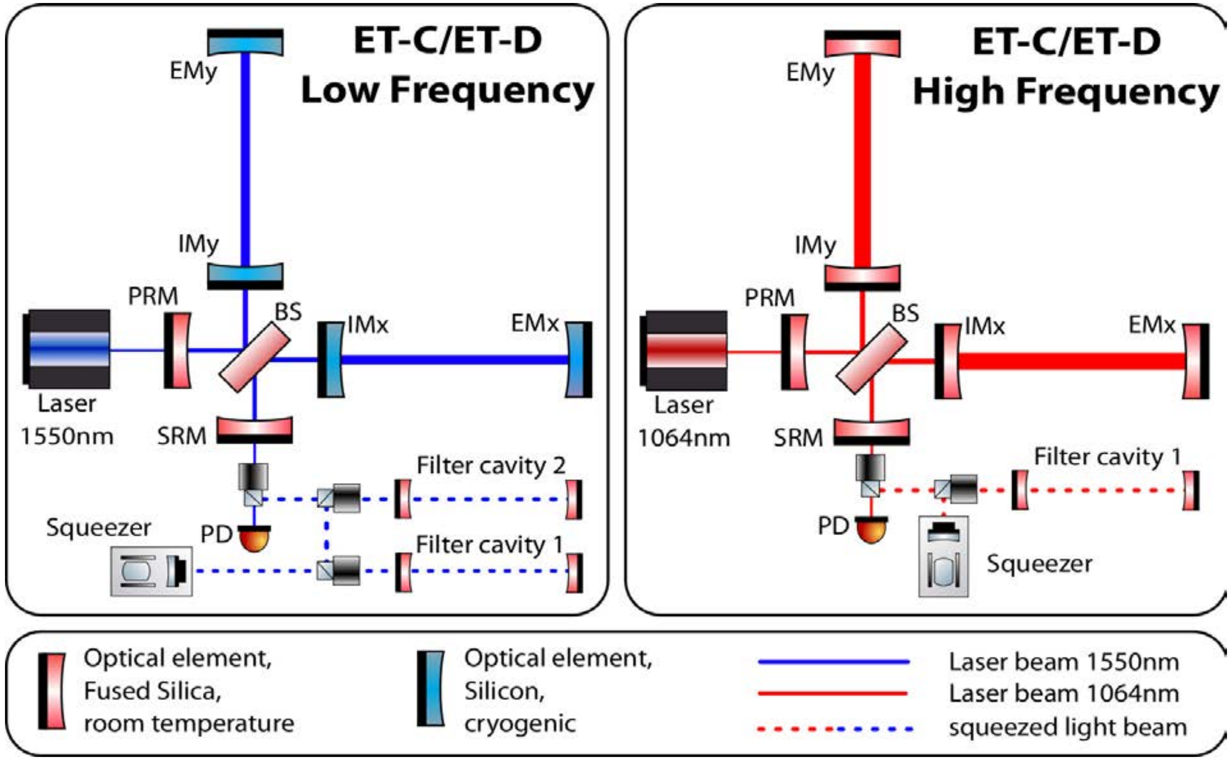


- In 2020 governments of 5 EU countries (Italy, The Netherlands, Belgium, Spain and Poland) submitted the ET application to ESFRI (European Strategy Forum on Research Infrastructure).
- July 2021 ET obtained ESFRI status, as the highest value project ever to feature on an ESFRI roadmap.

❖ **Constitution of the ET collaboration**
❖ **Site definition (2024=>2025)**

The novel concept introduced for ET, to widen the detection BW: two instruments in one (Hybrid Detector)

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



- Too stringent technical issues with a single instrument
- ➔Constrains on detectable sources

Optimization example, done in 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

- Very complex optimization, but more affordable, with the hybrid detector ET.

A "STAND-ALONE OBSERVATORY"

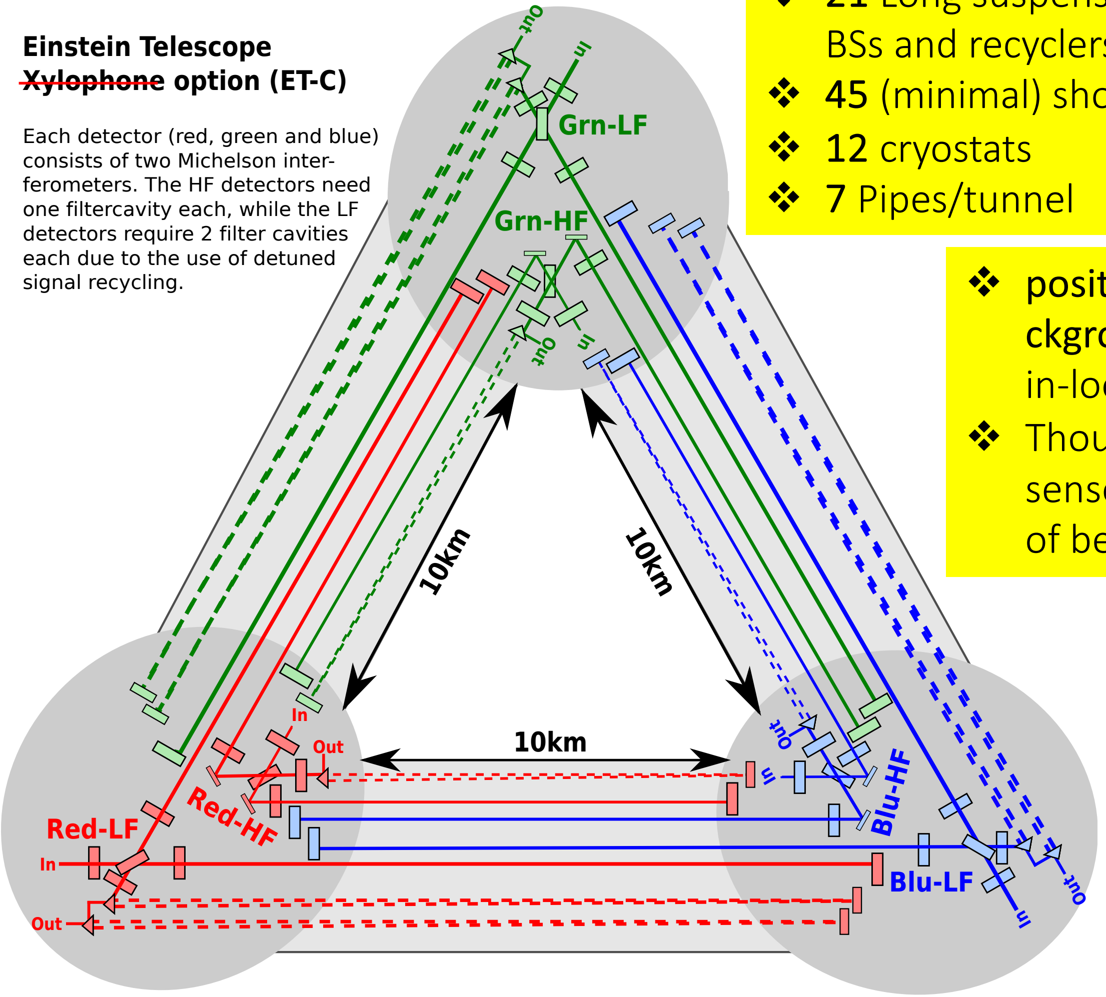
- Start with a "single" hybrid detector
- Add a 2nd one to resolve polarization
- **Add a 3rd one** for null stream (A. Freise et al 2009 Class. Quantum Grav. 26 085012)

- Redundancy allows to define a noise veto - sum channel, free from any tidal signal

- Redundancy is OK if:
  - duty cycle is high (6 ITFs working)
  - calibration is very accurate
  - noise is comparable

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

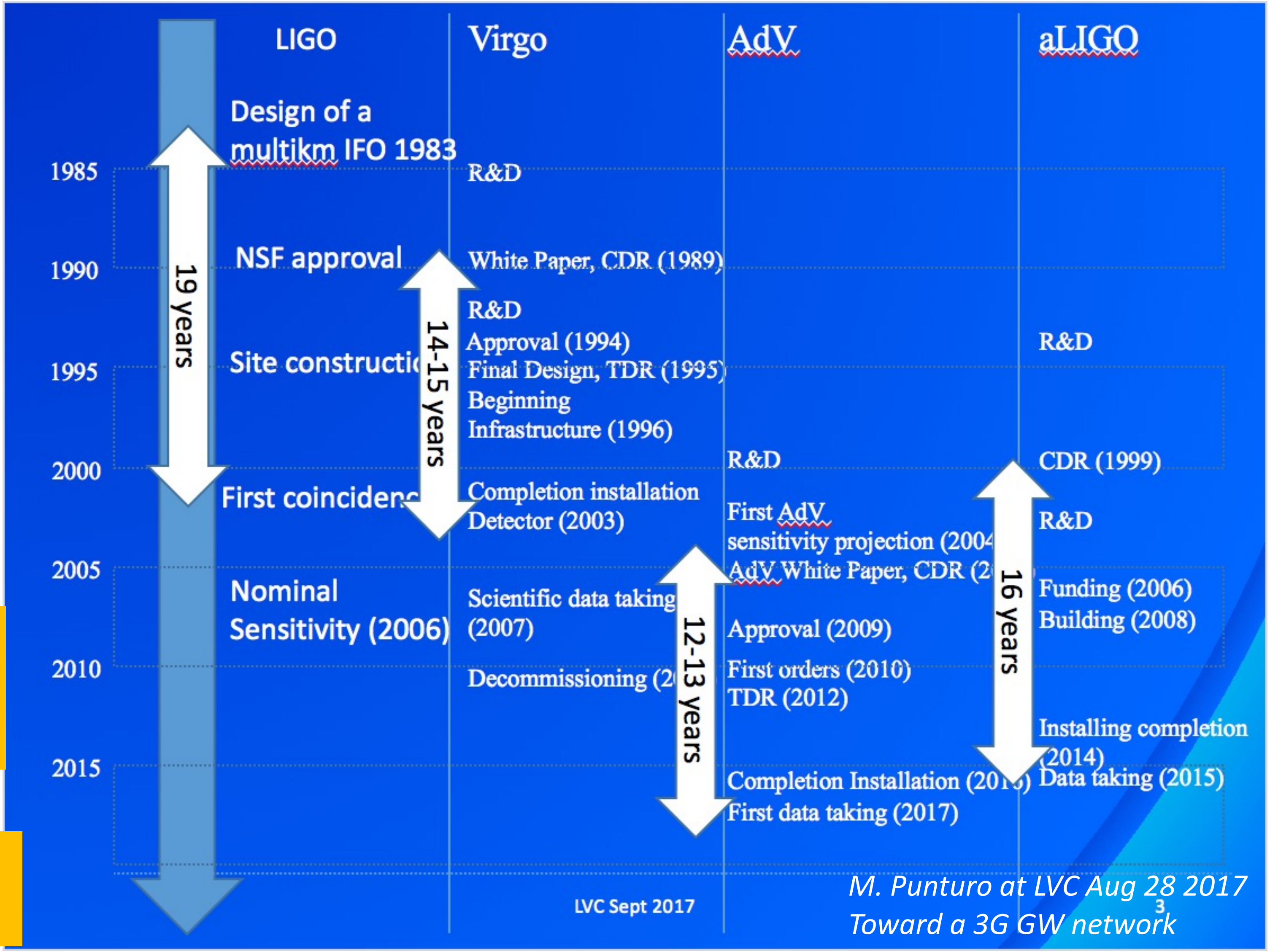
- 21 Long suspensions for Test masses BSs and recyclers (signal and power)
- 45 (minimal) shorter towers
- 12 cryostats
- 7 Pipes/tunnel

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

Typical Timelines, an historical wiewpoint

- 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 timeline (CDR-to-realisation) for a GW detector is ~15 years

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

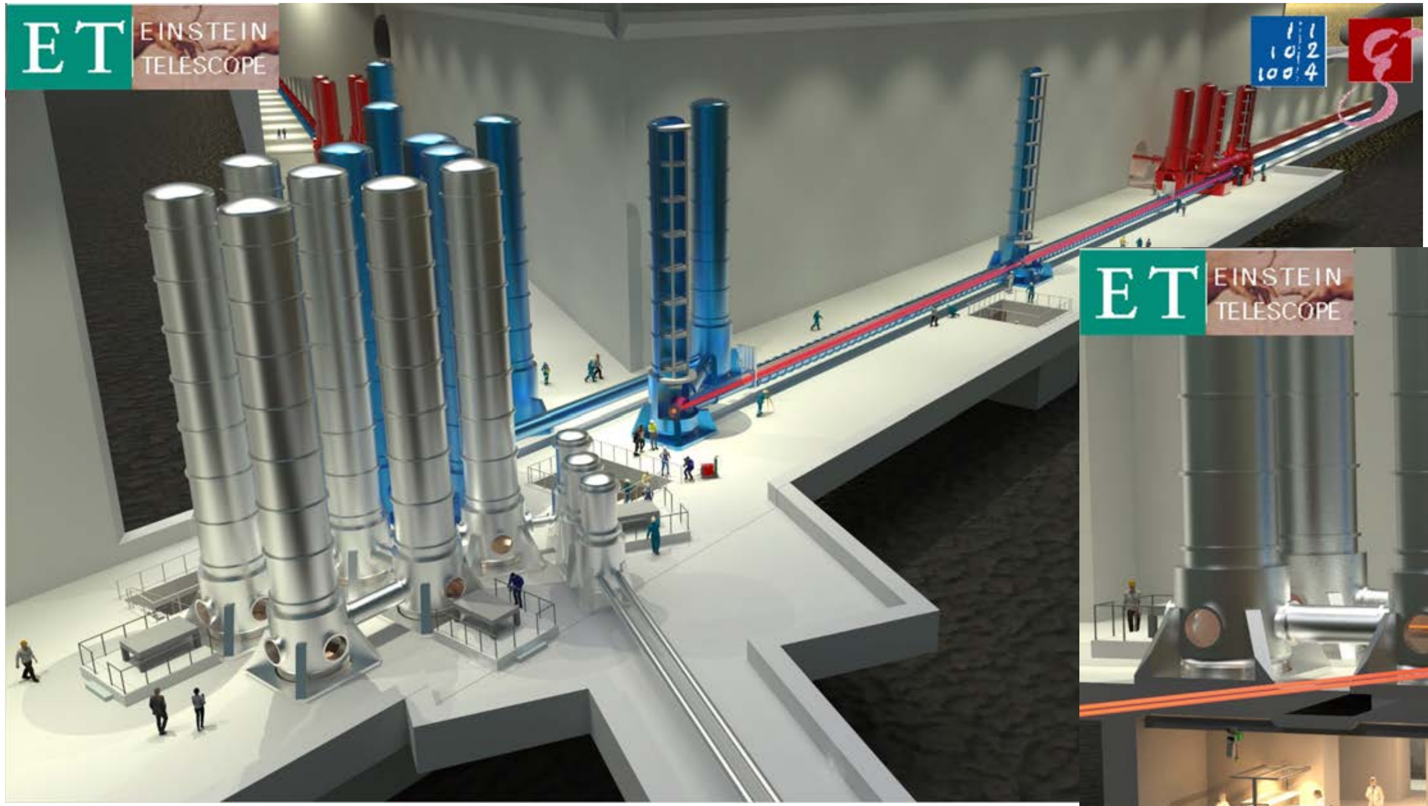


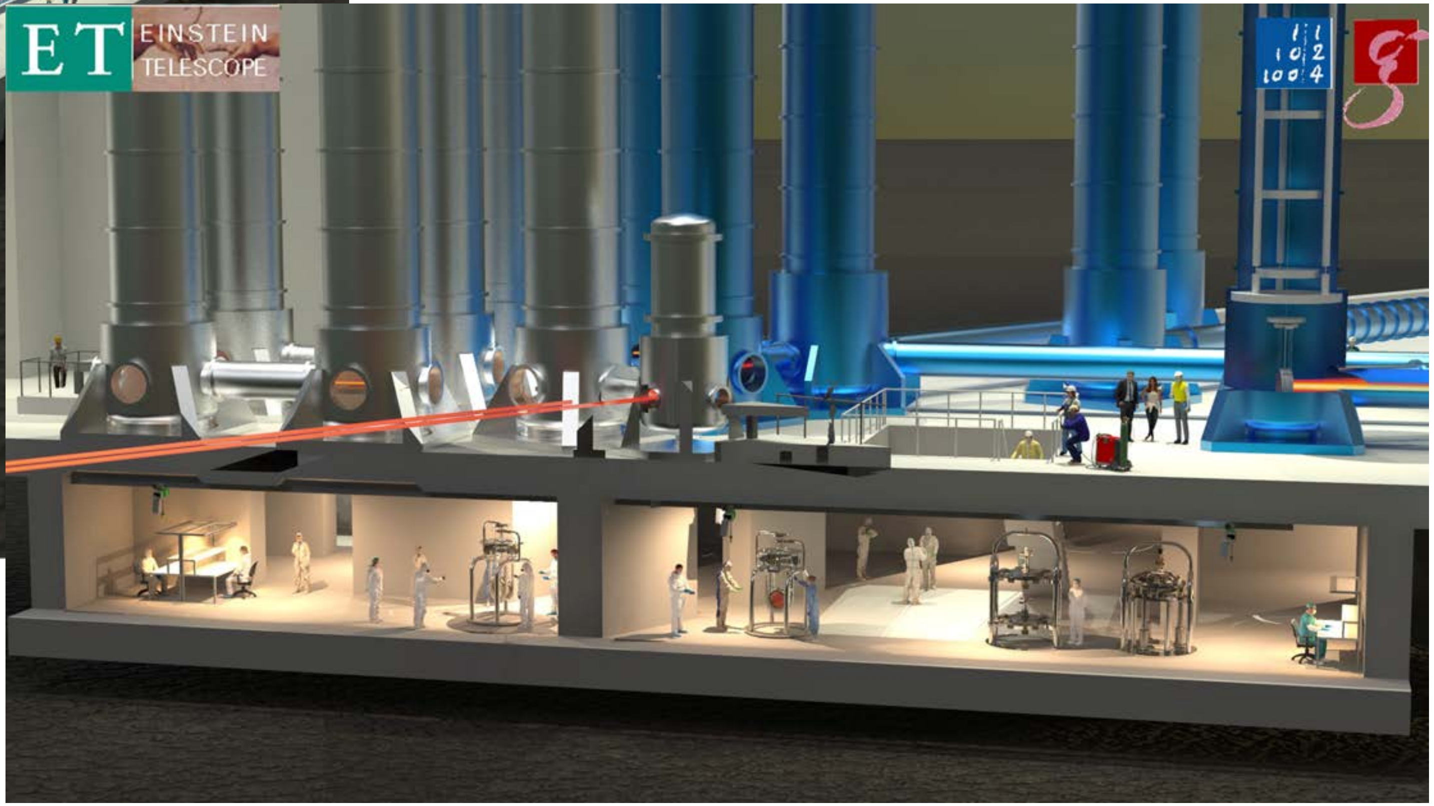
➔ Something must change !
❖ **The infrastructure** is the main issue
❖**Timeline** to **have the whole ITF** operation

➔ Who produces scientific data meanwhile?
❖ LVK

1st step needed: transition from pictorial views and concept designs to

- Actual infrastructures
- Technical Design Report





A sustainable approach

Analyse carefully the target

Experience with present detectors

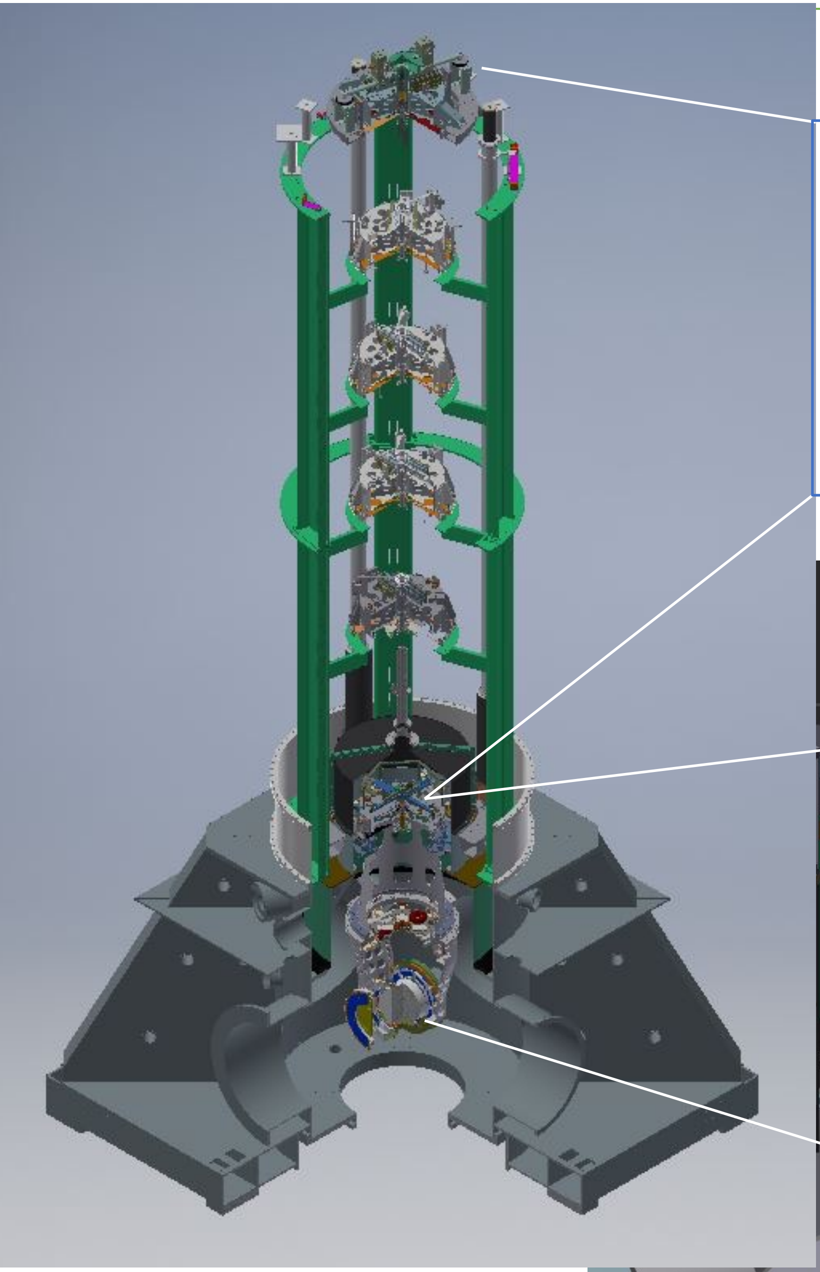
Widening the collaboration and gathering financial resources

Develop experimental facilities and identify the know-how

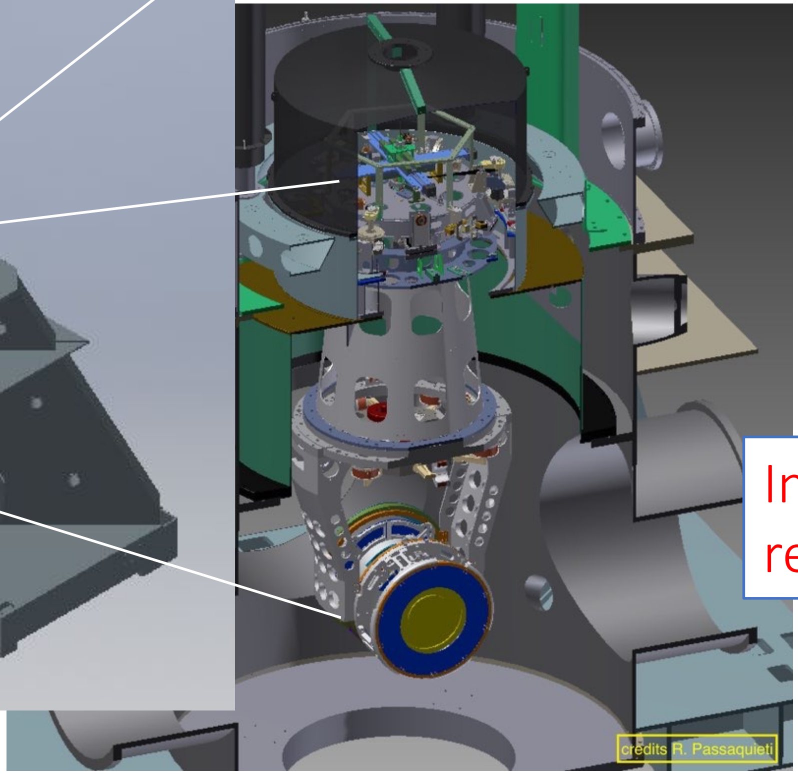
Aligning priorities and wisely schedule viable R&D milestones

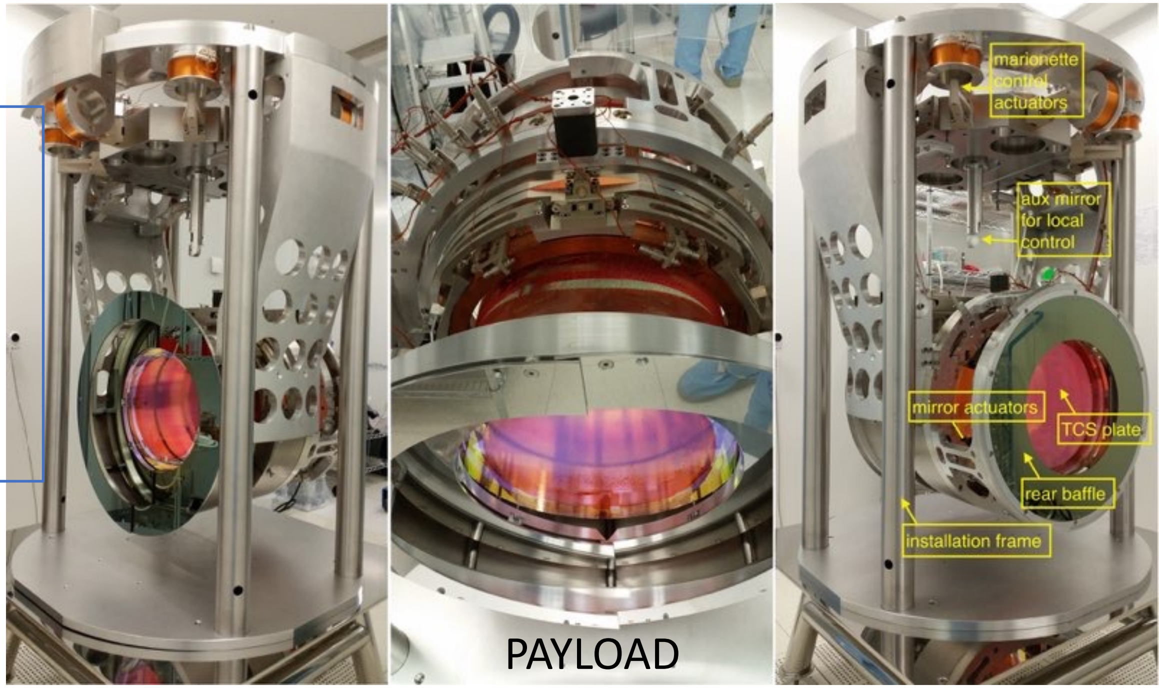
→ a meaningful TDR ?

Test mass suspensions and seismic isolator in Virgo: overall system



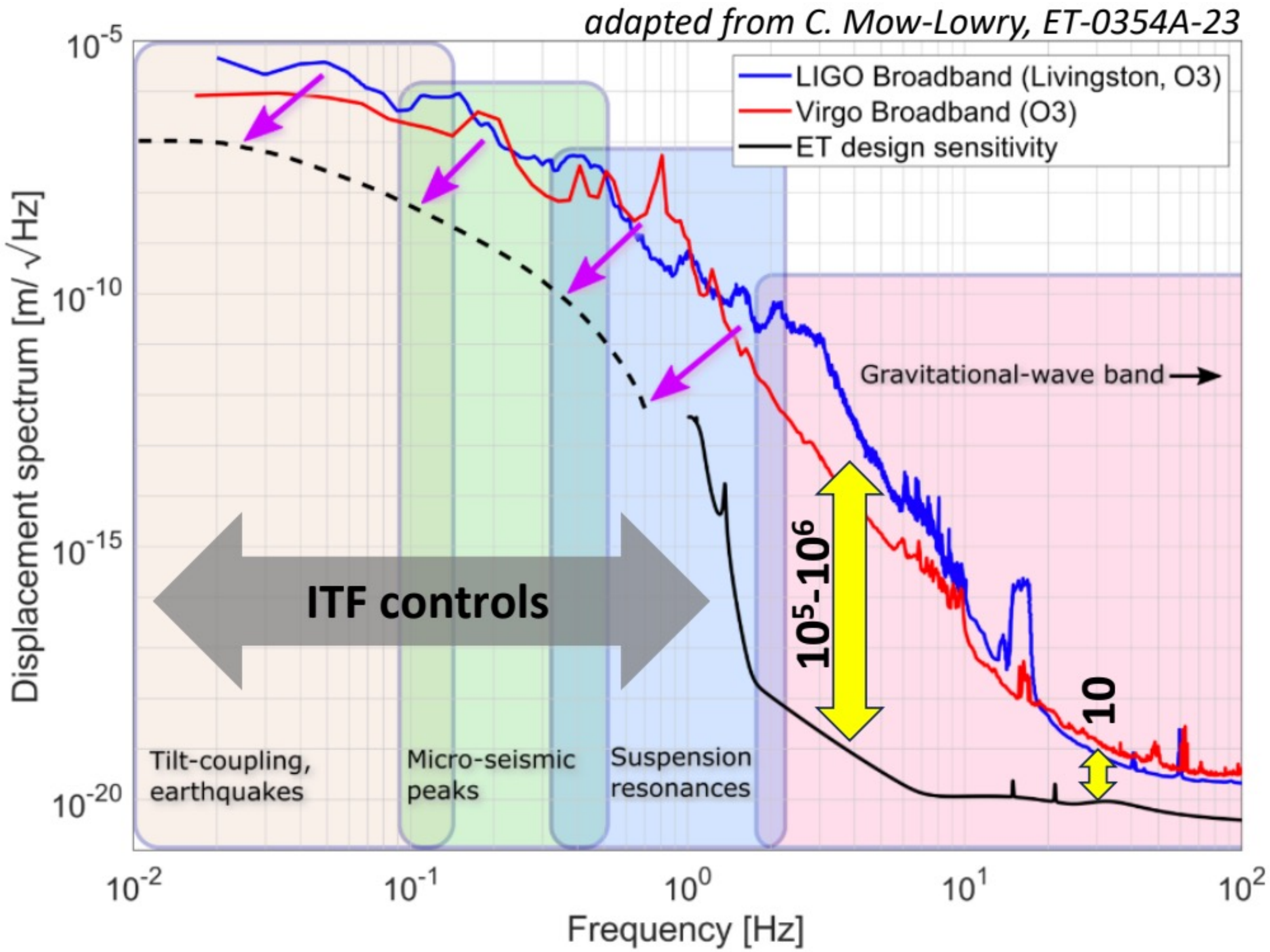
In AdV the first 5 stages of the Super-attenuator (horizontal and vertical) are roughly the same **designed ~30 years ago**





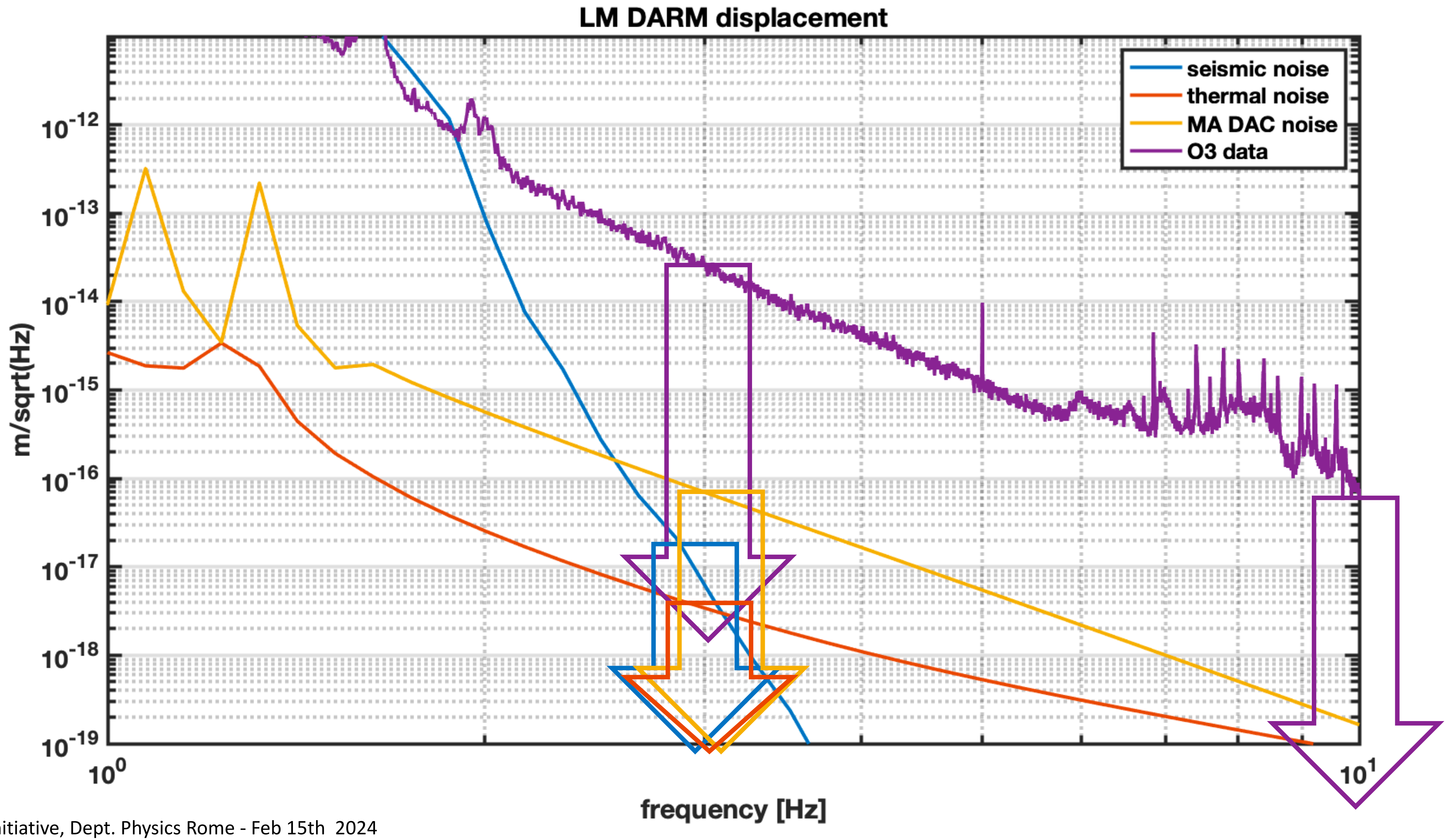
Indeed, the seismic suspension is already there ready for ET (!!), issues are elsewhere…

Low frequency sensitivity is not a trivial task: a comparison VS 2Generation detectors



From Room Temperature prospective: A) two issues TN (intrinsic),

B) Driving technical noise (electromechanical design a study is possible at RT) ➔ Let's track the intrinsic

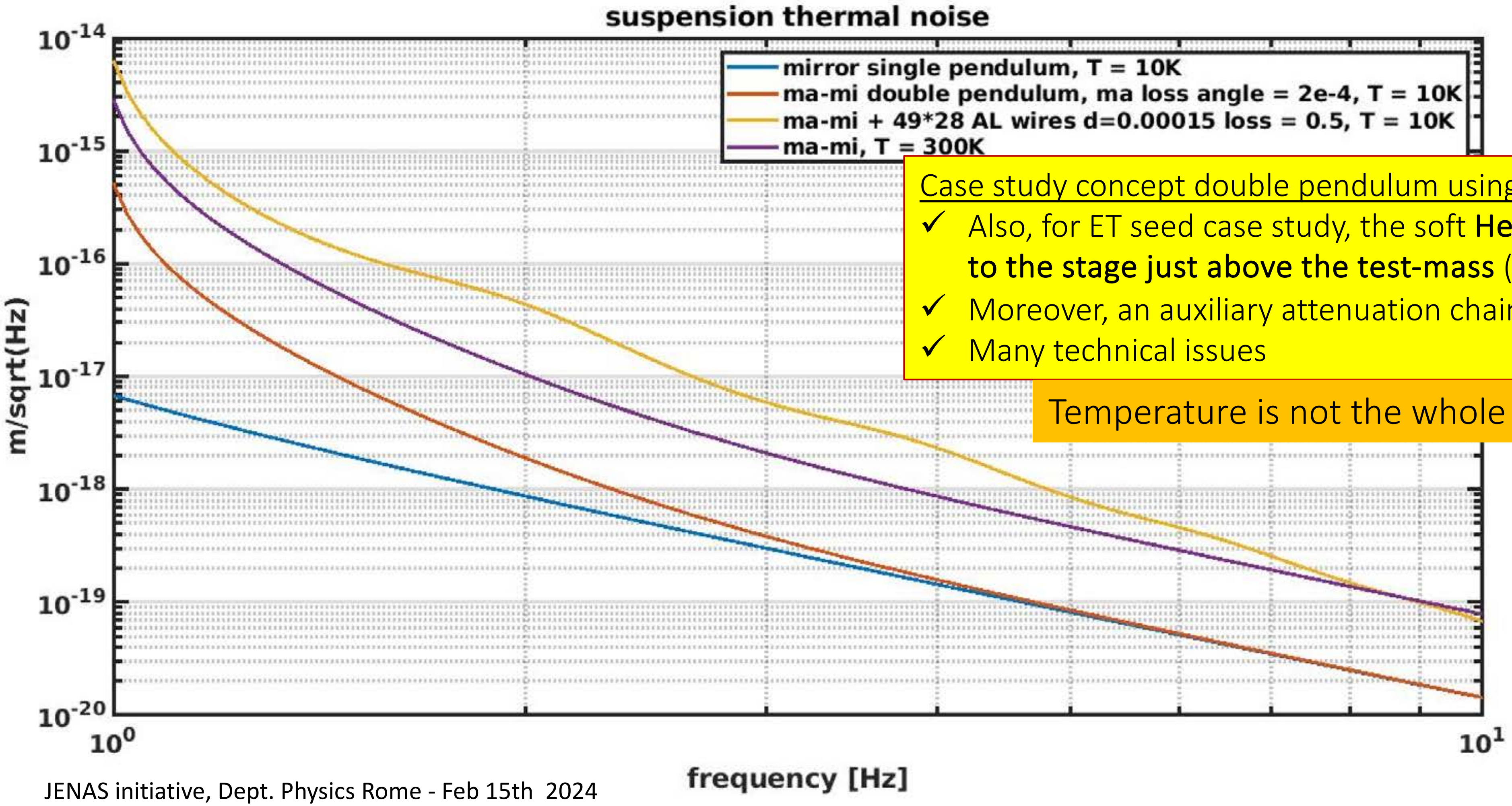


Example of HW examples, seed modelling for a “good test-mass payload”

- 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)



<u>Case study concept double pendulum using Al_2O_3 and Al6N multiwire</u>

- ✓ Also, for ET seed case study, the soft **HeatLinks cannot be connected to the stage just above the test-mass** (“marionette”)
- ✓ Moreover, an auxiliary attenuation chain inside the cryostat is needed
- ✓ Many technical issues

Temperature is not the whole story, FDT is what matters

E. Majorana GAWDW 2021

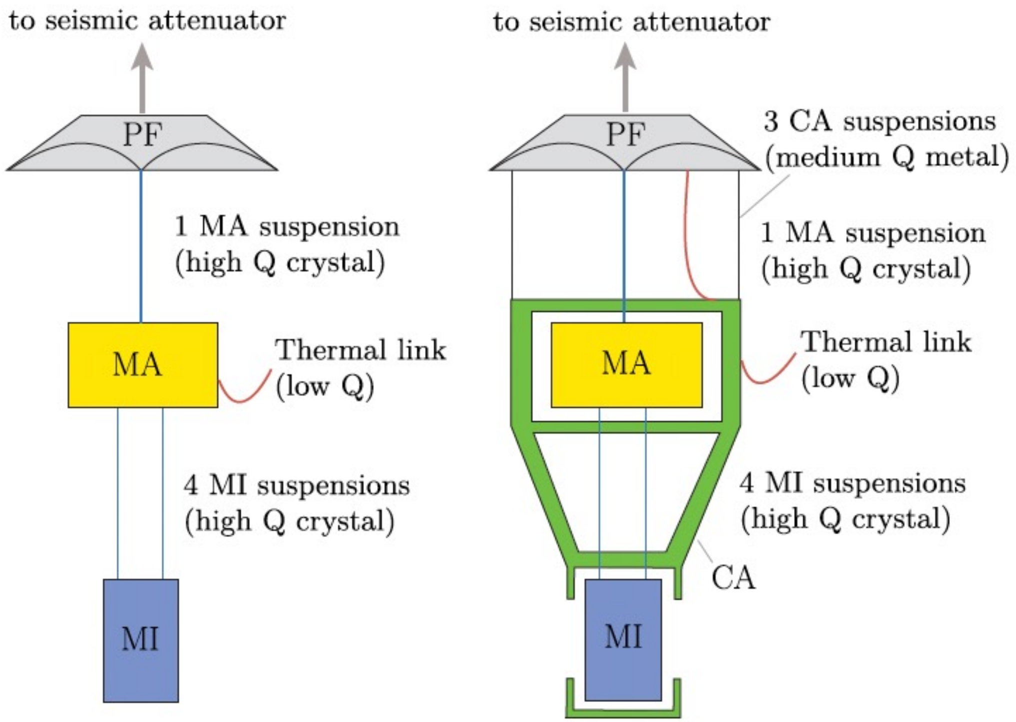
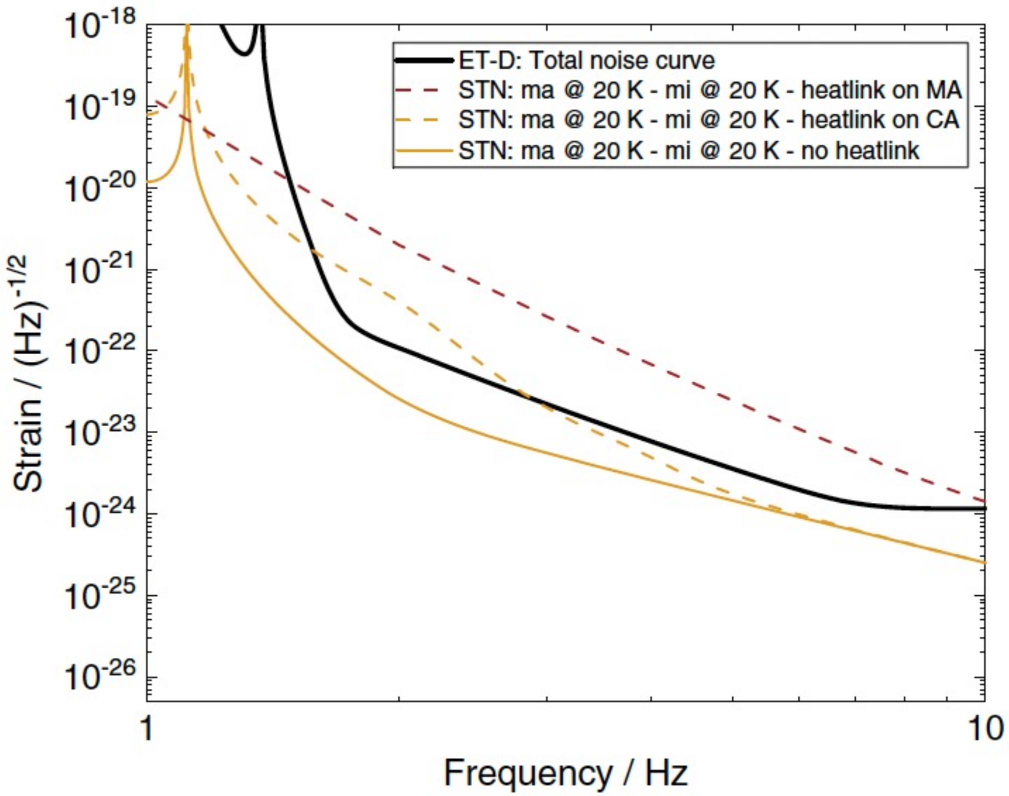


FIG. 3. Schemes of thermal link connection possibilities onto the cryogenic payload.

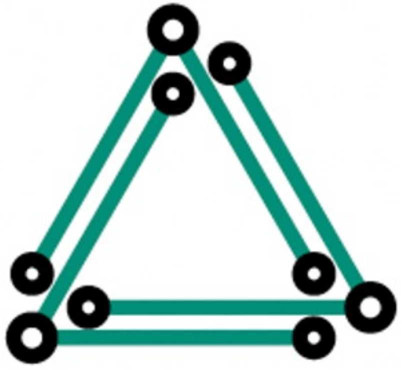


Suspension Thermal Noise

Seed designs are nowadays more accurate (X. Koroveshi et al., PHYS. REV. D 108, 123009 (2023)), but still require significant R&Ds

2nd step needed: decision about the site

EUregio Meuse-Rhine

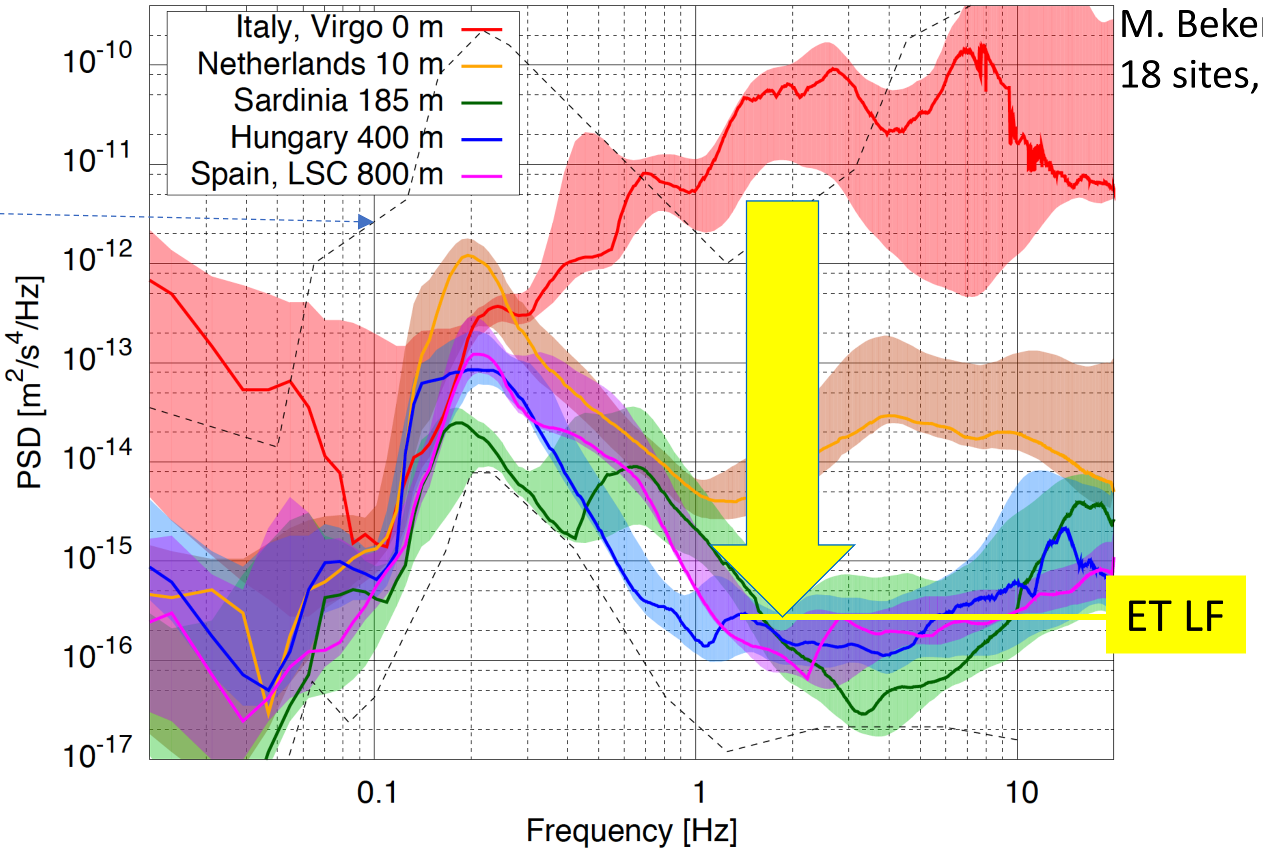


Sardinia

The site, an open issue…, but slowly converging

The site or "the sites" must be both located in a seismically quiet place

Peterson noise model: J. Havskov and G. Alguacil, "Instrumentation in Earthquake Seismology", Springer, 2009

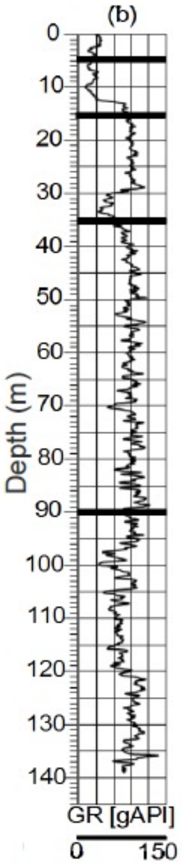


M. Beker exploration 2013:
18 sites, 12 underground: preliminary selection

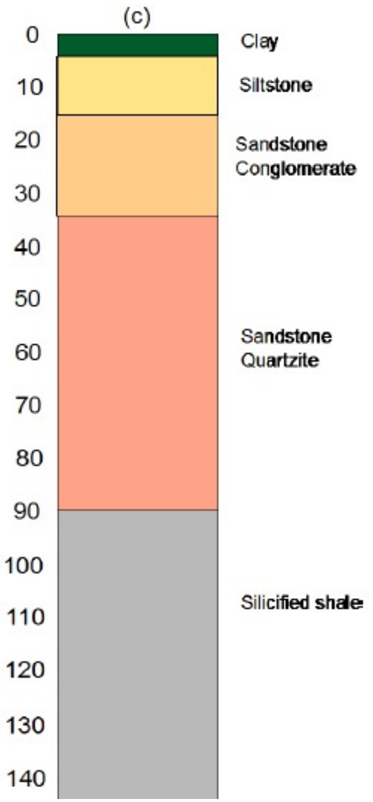
Severval possible sites in the world. Site selection started long ago, seismic aspects are not the whole story

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

Euregio Meuse-Rhine site (Terziet)



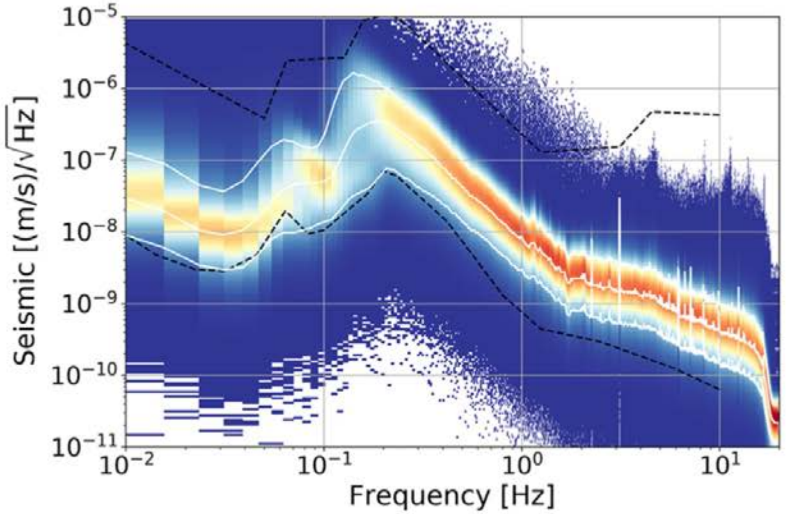
Gamma ray

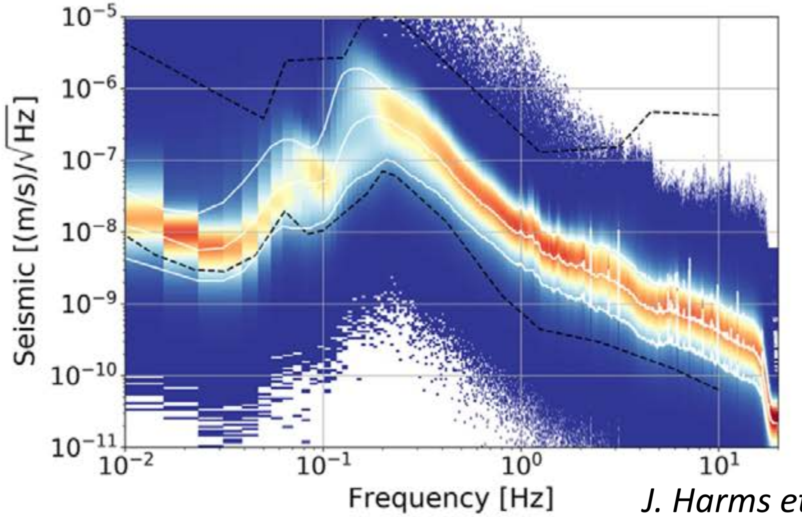


Credit: *S. Koley, GWADW 2021*

Lithology model

-250 m borehole





Notice that another candidate actor may enter in the game (Kamenz, in the Lusatia region, Saxony Germany)

J. Harms et al, Eur. Phys. J. Plus (2022) 137:687

Sardinia Sos Enattos

TAUP VIENNA 2023

Characterization of the Δ corners

INFN Istituto Nazionale di Fisica Nucleare

Seismometer installations & active seismic campaign

ET-0426A-21, https://apps.et-gw.eu/tds/?content=3&r=17710

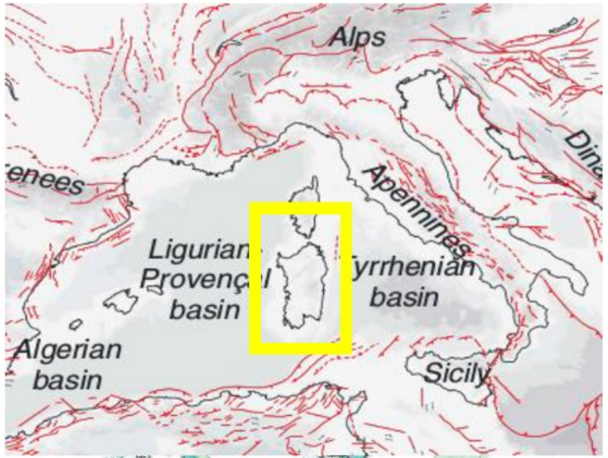
- Surface & borehole seismometer installed in Sept. 2021. Stations were improved during 2022, also with the installation of 2 magnetometers (P2). Optical fiber strainmeter deployed along both boreholes.
- Temporary surface array for passive and active seismic measurement at both corners.

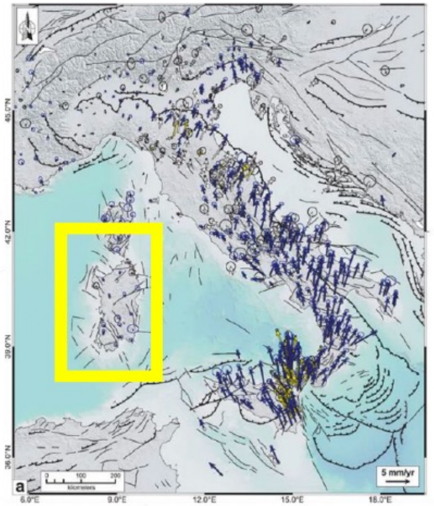
27

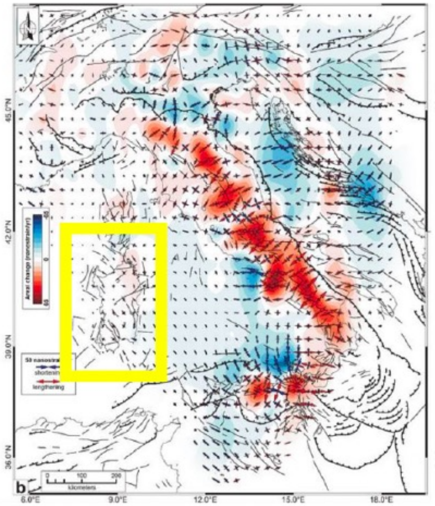
L. Naticchioni. Site Characterization in Sardinia for ET – XVIII TAUP 2023

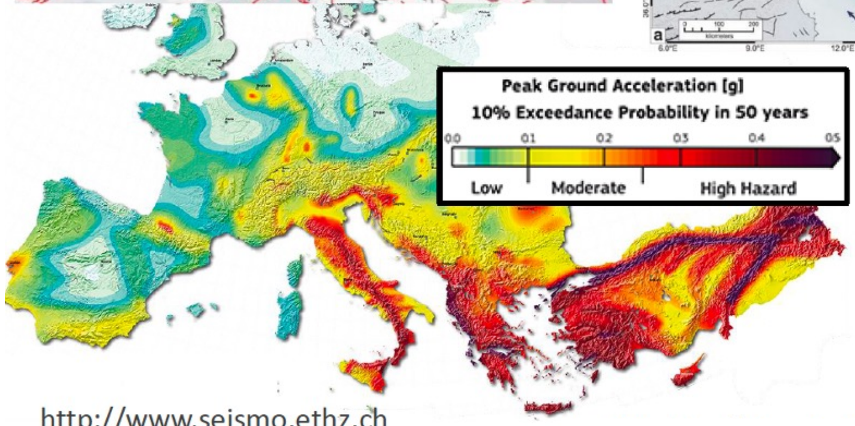
Sardinia Sos Enattos

Far from active fault lines, the Corsica-Sardinia microplate is very stable → low crustal deformation.

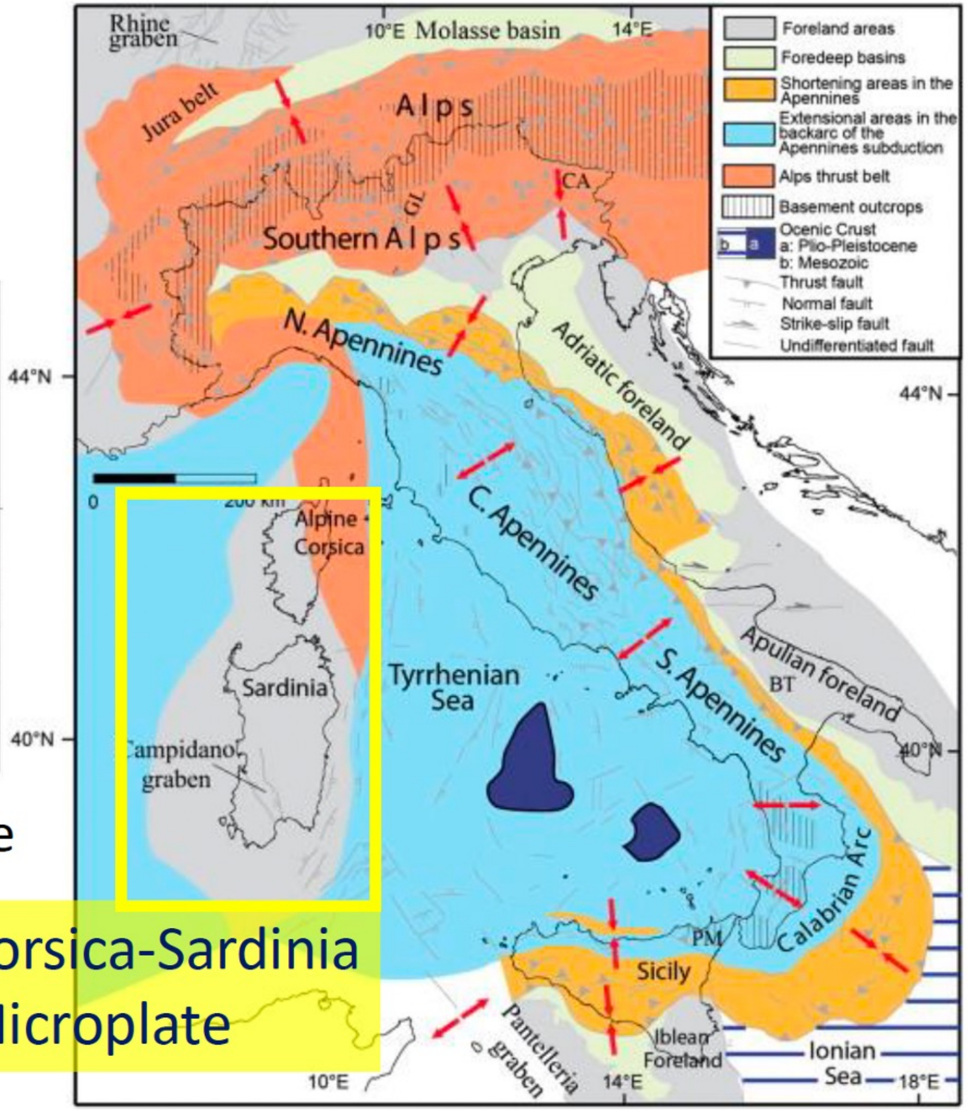








Unaffected by significative seismic activity.



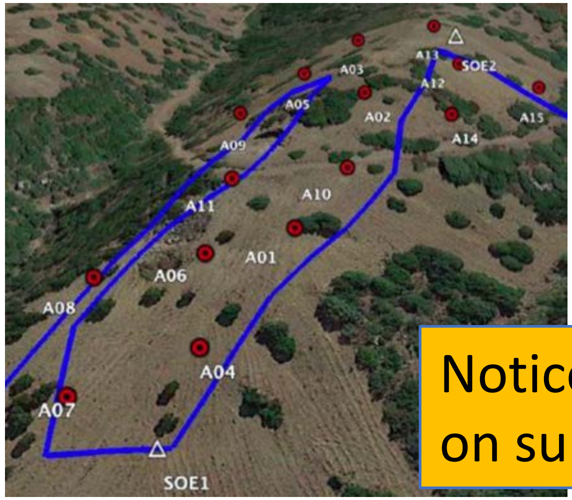
http://www.seismo.ethz.ch

Credits L. Naticchioni

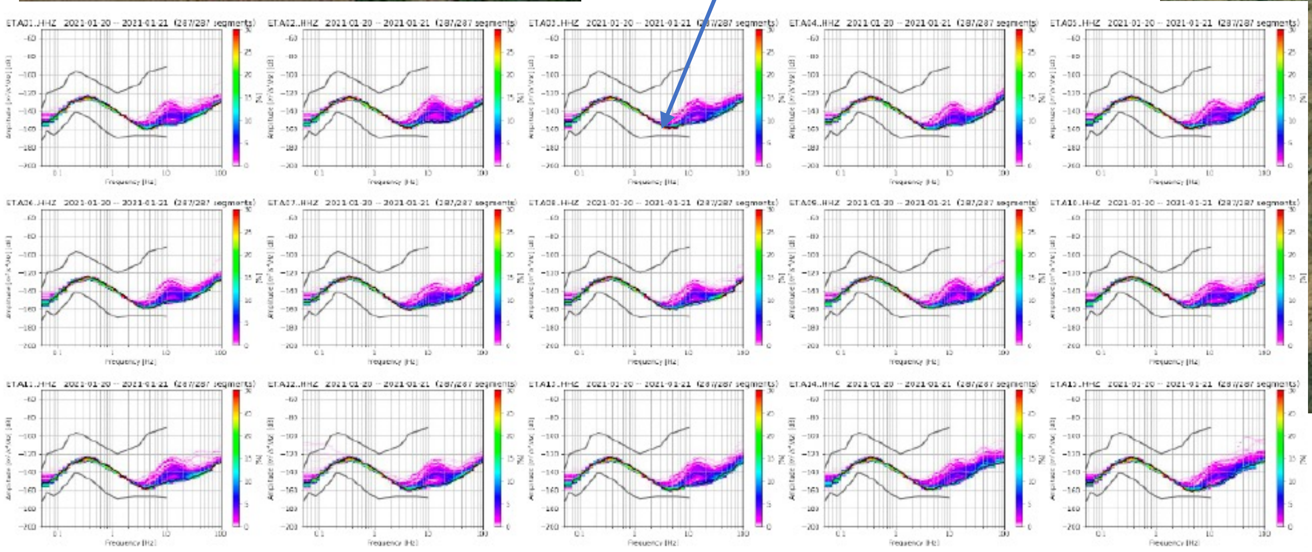
7

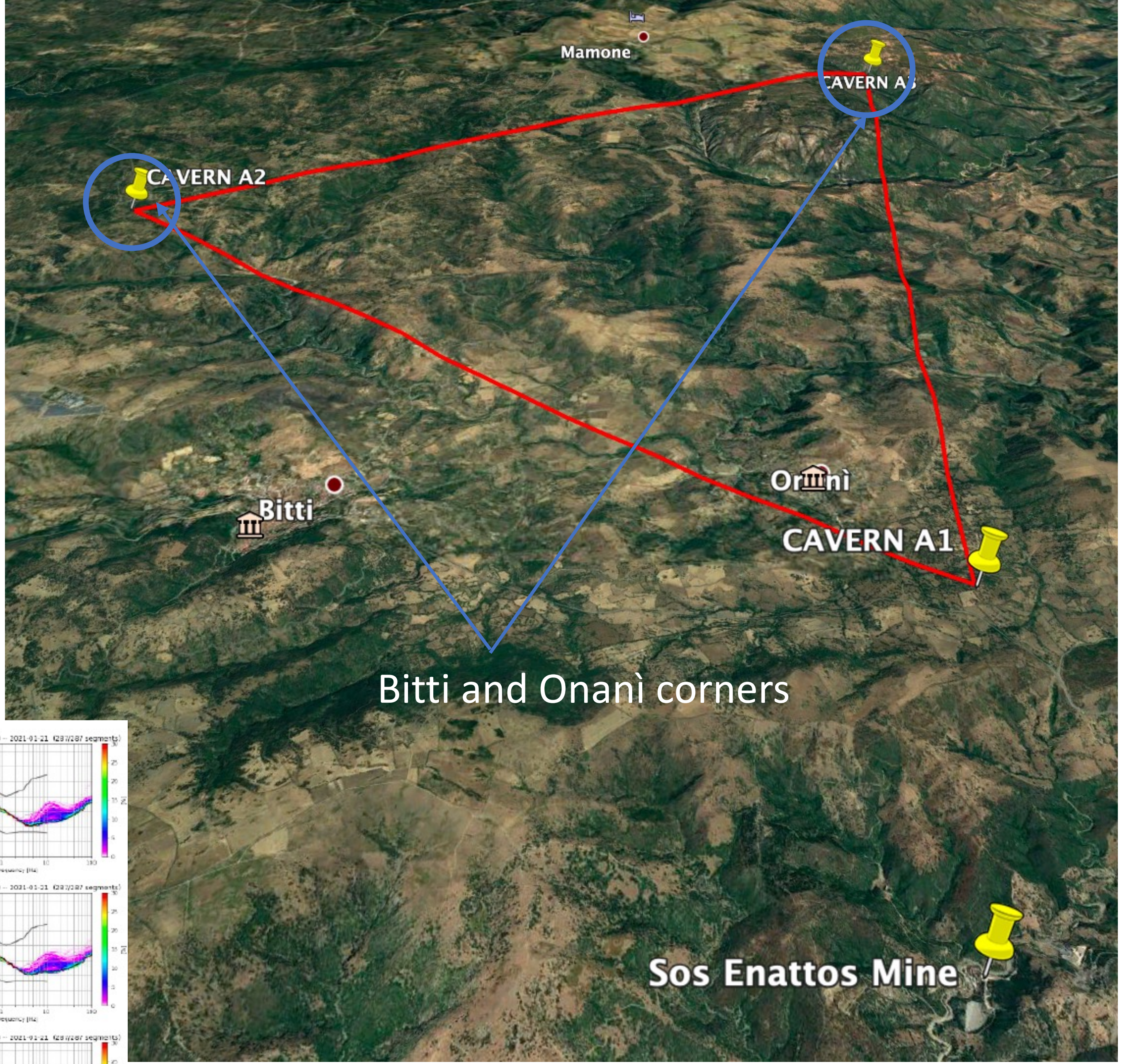
Sardinia Sos Enattos

A similar campaign with boreholes and surface started in 2021



Notice: measurements on surface on a hill!





Sardinia Sos Enattos

A very clear result

Other studies concern:
- Newtonian glitching
- E.M. noise (Schumann)
- Microseism
- Antropic

Sardinia site cannot be compared to Terziet

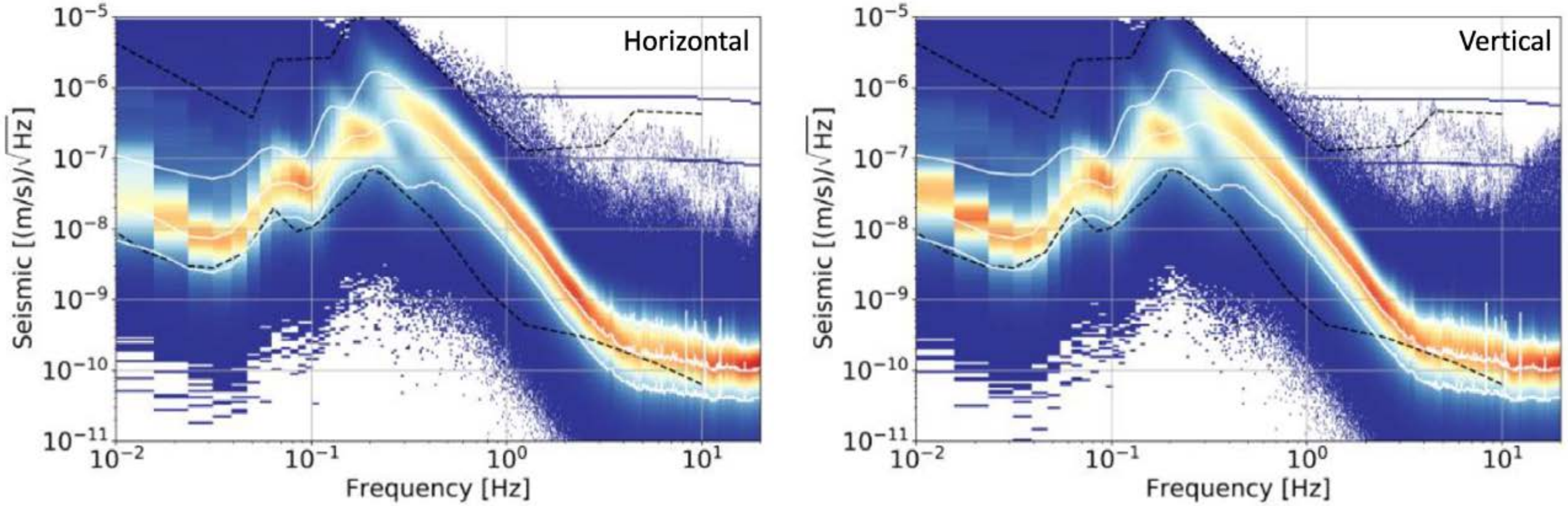
TAUP VIENNA 2023

Characterization of the Δ corners

INFN Istituto Nazionale di Fisica Nucleare

A quick glance at the measurements

PPSD - P2 borehole seismometer



Very low noise background in the 2-10 Hz band, sometimes even **below** the Peterson's **New Low Noise Model**!

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L. Naticchioni, Site Characterization in Sardinia for ET – XVIII TAUP 2023

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

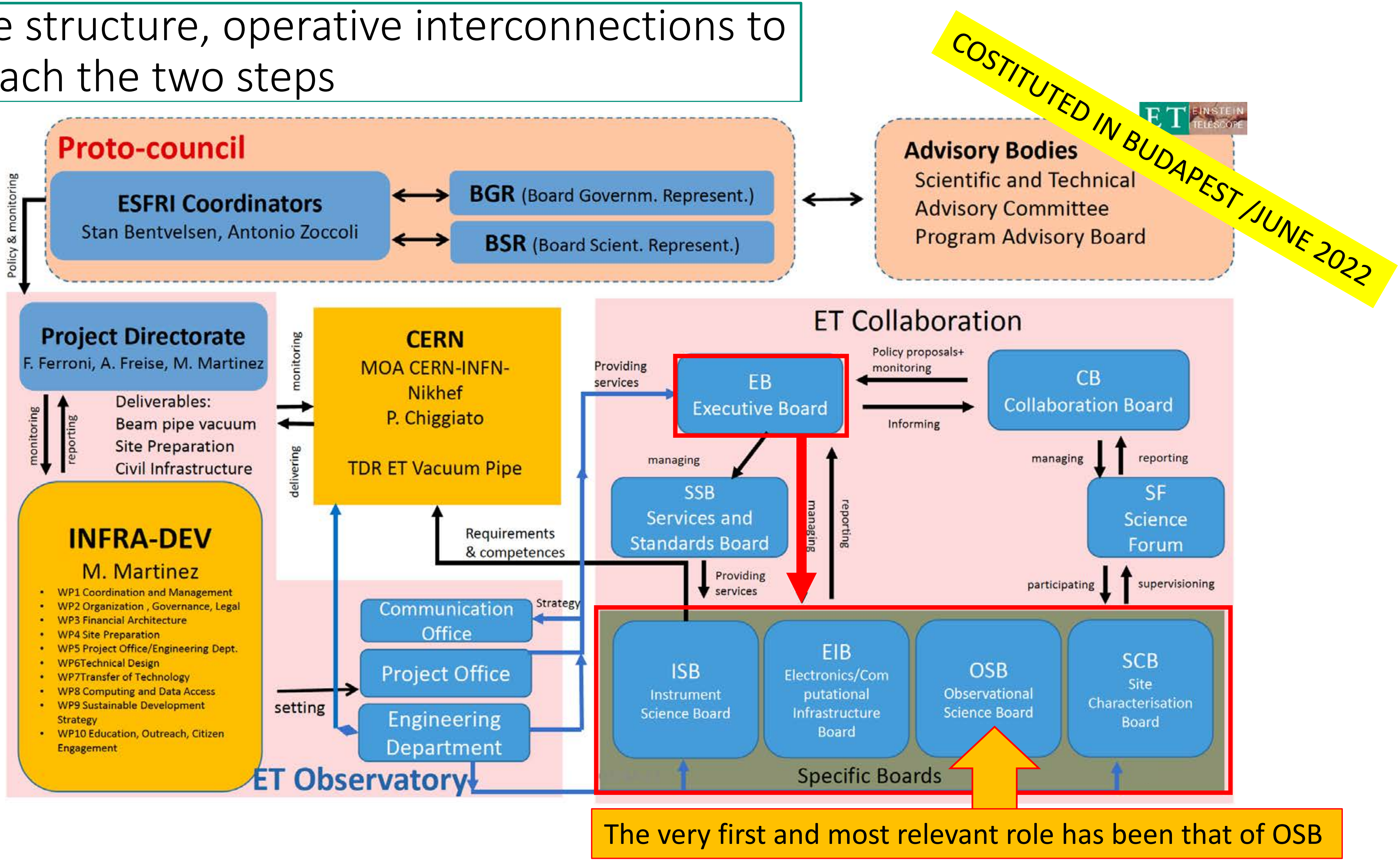
M. Di Giovanni et al., ***A seismological study of the SosEnattos Area - the Sardinia Candidate Site for the Einstein Telescope***, **SRL**, 2020 https://doi.org/10.1785/0220200186

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

M. Di Giovanni et al, ***Temporal variations of the ambient seismic field at the Sardinia candidate site of the Einstein Telescope*** *Geophys. J. Int.* (2023) **234,** 1943–1964

G. Saccorotti et al., Array analysis of seismic noise at the Sos Enattos mine, the Italian candidate site for the Einstein Telescope, accepted by EPJP, 2023.

ET, the structure, operative interconnections to approach the two steps



CoBA: cost benefit analysis to orientate choices

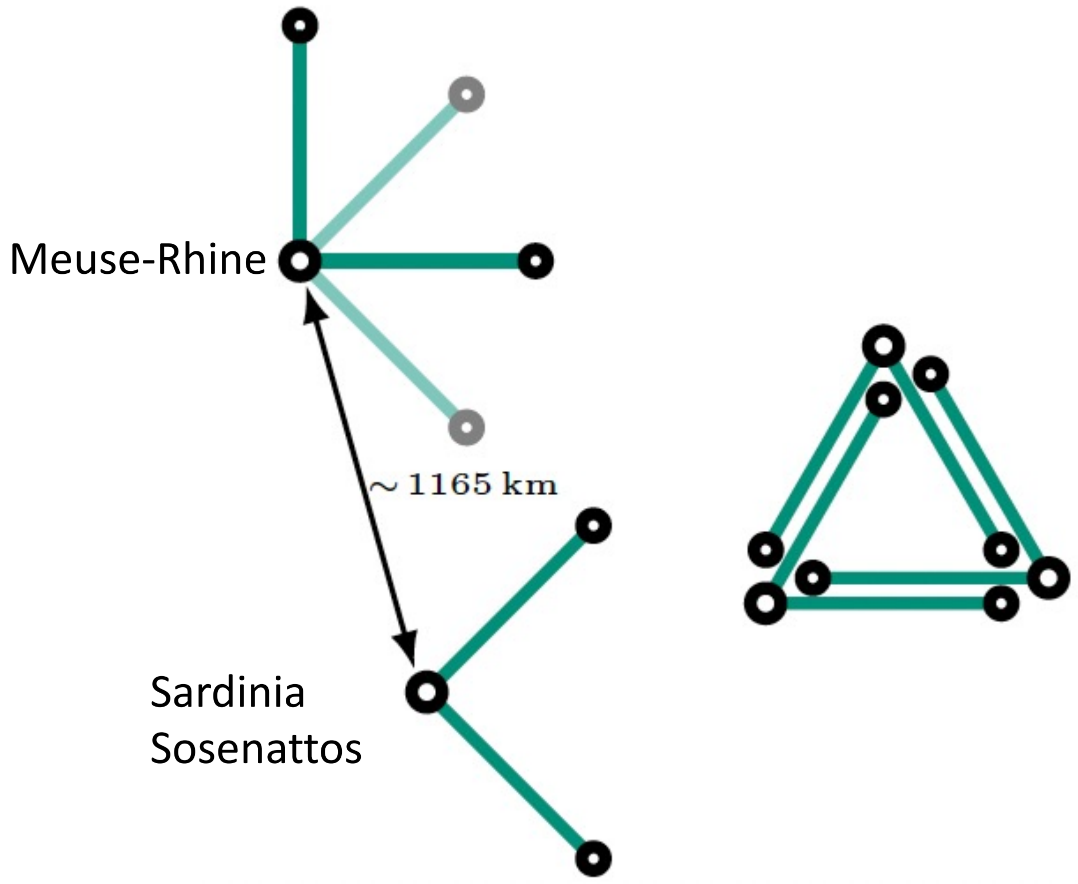
Given reasonable estimate of budget constraints, upon Concept Designs 2010-2020, the targets are:

❖ Shortening the implementation schedule

❖ Enhancing the scientific outcome

The method, crucial to go ahead, are:

1) First, analysing ET configuration system



2) Then, projecting in the network context with Cosmic Explorer

The triangle/L debate (indeed … quite advanced!)

A second study :mostly dedicated to Cost-Benefit Analysis

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Science with the Einstein Telescope: a comparison of different designs

Marica Branchesi et al. JCAP07(2023)068

$\mathcal{M}_c, \eta, d_L, \theta, \phi, \iota, \psi, t_c, \Phi_c, \chi_{1,x}, \chi_{2,x}, \chi_{1,y}, \chi_{2,y}, \chi_{1,z}, \chi_{2,z}, \Lambda_1, \Lambda_2$

VS

Geometry and topology

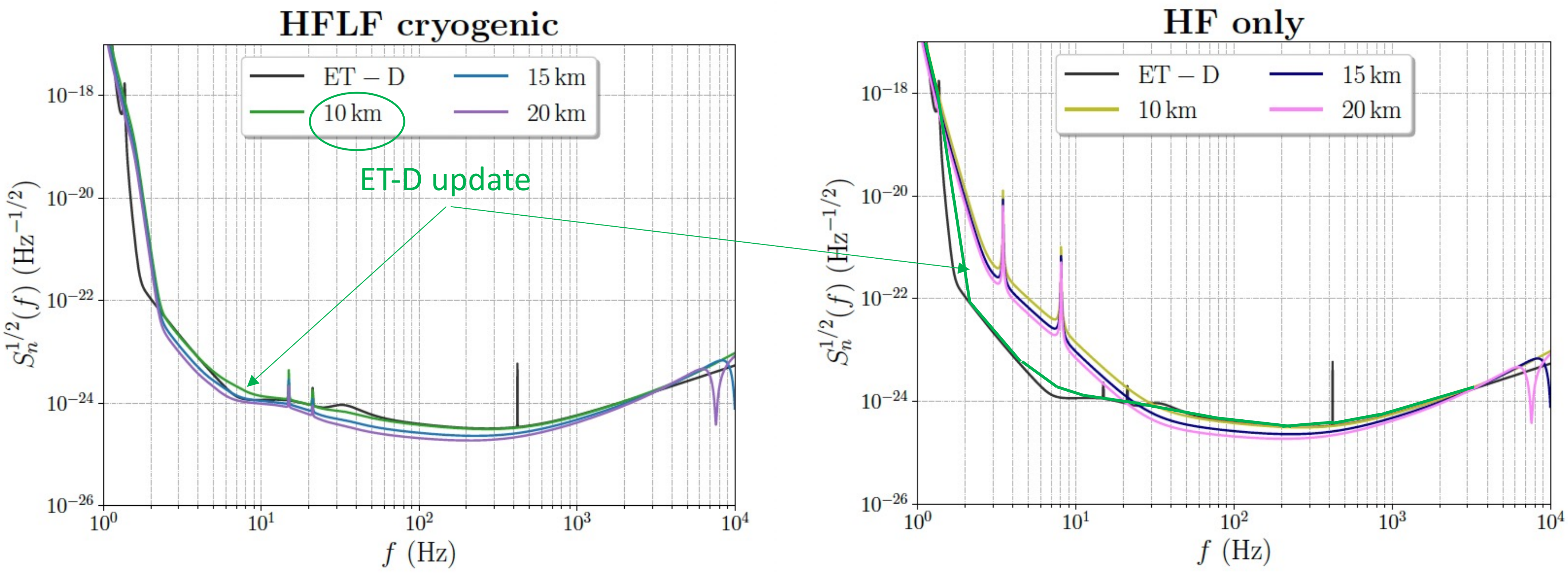
- triangle, 10km arms (current ET geometry baseline)
- 2L, 15 km arms, parallel
- 2L, 15 km arms at 45 deg
- triangle, 15 km arms
- 2L, 20 km arms, parallel
- 2L, 20 km arms at 45 deg

Notice

Due to different tunnel diameters, triangle-15km and 2L-20km have **comparable excavation** volumes

A detailed cost analysis is ongoing

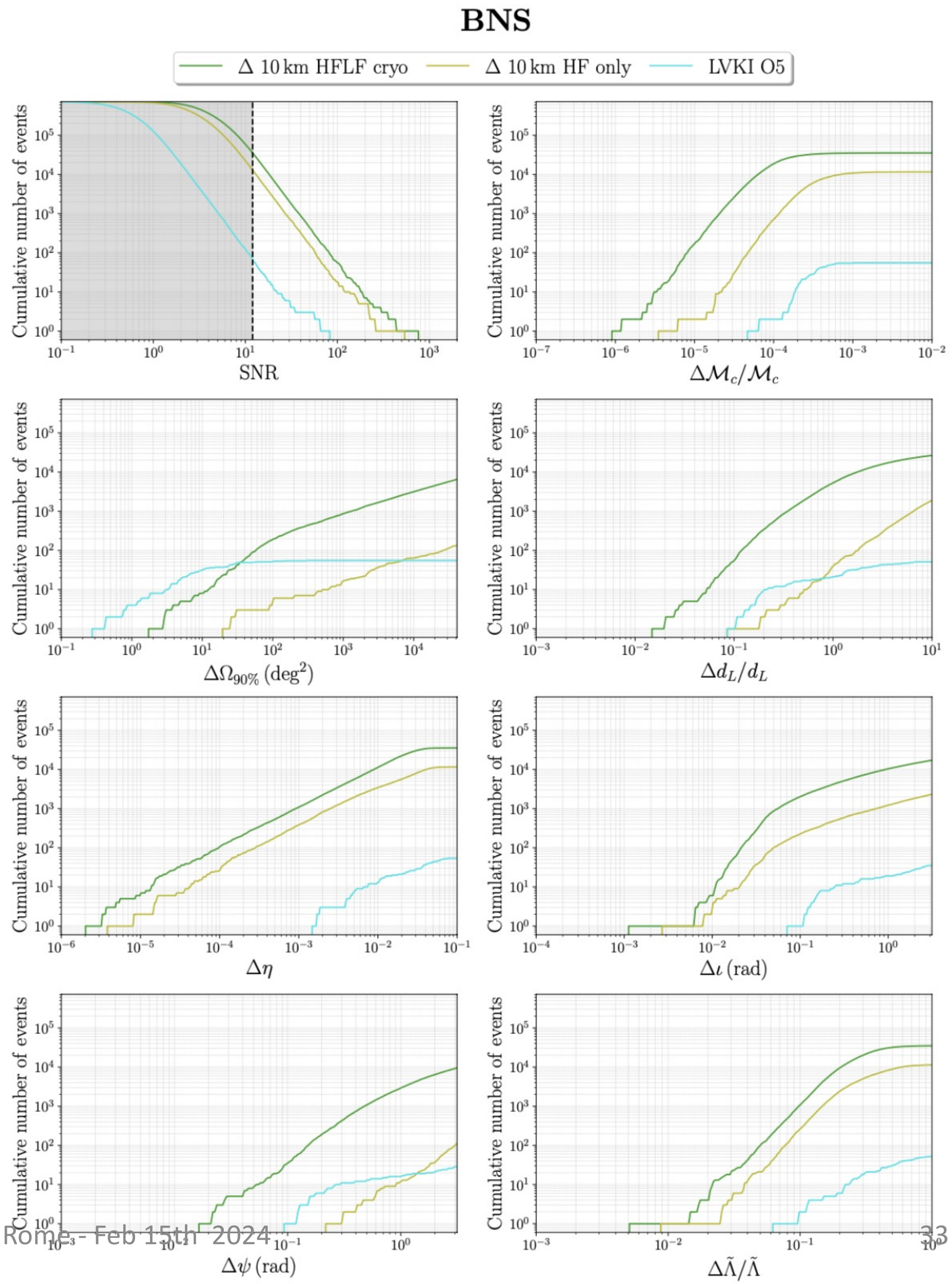
Pure impact of length on triangle geometry w/wo LF instrument



Not so impressive WRT the cost increase expectation foreseen for the triangle and concerning vacuum and excavation

BNS

Missing Low Frequency sensitivity with ET (to save money, to hurry up), or because the hardware does not work… (seismic isolation, cryogenics, low noise electronics …)
➔ strongly affects BNS detection (longer time in bandwidth)
E.g. GW170817 would stay about 1 day in ET BW before the merger with the full HFLF-cryo sensitivity, but only O(10) minutes before the merger.

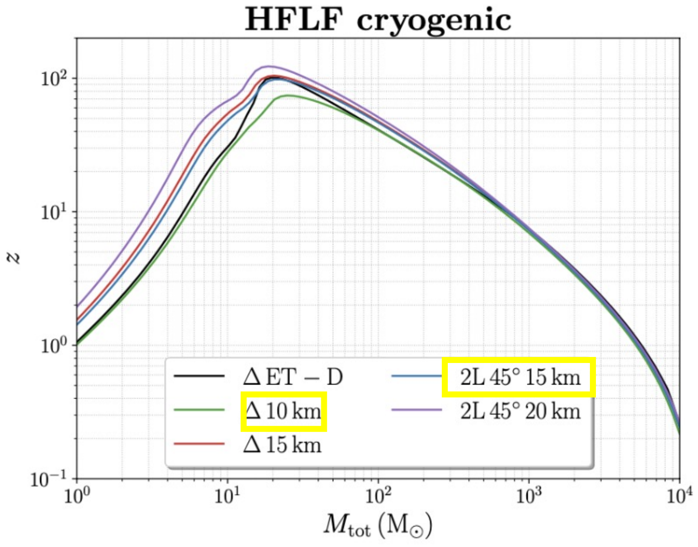


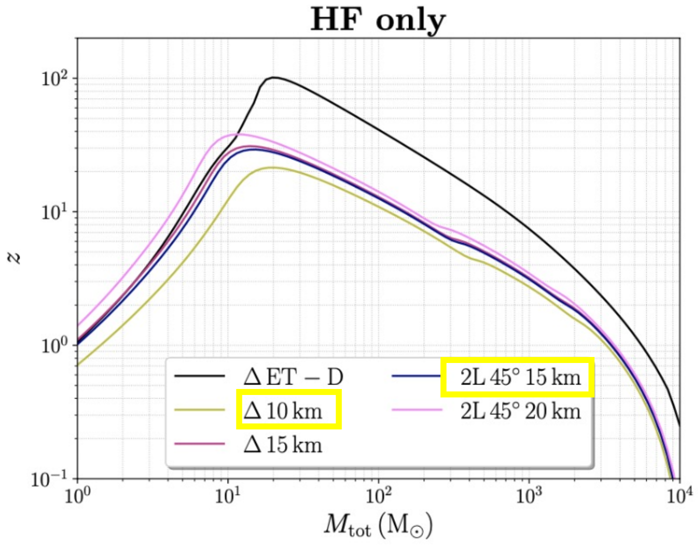
All the cases have been studied and in particular:

- W/WO LowFreq implementations

❖ localization loosing Δ10km VS 2L-15km45deg
❖ event rates VS z

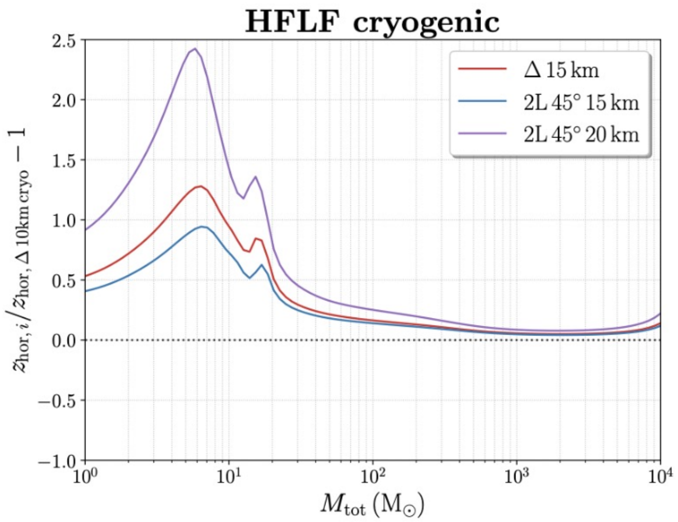
NSNS range

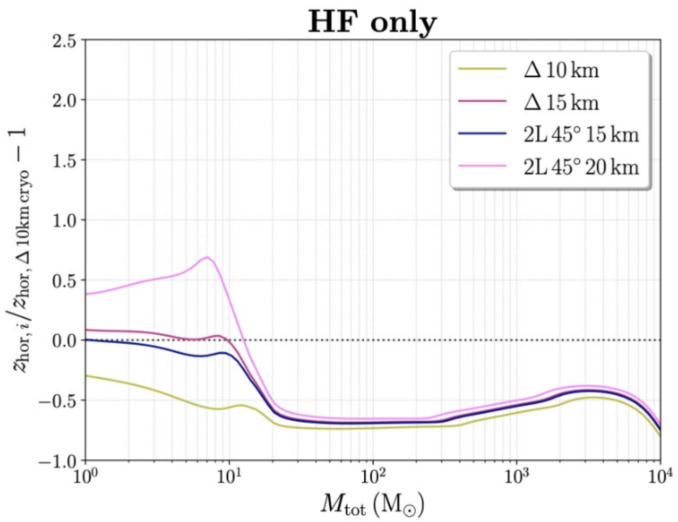




2L 15 km 45 deg
are better than tringle
15 km

Horizon: relative differences VS full (HFLF-cryo) 10km triangle





Full (HFLF cryo) sensitivity detectors

$\Delta\Omega_{90\%}(\mathrm{deg}^2)$	All orientation BNSs				BNSs with viewing angle $\Theta_v < 15°$			
	Δ10	Δ15	2L 15	2L 20	Δ10	Δ15	2L 15	2L 20
10	11	27	24	45	0	1	2	5
40	78	215	162	350	8	22	20	33
100	280	764	644	1282	26	74	68	133
1000	2112	5441	7478	13482	272	632	1045	1725

Table 1. Expected number of detection (SNR $\geq$ 8) per year with sky-localization uncertainty $\Delta\Omega_{90\%}(\mathrm{deg}^2)$ smaller than the threshold indicated in the first column. While the columns 2-5 give the detections for BNS systems randomly oriented, the columns 5-9 give the detection of on-axis events, whose viewing angle is smaller than 15°. The numbers are relative to one year of observation assuming a duty cycle of 0.85 as described in the text.

HF sensitivity detectors

$\Delta\Omega_{90\%}(\mathrm{deg}^2)$	All orientation BNSs				BNSs with viewing angle $\Theta_v < 15°$			
	Δ10	Δ15	2L 15	2L 20	Δ10	Δ15	2L 15	2L 20
10	0	1	5	5	0	0	2	2
40	4	10	20	47	0	5	6	17
100	14	53	76	144	7	33	35	64
1000	145	548	1662	3378	80	336	672	1302

Table 2. Same as table 1 but considering the detectors operating with only the HF interferometers.

GRB correlated detection rate depletion due to Full LF ➔ HF

Full (HFLF cryo) sensitivity detectors

Instrument	$\Delta 10$	$\Delta 15$	2L 15	2L 20	$\Delta 10$	$\Delta 15$	2L 15	2L 20
Fermi-GBM	31^{+9}_{-9}	42^{+11}_{-13}	39^{+11}_{-9}	44^{+13}_{-11}	$61^{+12}_{-11}\%$	$83^{+9}_{-10}\%$	$79^{+8}_{-11}\%$	$89^{+4}_{-8}\%$
GECAM	61^{+39}_{-25}	89^{+54}_{-34}	81^{+51}_{-32}	96^{+52}_{-36}	$51^{+5}_{-6}\%$	$74^{+5}_{-5}\%$	$70^{+3}_{-6}\%$	$80^{+4}_{-4}\%$
HERMES	86^{+31}_{-28}	120^{+40}_{-31}	117^{+37}_{-34}	132^{+34}_{-34}	$55^{+9}_{-7}\%$	$78^{+8}_{-7}\%$	$74^{+9}_{-9}\%$	$85^{+5}_{-6}\%$
GRINTA-TED	77^{+31}_{-25}	107^{+31}_{-28}	98^{+31}_{-25}	114^{+34}_{-28}	$57^{+10}_{-9}\%$	$79^{+8}_{-8}\%$	$74^{+9}_{-9}\%$	$85^{+5}_{-5}\%$
ASTROGAM	18^{+8}_{-5}	24^{+9}_{-7}	24^{+9}_{-6}	27^{+8}_{-7}	$59^{+11}_{-9}\%$	$80^{+8}_{-8}\%$	$77^{+8}_{-9}\%$	$86^{+6}_{-9}\%$
THESEUS-XGIS	10^{+3}_{-3}	13^{+3}_{-3}	13^{+3}_{-3}	15^{+3}_{-4}	$57^{+9}_{-10}\%$	$79^{+8}_{-9}\%$	$73^{+11}_{-7}\%$	$85^{+7}_{-5}\%$

- 40%

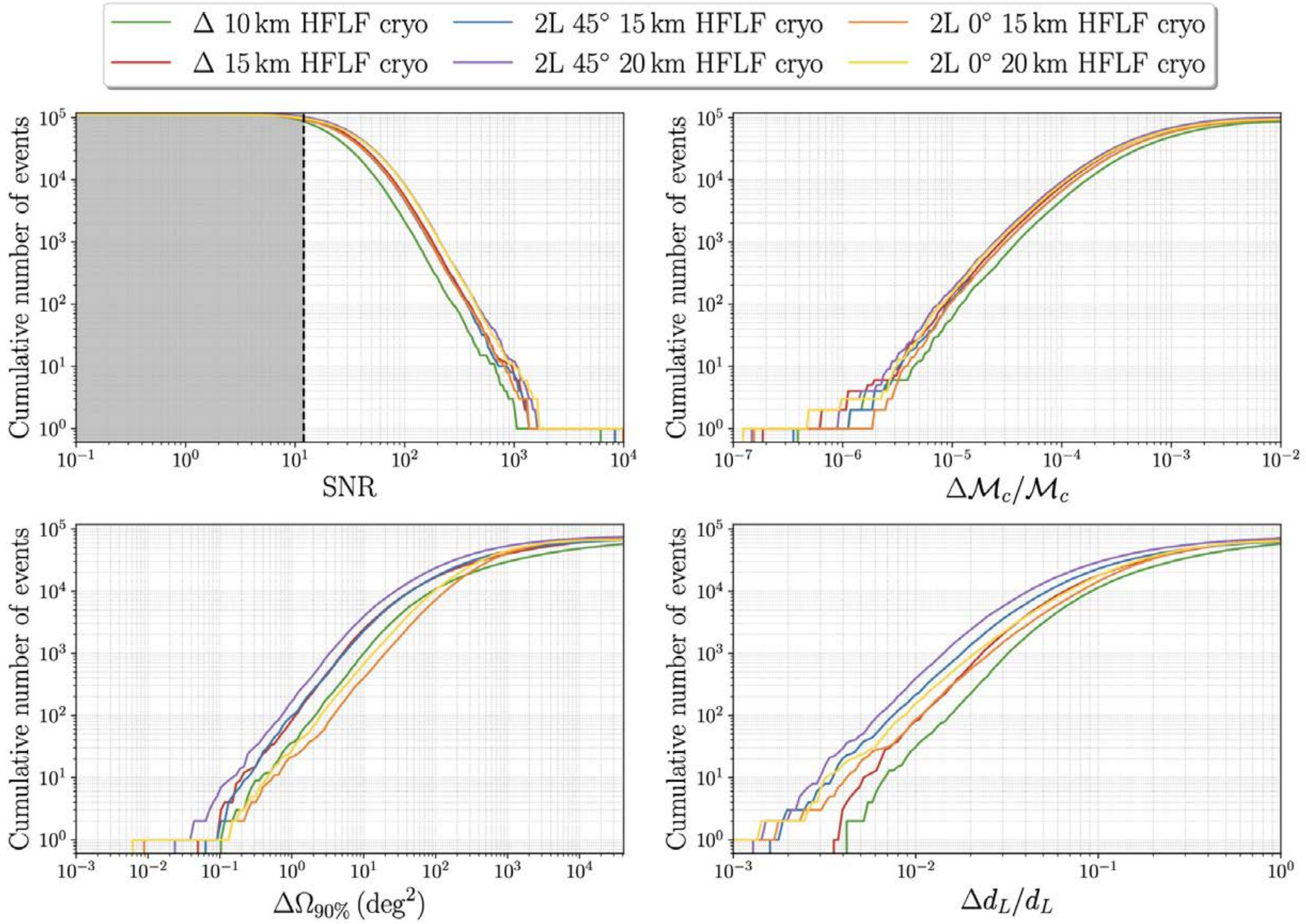
- 20%

HF sensitivity detectors

Instrument	$\Delta 10$	$\Delta 15$	2L 15	2L 20	$\Delta 10$	$\Delta 15$	2L 15	2L 20
Fermi-GBM	20^{+8}_{-7}	33^{+9}_{-9}	29^{+11}_{-9}	38^{+12}_{-10}	$39^{+11}_{-8}\%$	$64^{+12}_{-11}\%$	$60^{+12}_{-11}\%$	$76^{+9}_{-9}\%$
GECAM	35^{+21}_{-15}	62^{+38}_{-22}	58^{+38}_{-22}	77^{+47}_{-30}	$29^{+4}_{-5}\%$	$54^{+4}_{-5}\%$	$49^{+4}_{-7}\%$	$66^{+4}_{-6}\%$
HERMES	52^{+21}_{-18}	91^{+30}_{-29}	83^{+28}_{-28}	107^{+40}_{-31}	$33^{+7}_{-8}\%$	$58^{+10}_{-8}\%$	$53^{+10}_{-8}\%$	$71^{+8}_{-8}\%$
GRINTA-TED	46^{+22}_{-16}	80^{+31}_{-25}	74^{+28}_{-25}	94^{+33}_{-23}	$34^{+9}_{-9}\%$	$61^{+9}_{-11}\%$	$55^{+9}_{-10}\%$	$72^{+9}_{-9}\%$
ASTROGAM	12^{+6}_{-5}	19^{+7}_{-5}	18^{+6}_{-6}	23^{+8}_{-7}	$37^{+11}_{-10}\%$	$62^{+9}_{-11}\%$	$57^{+10}_{-9}\%$	$74^{+9}_{-10}\%$
THESEUS-XGIS	6^{+2}_{-2}	10^{+3}_{-3}	9^{+3}_{-3}	12^{+3}_{-3}	$34^{+8}_{-9}\%$	$59^{+10}_{-8}\%$	$54^{+10}_{-9}\%$	$71^{+9}_{-9}\%$

In general shorter permanence in the BW affect other HF detectable MMS signals (e.g. kNovae)

BBH



2L 20 km 45 deg is the best, but even 2L 15 km 45 deg is better than 10 km triangle

Configuration	SNR ≥ 8	SNR ≥ 12	SNR ≥ 50	SNR ≥ 100	SNR ≥ 200
Δ-10km-HFLF-Cryo	103 528	87 568	13 674	2298	282
Δ-15km-HFLF-Cryo	111 231	101 308	26 092	5730	759
2L-15km-45°-HFLF-Cryo	107 661	97 205	23 491	4933	644
2L-20km-45°-HFLF-Cryo	110 698	103 773	34 009	8828	1267
2L-15km-0°-HFLF-Cryo	104 935	94 015	24 088	5143	642
2L-20km-0°-HFLF-Cryo	106 417	98 274	32 915	8551	1246
Δ-10km-HF	87 125	65 092	5595	773	98
Δ-15km-HF	102 149	85 698	13 697	2360	292
2L-15km-45°-HF	97 881	81 210	12 089	1987	248
2L-20km-45°-HF	105 032	93 050	20 551	4144	515
2L-15km-0°-HF	89 707	73 696	10 688	1732	201
2L-20km-0°-HF	104 558	92 308	21 970	4540	569
Δ-10km-HFLF-Cryo+CE-40km	115 179	110 118	44 676	12 590	1805
2L-15km-45°-HFLF-Cryo+CE-40km	116 328	112 661	50 947	15 545	2355
2L-15km-0°-HFLF-Cryo+CE-40km	114 816	110 265	49 034	14 820	2243
Δ-10km-HFLF-Cryo+2CE	117 045	113 910	52 092	16 109	2505
2L-15km-45°-HFLF-Cryo+2CE	117 436	115 166	57 678	19 028	3126
2L-15km-0°-HFLF-Cryo+2CE	116 639	113 597	55 218	17 849	2917
LVKI-O5	8603	2861	47	4	2

Configuration	$\Delta d_L/d_L \leq 0.1$	$\Delta d_L/d_L \leq 0.01$	$\Delta\Omega_{90\%} \leq 50\,\text{deg}^2$	$\Delta\Omega_{90\%} \leq 10\,\text{deg}^2$
Δ-10km-HFLF-Cryo	10 969	28	6064	914
Δ-15km-HFLF-Cryo	17 321	77	10 470	2273
2L-15km-45°-HFLF-Cryo	22 237	202	10 304	2124
2L-20km-45°-HFLF-Cryo	28 801	365	14 920	3648
2L-15km-0°-HFLF-Cryo	13 865	79	3030	374
2L-20km-0°-HFLF-Cryo	17 008	144	4706	608
LVKI-O5	767	1	1607	599

Configuration	$\Delta\mathcal{M}_c/\mathcal{M}_c \leq 10^{-3}$	$\Delta\mathcal{M}_c/\mathcal{M}_c \leq 10^{-4}$	$\Delta\chi_1 \leq 0.05$	$\Delta\chi_1 \leq 0.01$
Δ-10km-HFLF-Cryo	48 922	4549	27 877	2811
Δ-15km-HFLF-Cryo	64 469	7703	41 612	4856
2L-15km-45°-HFLF-Cryo	58 371	6456	35 943	3958
2L-20km-45°-HFLF-Cryo	67 999	9073	45 666	5706
2L-15km-0°-HFLF-Cryo	57 330	6472	33 236	3653
2L-20km-0°-HFLF-Cryo	63 154	8279	40 068	4935
LVKI-O5	78	1	155	20

In general 2L-15km 45 deg shows up as a better choice for the determination of the majority of parameters

Network Science Case

ET (+1CE)	$N_{det}(SNR \geq 12)$	$N_{det}(SNR \geq 50)$	$N_{det}(SNR \geq 100)$	max(SNR)
Δ-10 km	17690	202	17	296
Δ-15 km	24495	335	32	346
2L-15 km-0°	23202	311	29	304
2L-15 km-45°	23125	308	30	356
2L-20 km-0°	29278	490	45	343
2L-20 km-45°	29298	482	42	405
ET (+2CE)				
Δ-10 km	22056	290	26	302
Δ-15 km	28498	424	40	351
2L-15 km-0°	27146	408	39	311
2L-15 km-45°	27134	396	38	362
2L-20 km-0°	32796	606	54	348
2L-20 km-45°	33006	593	53	409

A last aspect about triangle and L
CORRELATED NOISE @ Δ

Affected search / Noise sources	Triangle			2L	
	ASD	GWB		ASD	GWB
Seismic noise	-	< 4Hz		No	No
Rayleigh NN	-	< 5Hz $\mathcal{O}(10^3)$ @ $3\ Hz$		No	No
Body wave NN	-	*Optimistic* < 10Hz $\mathcal{O}(10^2)$ @ $3\ Hz$	*Pessimistic* < 50Hz $\mathcal{O}(10^6)$ @ $3\ Hz$	No	No
Infrastructural magnetic noise	*Pessimistic* 1Hz-700Hz $\mathcal{O}(10^5)$ @ $7\ Hz$	*Pessimistic* 1Hz-700Hz $\mathcal{O}(10^6)$ @ $7\ Hz$		No	No
Lightning glitches	< 50Hz $\mathcal{O}(10^4 - 10^5)$ @ $7\ Hz$	-		< 50Hz $\mathcal{O}(10^4 - 10^5)$ @ $7\ Hz$	-
Schumann resonances	< 20Hz $\mathcal{O}(10^3)$ @ $7\ Hz$	< 30Hz $\mathcal{O}(10^4)$ @ $7\ Hz$		< 20 Hz $\mathcal{O}(10^3)$ @ $7\ Hz$	< 30Hz $\mathcal{O}(10^4)$ @ $7\ Hz$

Picking-up three relevant CoBA statemets

2a. The 2L-15km-45° configuration in general offers better scientific return with respect to the 10 km triangle, improving on most figures of merits and scientific cases, by factors typically of order 2-3 on the errors of the relevant parameters.

4. The low-frequency sensitivity is crucial for exploiting the full scientific potential of ET. In the HF-only configuration, independently of the geometry chosen, several crucial scientific targets of the science case would be lost or significantly diminished.

6. For some important aspects of the Science Case, the 2L with 15 km arms at 45°, already in the HF-only configuration, is comparable the 10 km triangle in a full HFLF-cryo configuration.

Post merger / sub-solar primordial BH / Cosmologic Stochastic BG /BH ringdown… / MM with BNS afterglow…

We may be forced to start with that plate, but
➔we must start suitable R&D and design for LF right now
➔do not beleave ET-HF will be that easy to cook…

ET idea was born more than fifteen years ago, and is a great European opportunity