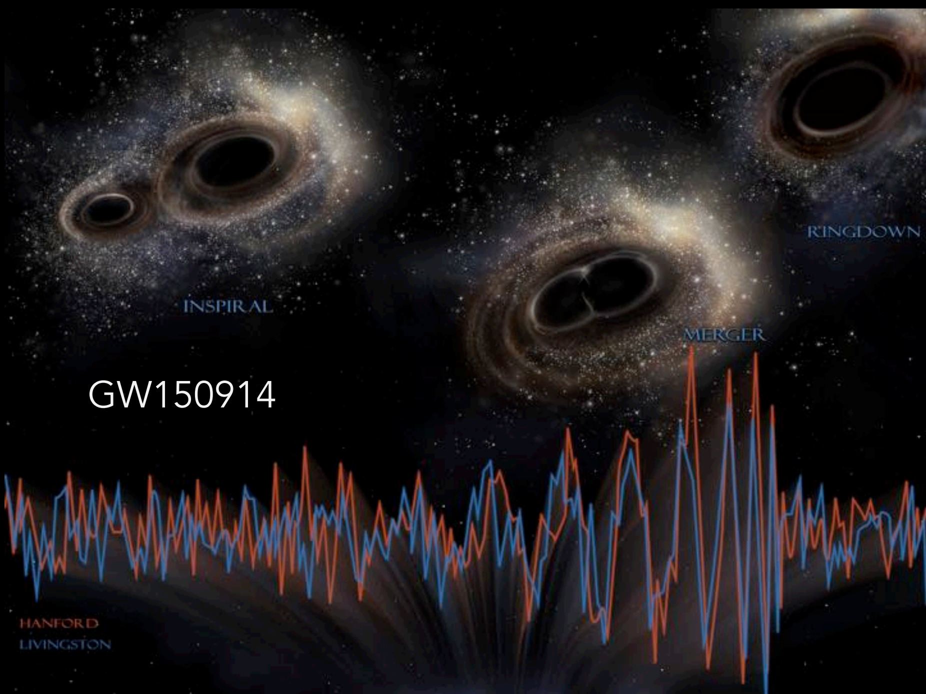
EINSTEIN TELESCOPE
probing the extreme through gravitational waves

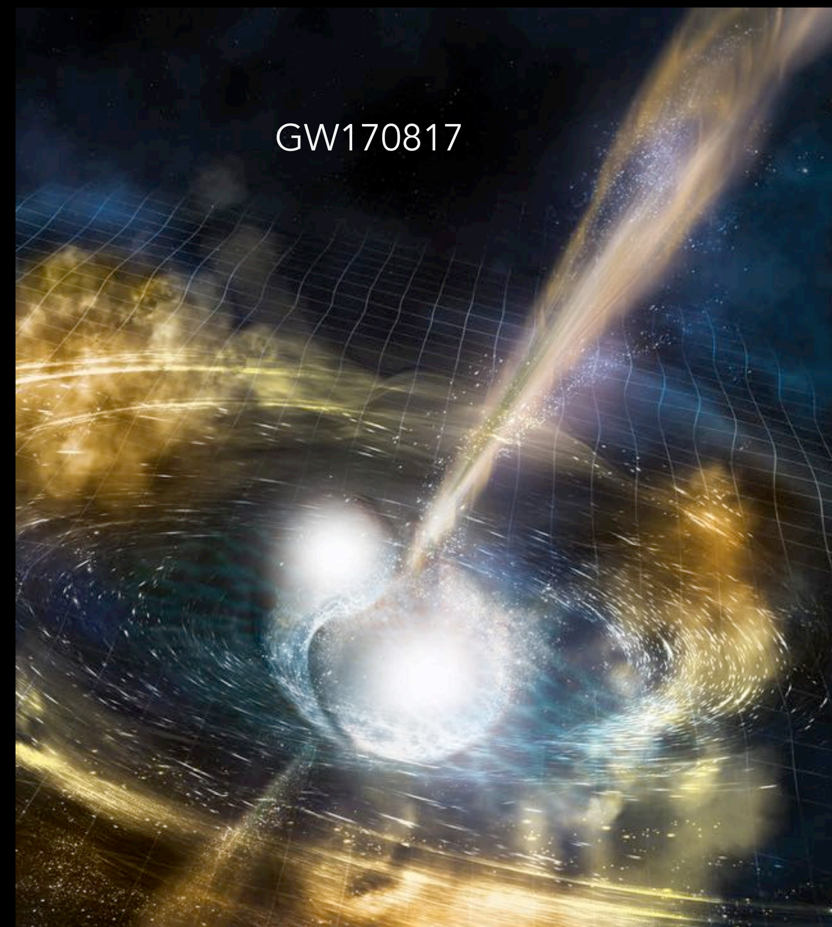
G Losurdo – INFN Pisa

on behalf of the ET Collaboration

Slide credits: S Hild, F Linde, H Lück, M Punturo, B Sathyaprakash, M Vasuth, …

TWO GROUND-BREAKING DISCOVERIES
A NEW ERA IN THE OBSERVATION OF THE UNIVERSE





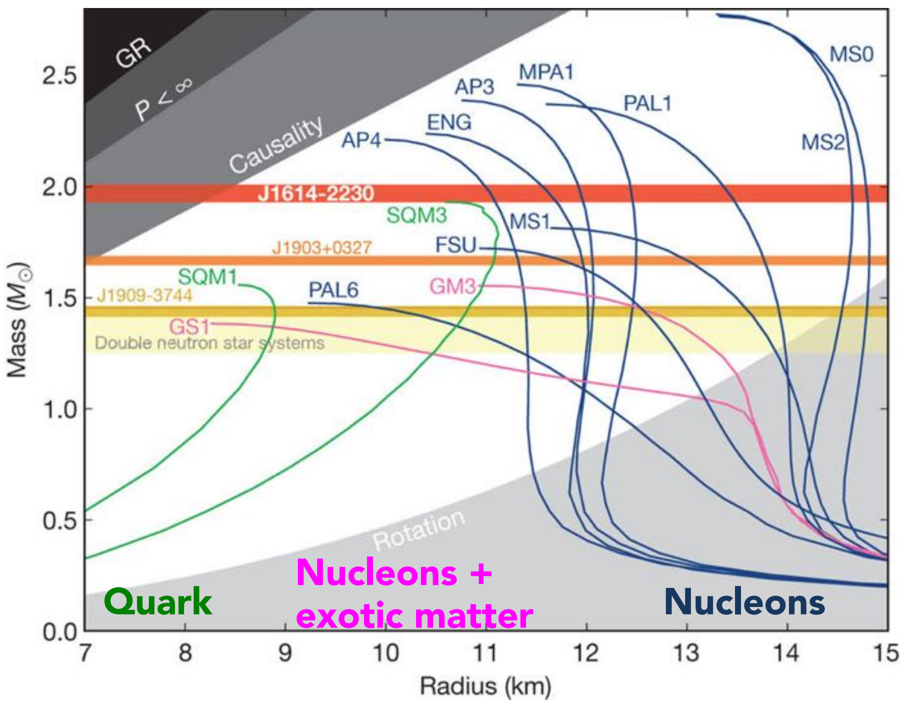
WHY 3G? WHY NOW?

- LIGO and Virgo both have facility-imposed limits on sensitivity
  - length, on surface site, obsolescence
  - At best a factor 3 in sensitivity can be gained wrt to the "advanced" LIGO/Virgo
- We are ready to realize an infrastructure compatible with the development of the interferometric detectors for decades
- 3G detector:
  - extend by ~10x the distance of sight wrt to the "advanced detectors"
  - entend the bandwidth towards lower frequencies (1 Hz target)
- The first and second generations have required ~15 years between the concept and the operation
- EINSTEIN TELESCOPE: concept developed in a FP7 Design Study, involving France, Germany, Italy, the Netherlands, UK
  - today the ET community also involves Belgium, Hungary, Poland, Spain, …

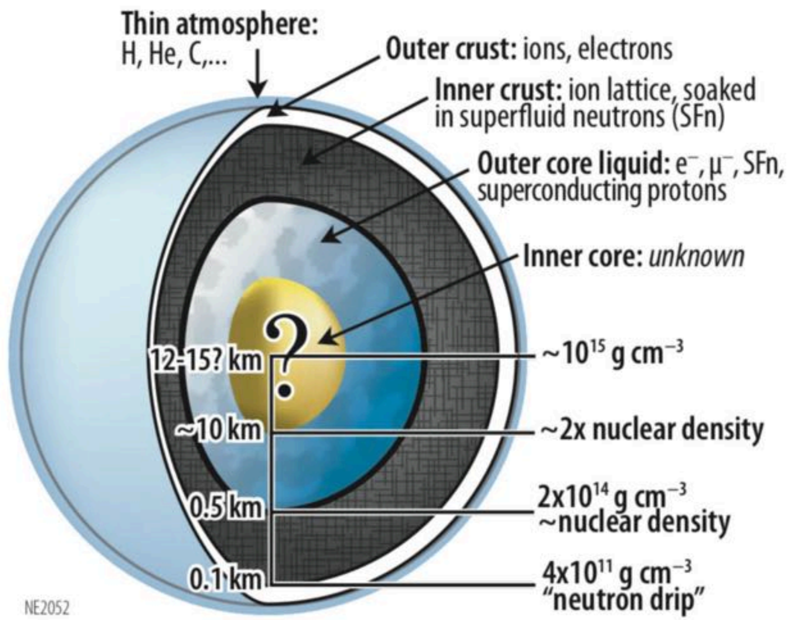
SCIENCE CASE

Extreme matter
Extreme gravity
Extreme universe

EXTREME MATTER



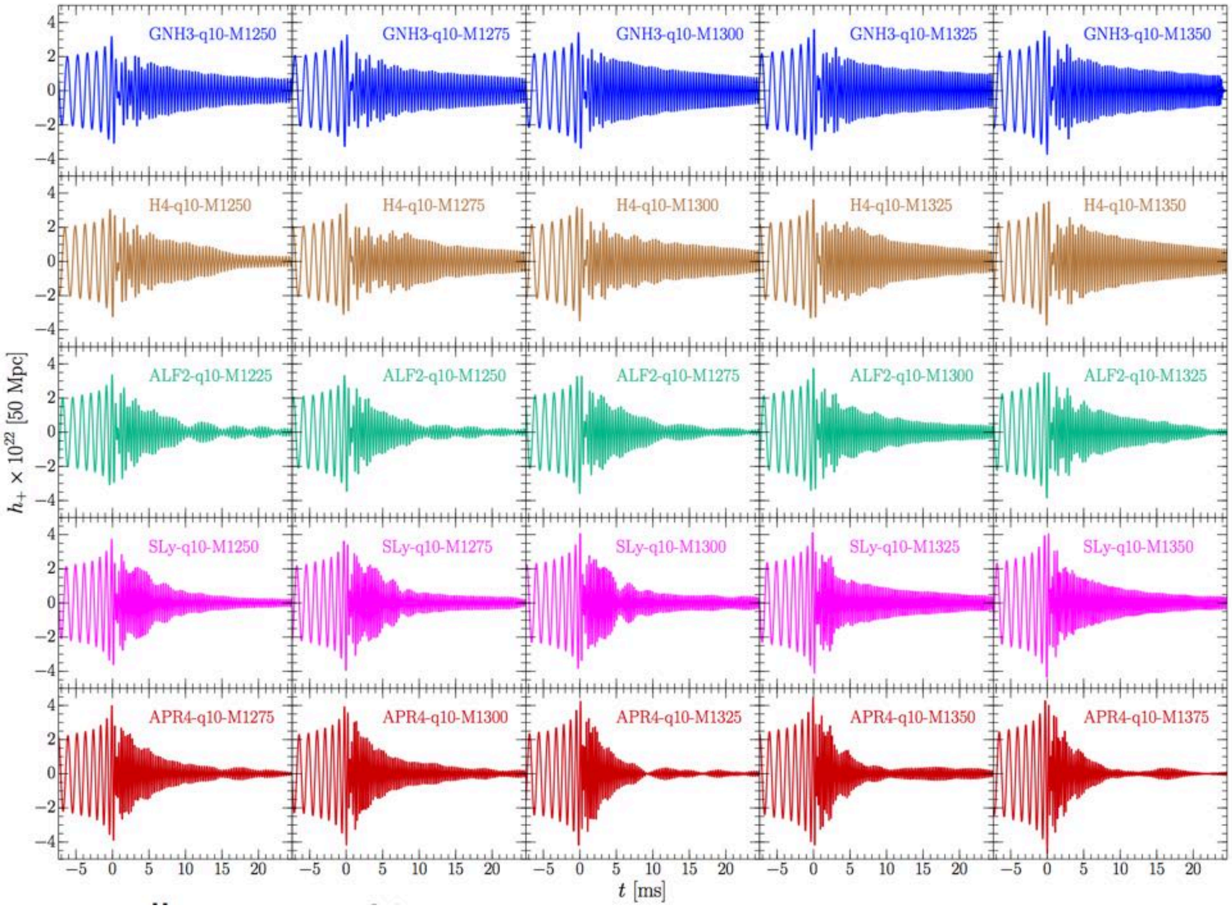
DEMOREST+, 2010



INTERNAL STRUCTURE AND COMPOSITION OF NS (LARGELY UNKNOWN) ENCODED IN THE EQUATION OF STATE

EXTREME MATTER

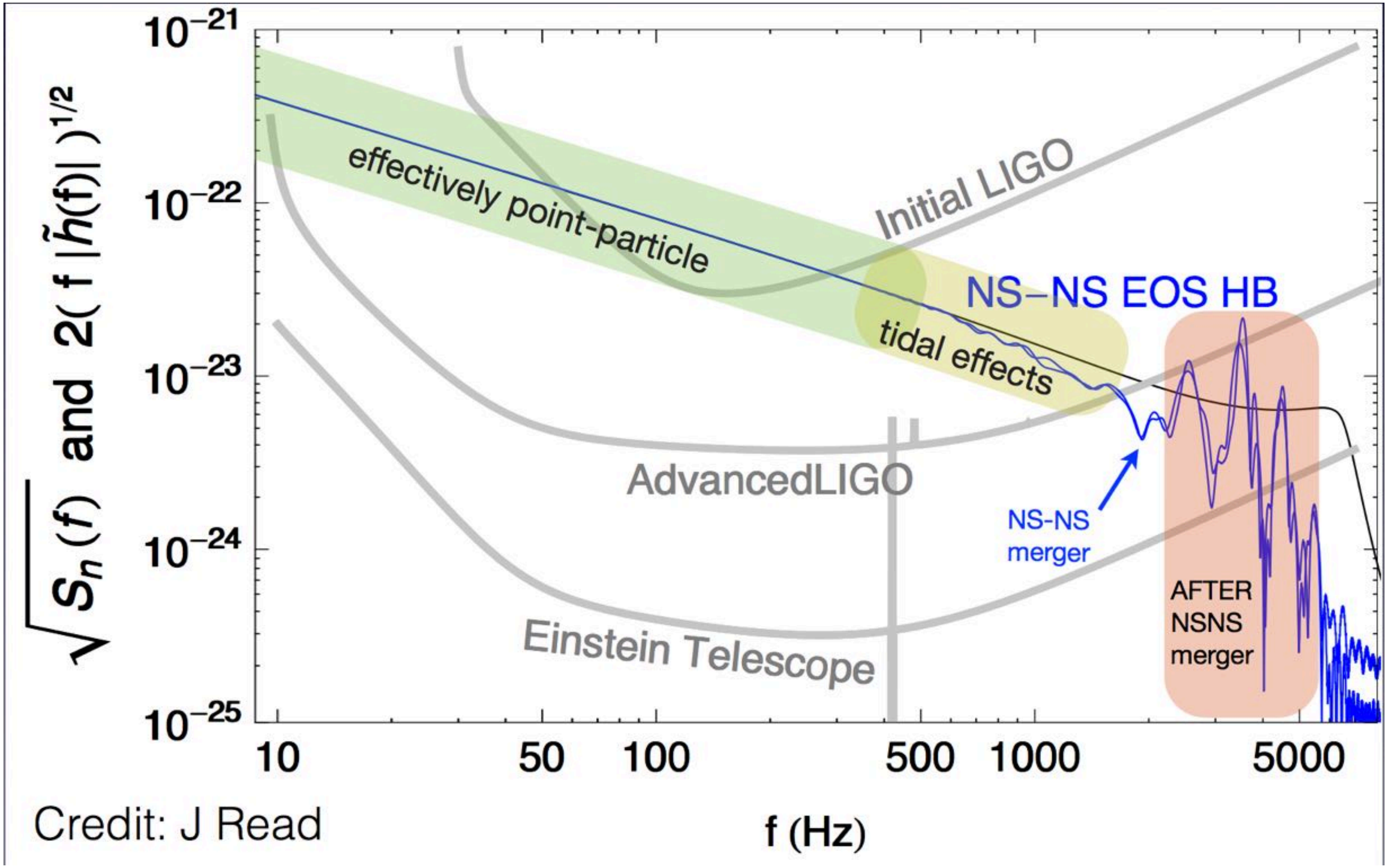
WE ARE ABLE TO COMPUTE THE WAVEFORMS FOR THE VARIOUS EOS



Takami, Rezzolla, Baiotti (2014)

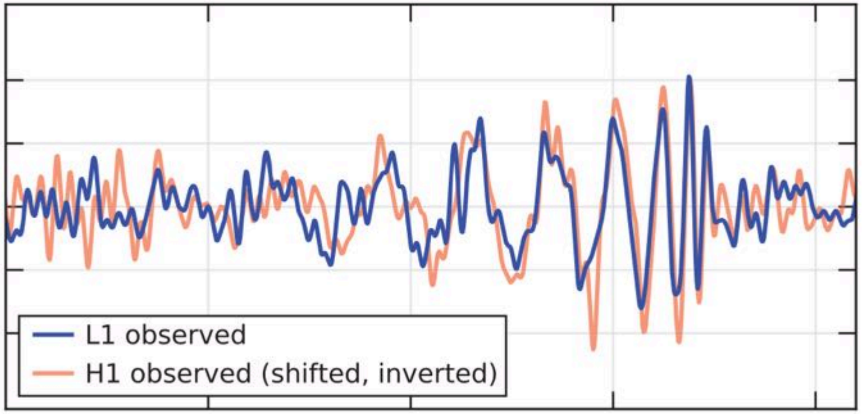
EXTREME MATTER

A 3G DETECTOR IS NEEDED TO MEASURE WHICH EOS IS THE RIGHT ONE



EXTREME GRAVITY

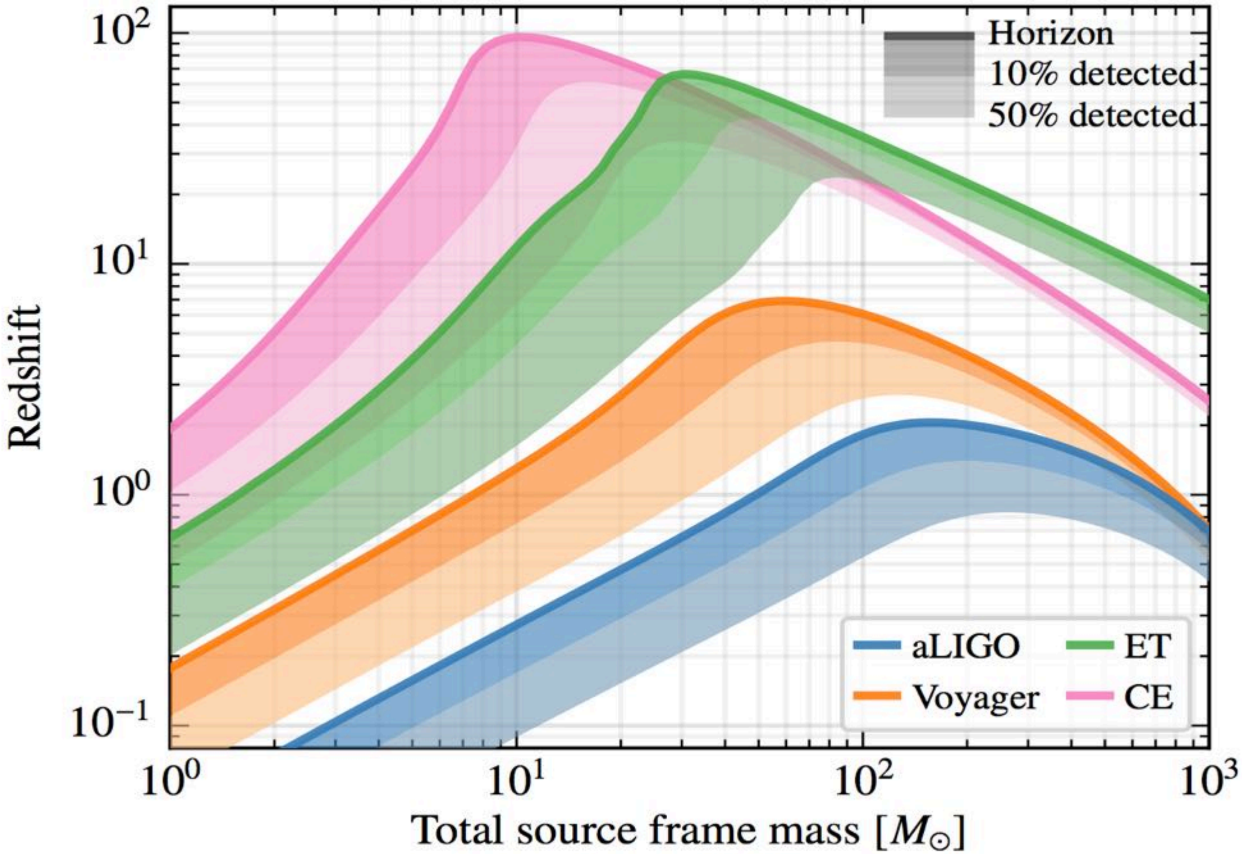
- Precision tests of alternative theories
  - polarizations
  - graviton mass
  - Lorentz invariance
- Exotic compact objects
- BH QNM



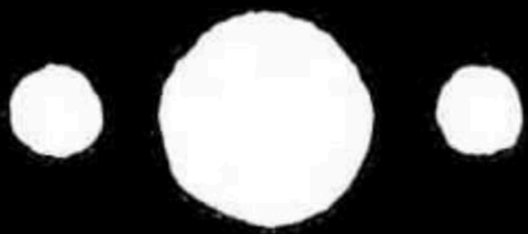
Detector	GW150914 SNR	QNM SNR
O1	25	7
Advanced LIGO	80	20
LIGO-India ALIGO+ (2024)	250	80
ET (2030)	800	200
Cosmic Explorer (2034)	2400	800

EXTREME UNIVERSE

- Hubble parameter
- Stochastic background

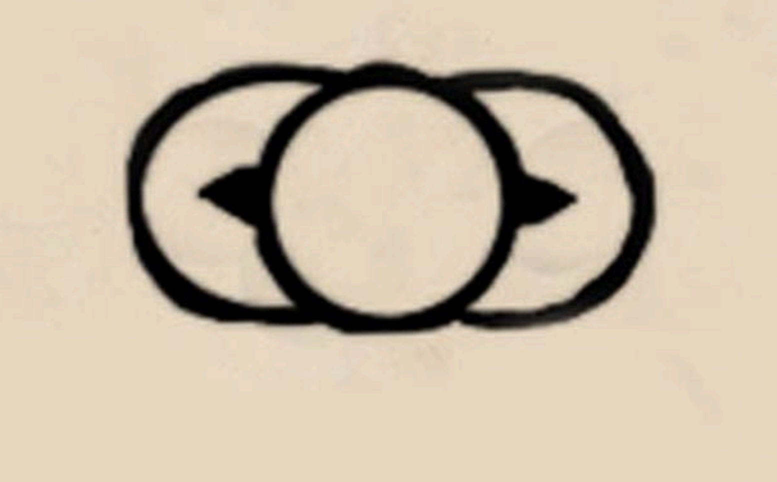


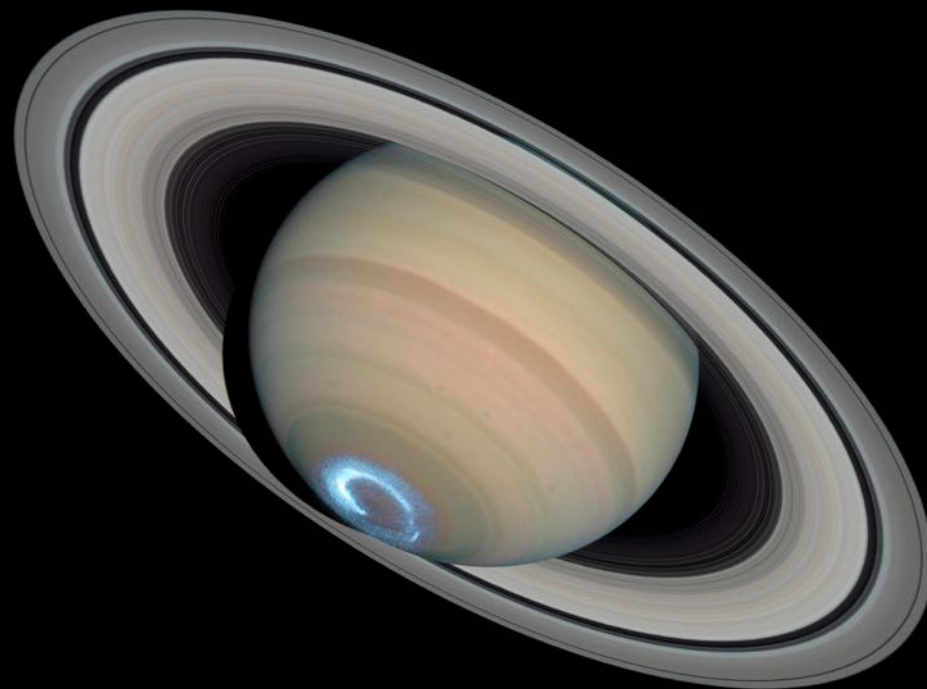
WE HAVE THE RIGHT INSTRUMENT.
NOW WE NEED TO MAKE IT BETTER AND BETTER AND BETTER…



Galileo, 1610

Galileo, 1616

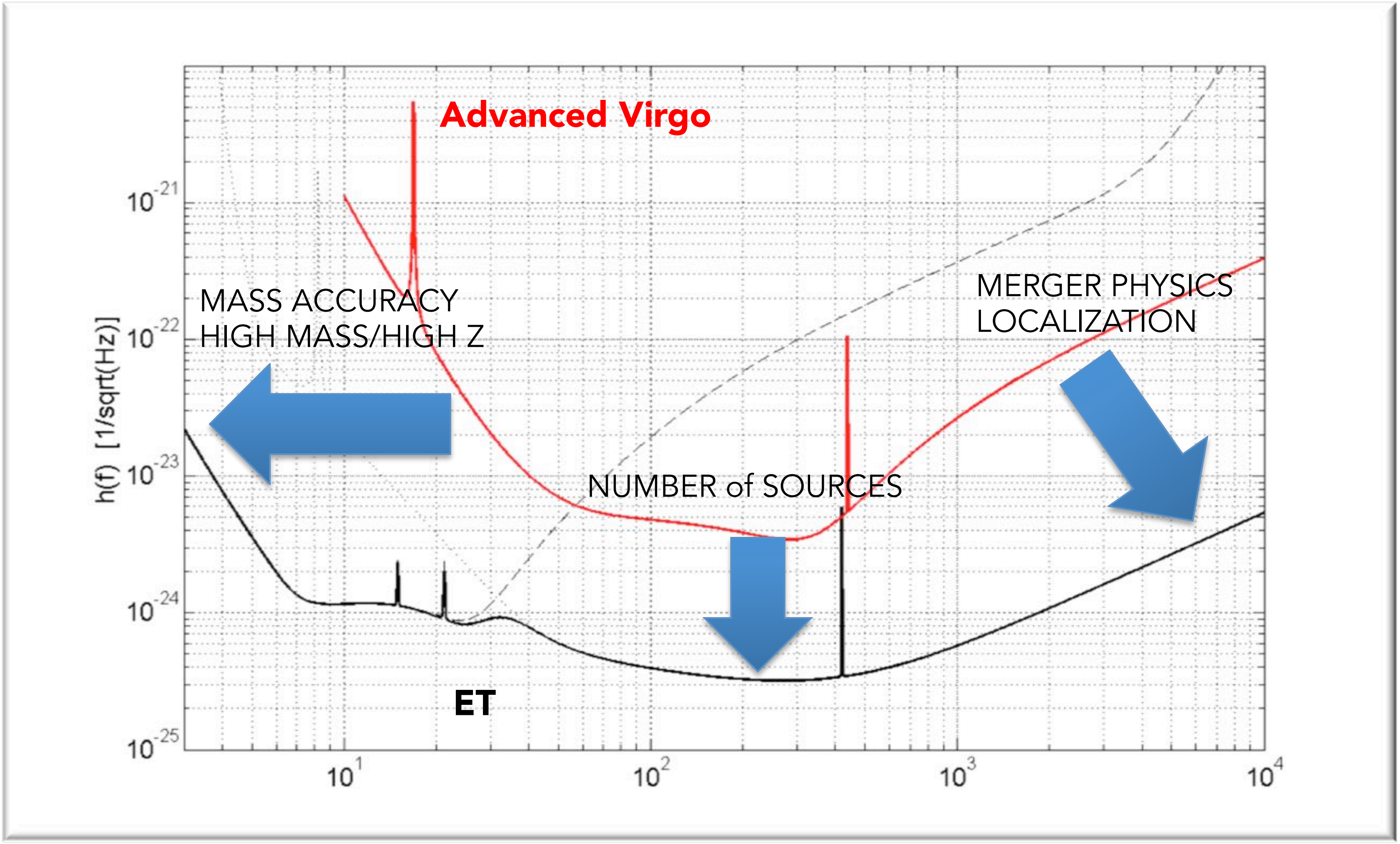




HST, 400 yrs later

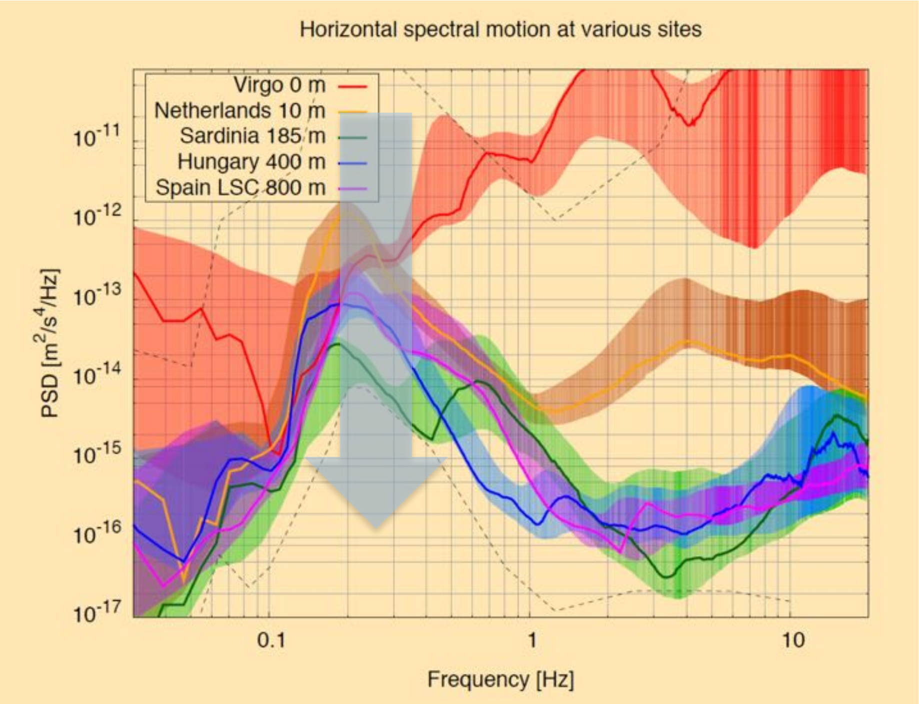
DETECTOR CONCEPT

SENSITIVITY GOAL



WIDEN THE BAND: UNDERGROUND

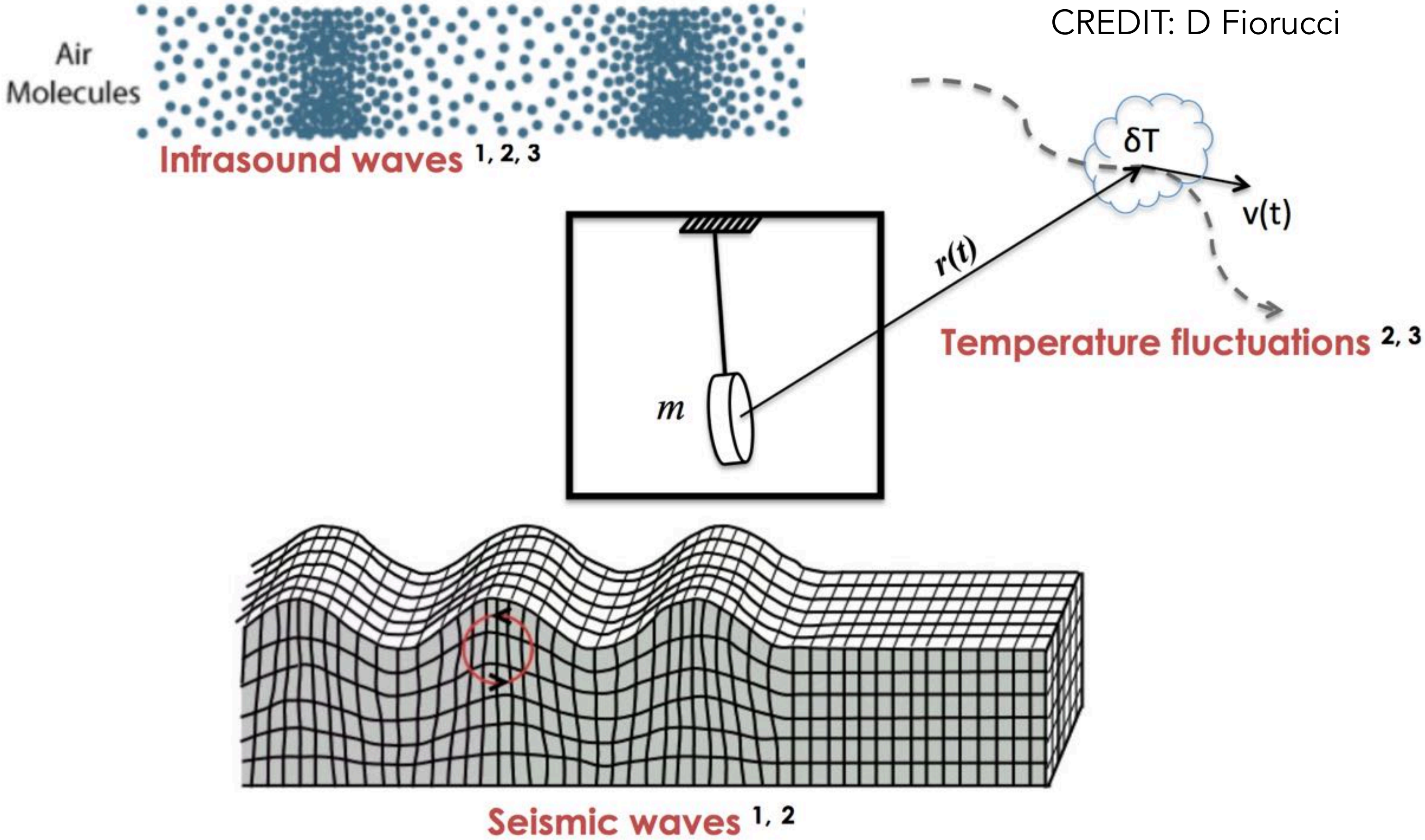
- Limitations to LF sensitivity
  - rejection of seismic noise
  - newtonian noise
- Both can be eased by going underground



noise at 2 Hz reduced by ~2 orders of magnitude

NEWTONIAN NOISE

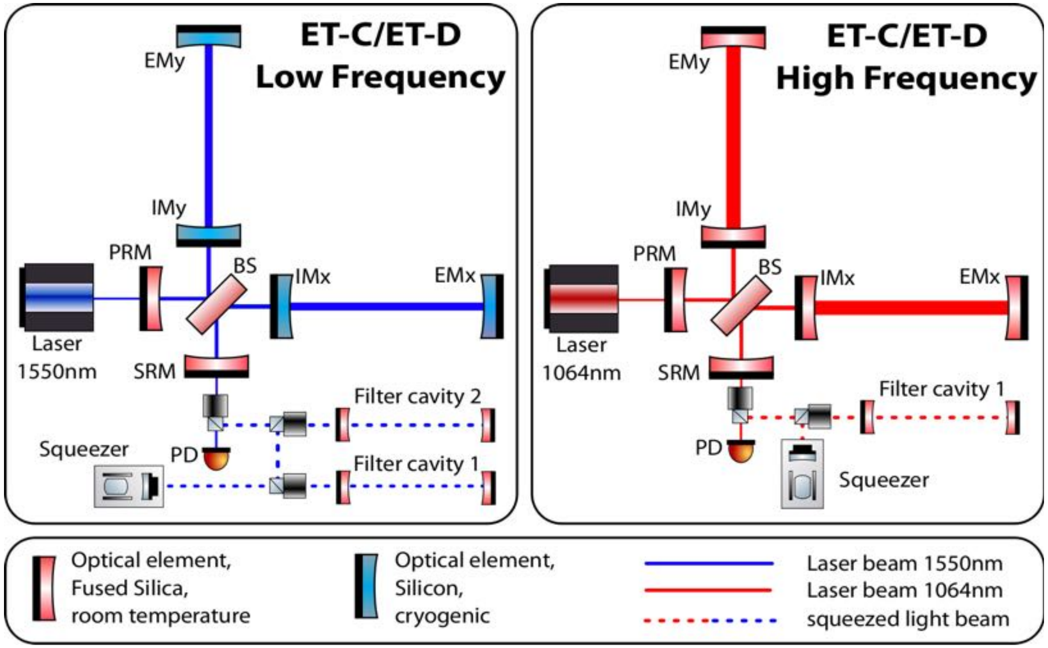
CREDIT: D Fiorucci

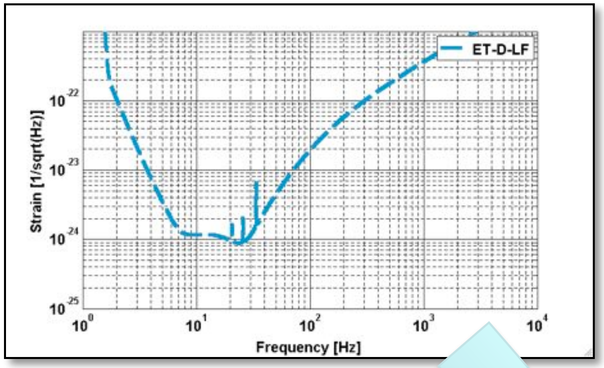


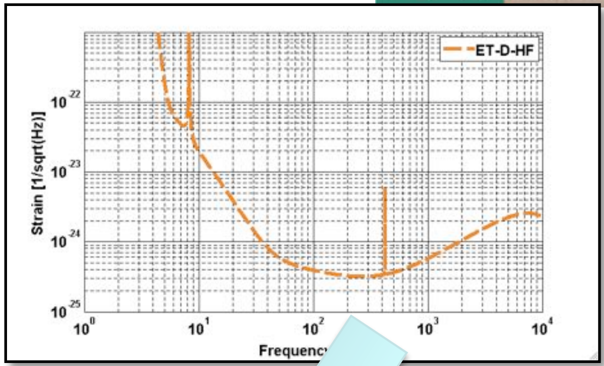
[1] Saulson Phys. Rev. D **30**, 732, [2] J. Harms Terrestrial Gravity Fluctuations,
[3] Creighton CQG. **25** (2008) 125011, C.Cafaro, S. A. Ali arXiv:0906.4844 [gr-qc] 2

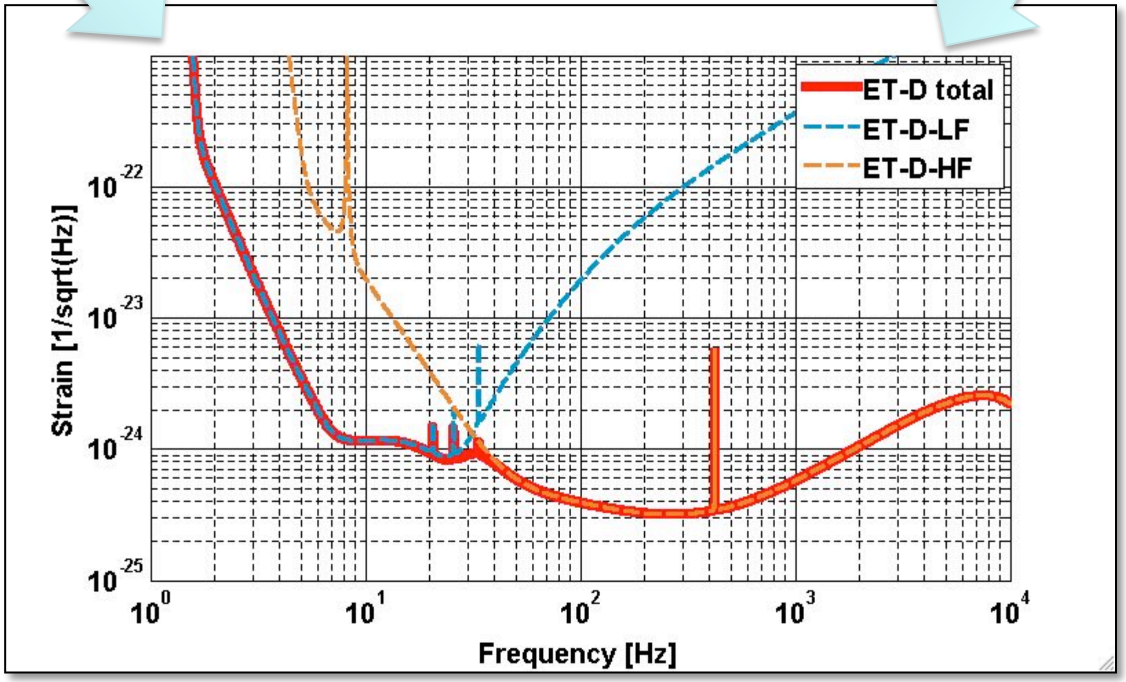
WIDEN THE BAND: XYLOPHONE

- Improving al low and high frequency with a single detector is very challenging
  - HF requires more laser power
  - LF requires cold mirrors
- Idea: split the detection band over 3 "specialized" instruments



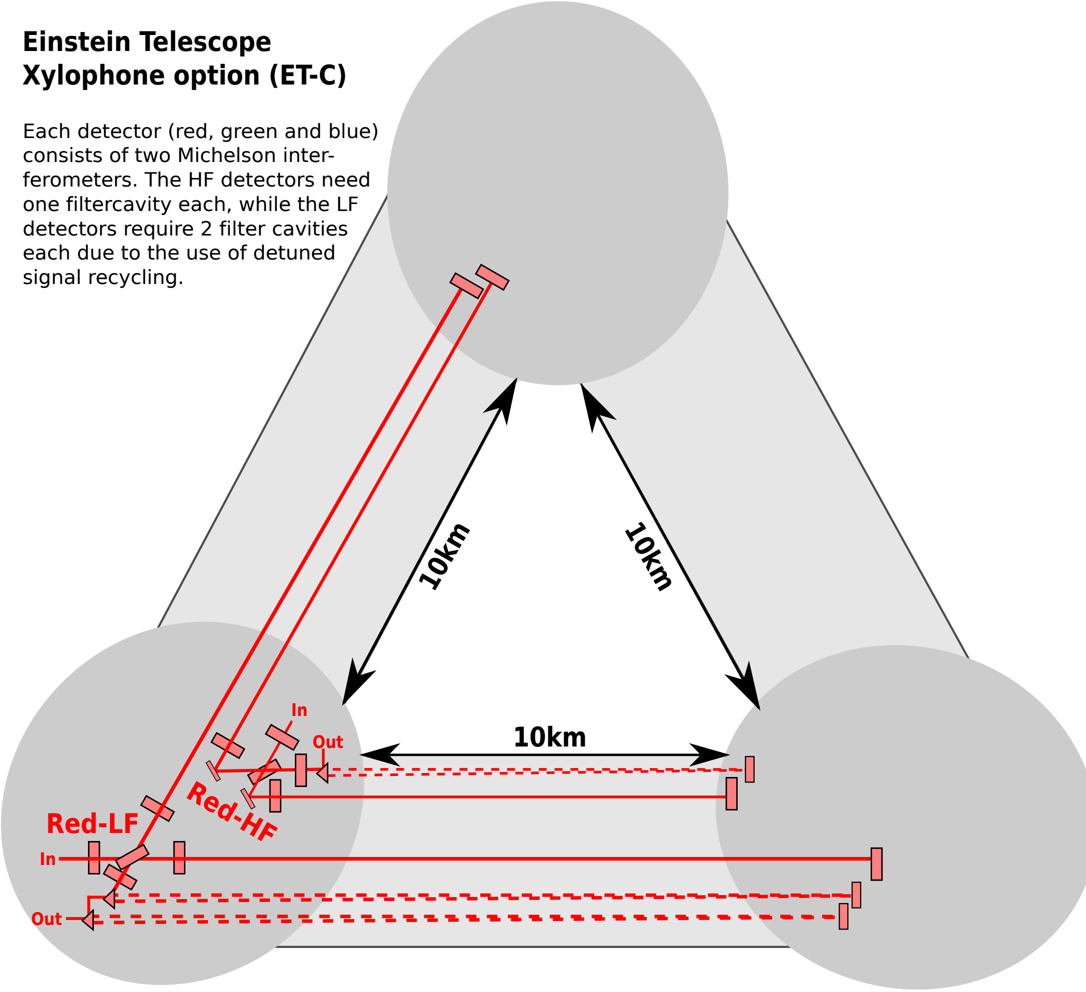

ET-D-LF
Strain [1/sqrt(Hz)]
Frequency [Hz]


ET-D-HF
Strain [1/sqrt(Hz)]


ET-D total
ET-D-LF
ET-D-HF
Strain [1/sqrt(Hz)]
Frequency [Hz]

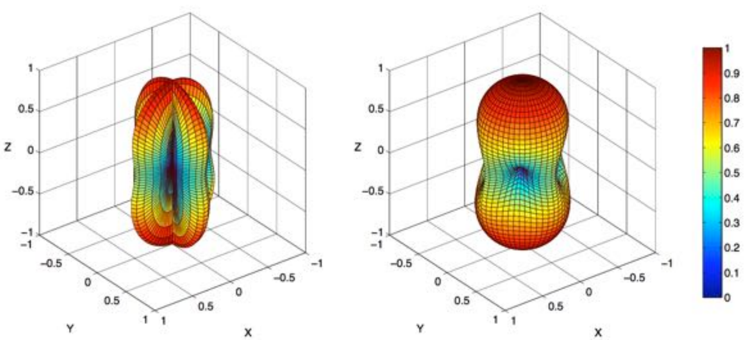
STAND-ALONE OBSERVATORY

- Start with a single (xylophone) detector



STAND-ALONE OBSERVATORY

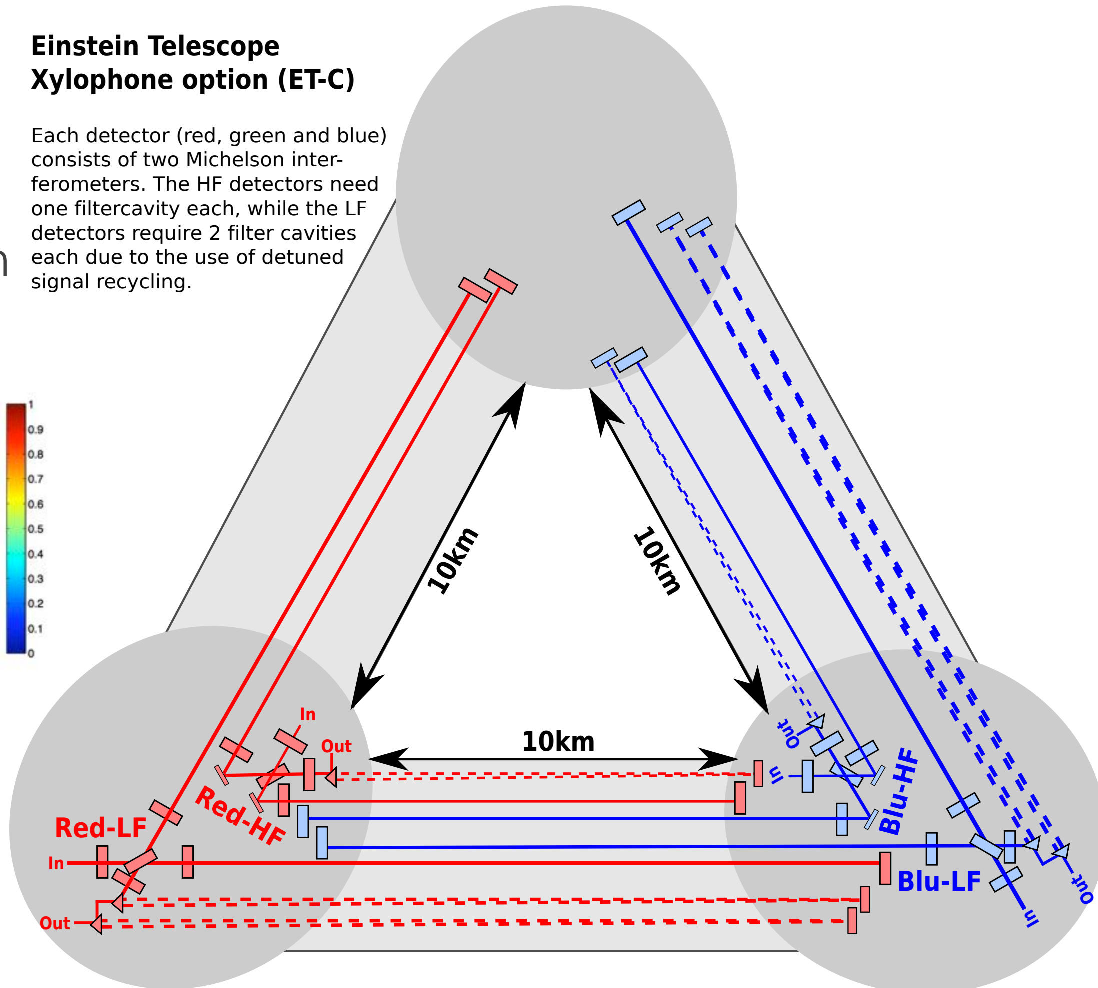
- Start with a single (xylophone) detector
- Add a second one to fully resolve polarization



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

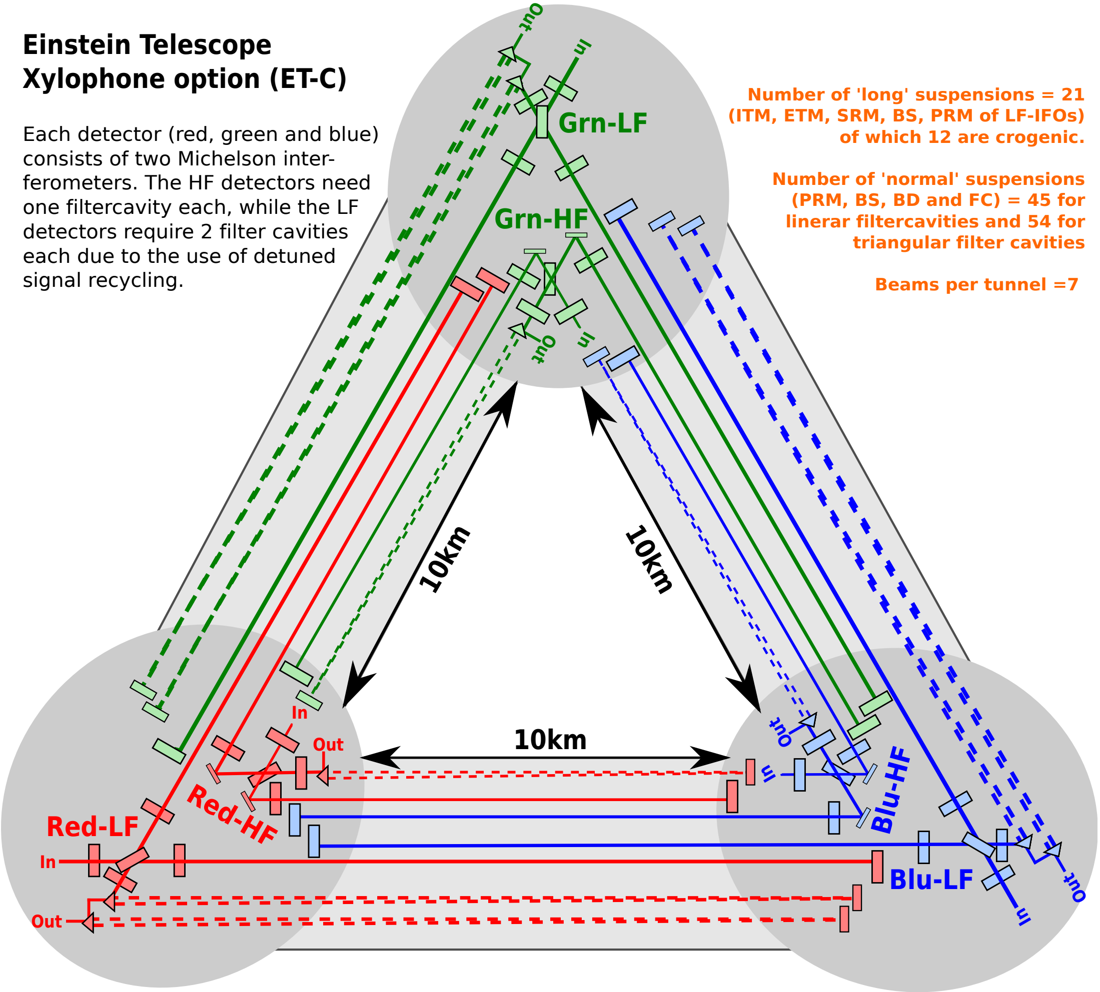
Einstein Telescope Xylophone option (ET-C)

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

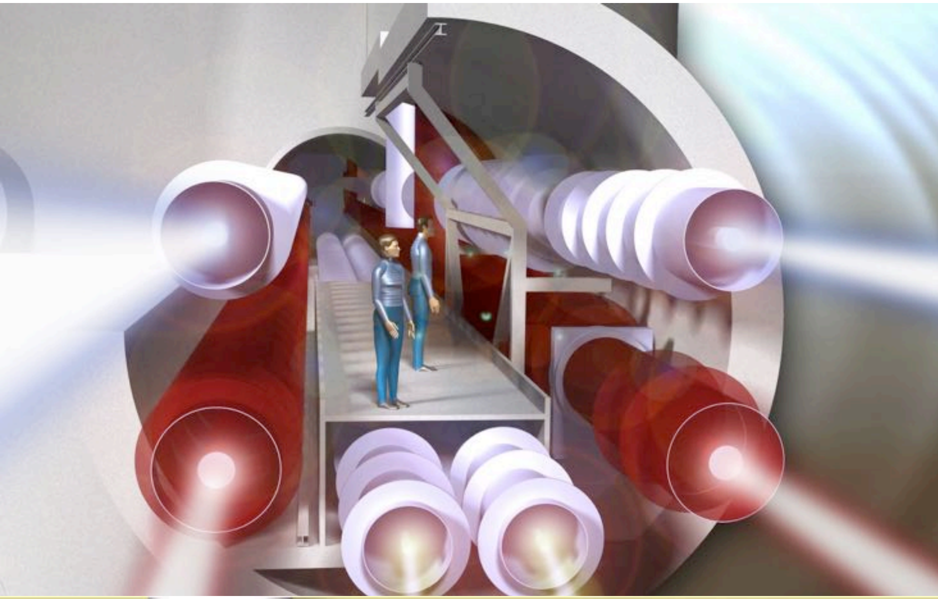


STAND-ALONE OBSERVATORY

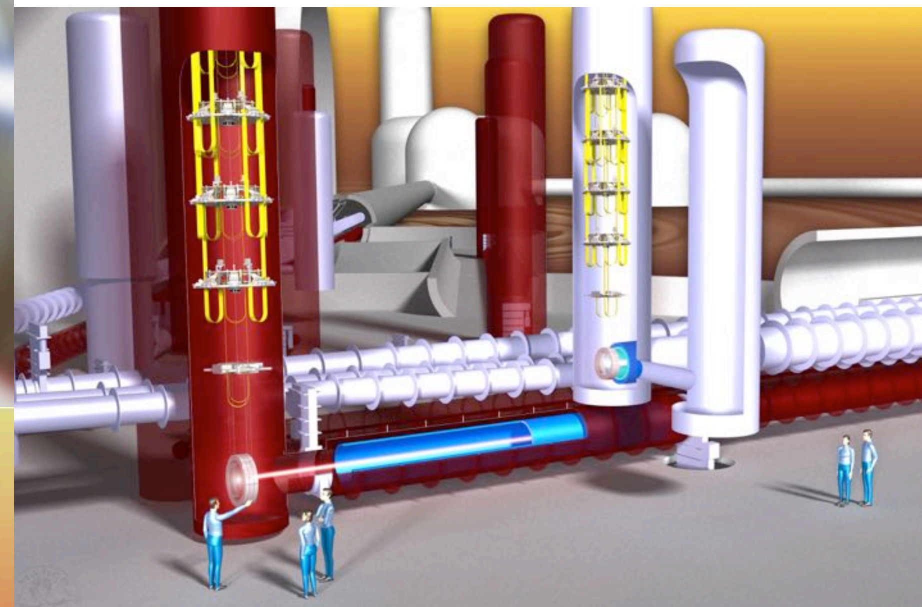
- Start with a single (xylophone) detector
- Add a 2nd one to fully resolve polarization
- Add a 3rd one for null stream and redundancy

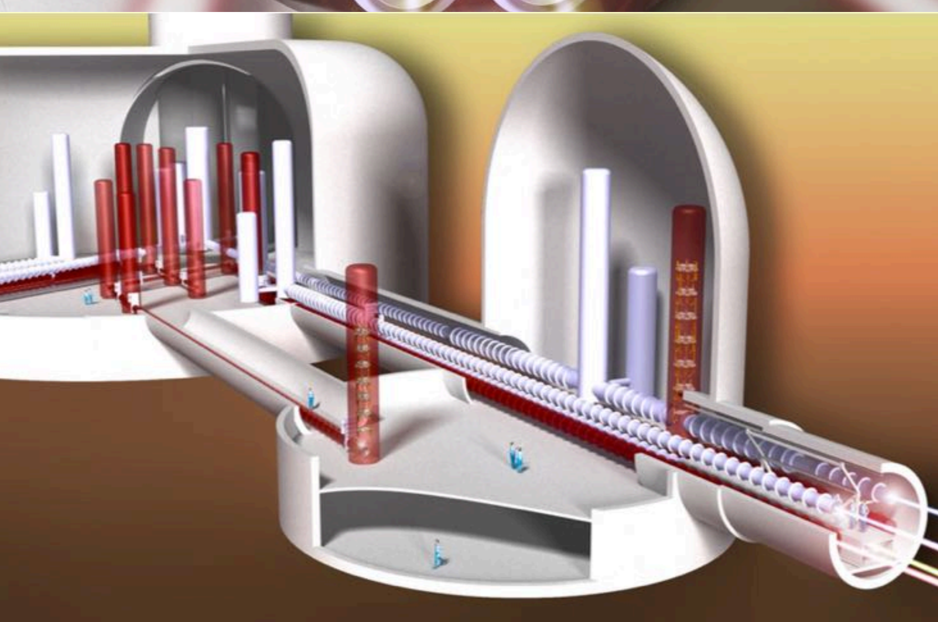


ET INFRASTRUCTURE CONCEPT



ET DESIGN STUDY, 2011

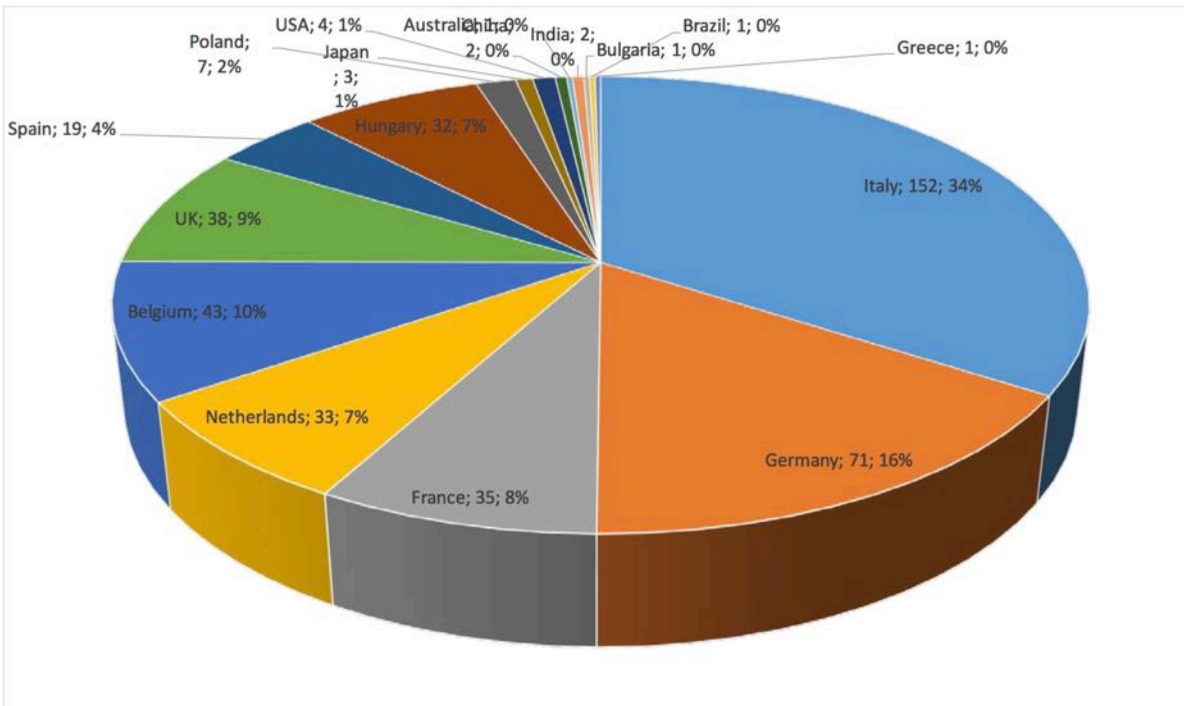




ET AND THE INTERNATIONAL FRAMEWORK

ET COLLABORATION

- Call for interested launched at the ET Symposium (May 19-20)
- Subscriptions by individual scientists (~450 so far)
- Steering Committee nominated to write the Collaboration statute and the governance rules



ESFRI

- It is crucial to enter in the 2020 update of the ESFRI roadmap
- Update window: Jan-Aug 2019
- We need to define the political support and financial commitment:
  - Lead Country/Entity
  - Participating countries/entities
  - Inclusion in National research infrastructure roadmap (when applicable)
  - Cost estimates and repartition
- No need to choose the site in the proposal

COST AND TIMELINE

- The realization of the ET observatory may cost **1-1.5 GEuros**. Final cost TBD on the basis of
  - final choice of geometry and infrastructure features
  - Techincal Design Report

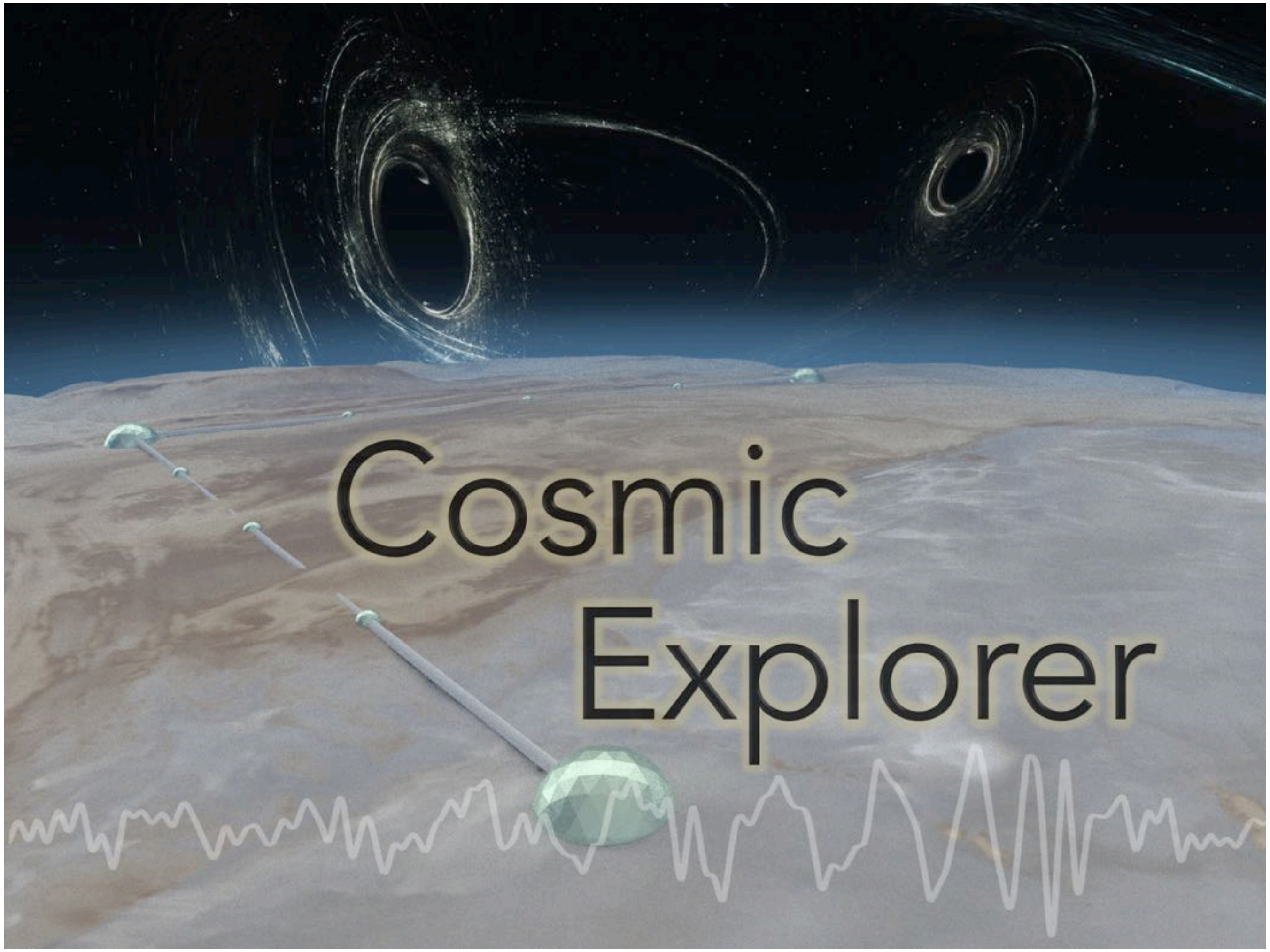
- TIMELINE:
  - **2021-22:** site selection
  - **2023-24:** TDR
  - **2025:** infrastructure realization start
  - **2030-31:** commissioning start
  - **2032+:** operation

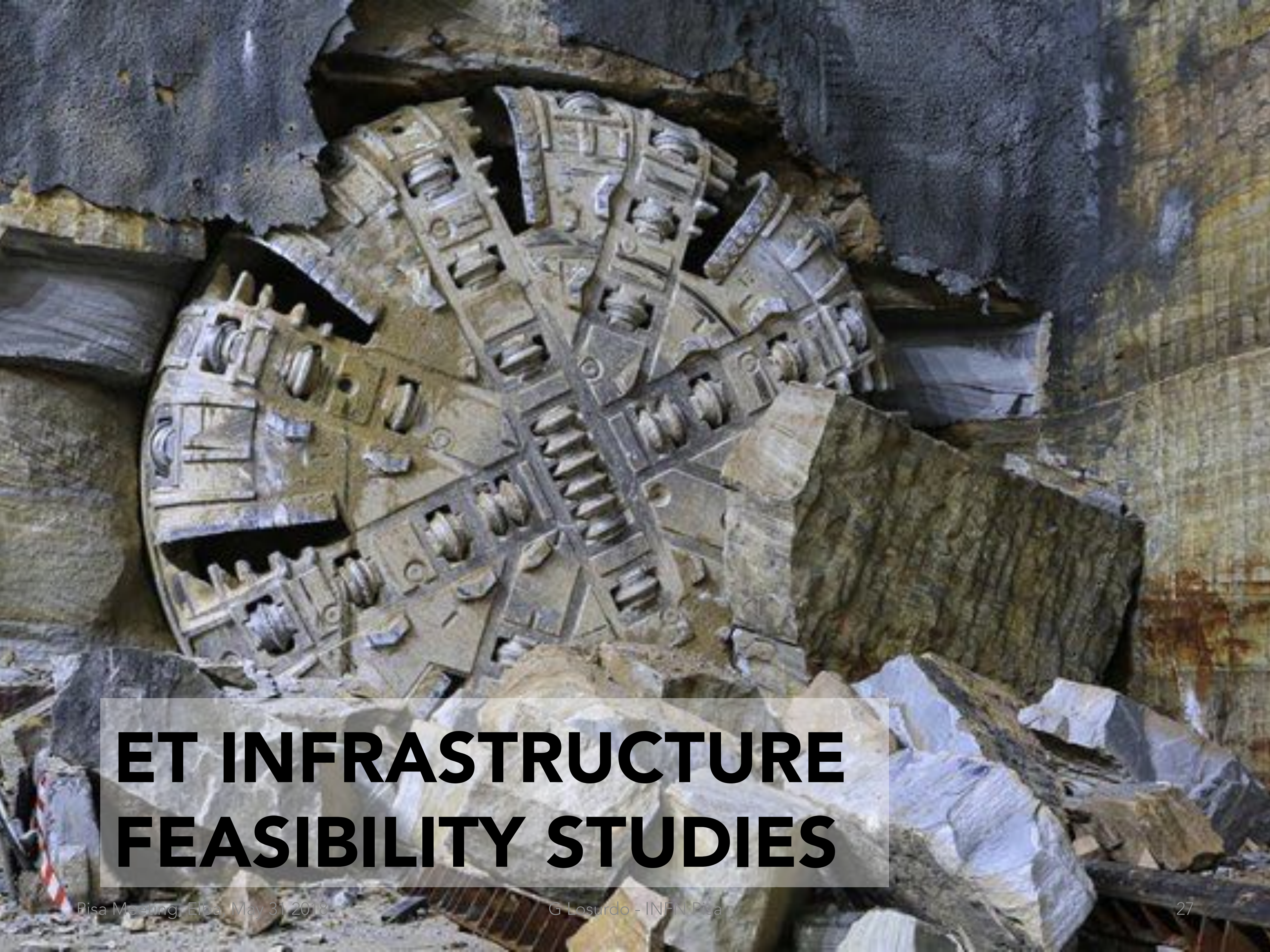
TOWARDS A 3G NETWORK

- ET-3G idea is spreading in the world
  - A similar scale GW observatory concept (Cosmic Explorer) is currently under consideration in the US
  - Or other designs that may emerge
- A global approach to coordinate the efforts toward a Global Research Infrastructure vision is underway
  - Bottom-Up approach: GWIC-3G
    - Through the “Gravitational Wave International Committee”, scientists have established a coordination team named GWIC-3G (see next slide) that is investigating the future network of 3G observatory from several points of view: addressing its scientific potential, the technological development needed, the opening and growing of the scientific community, the relationship with the funding agencies and the governance model to be adopted.
  - Top-Down approach: GWAC
    - Funding agencies supporting or interested in GW research activities have established the “Gravitational Wave Agencies Correspondents”, an information exchange forum to develop higher-level coordination

PLANS IN THE US

40 km ON-SURFACE DETECTOR



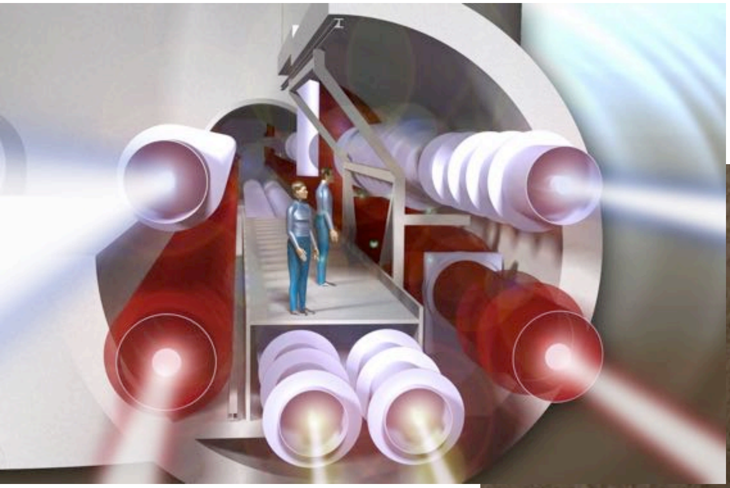


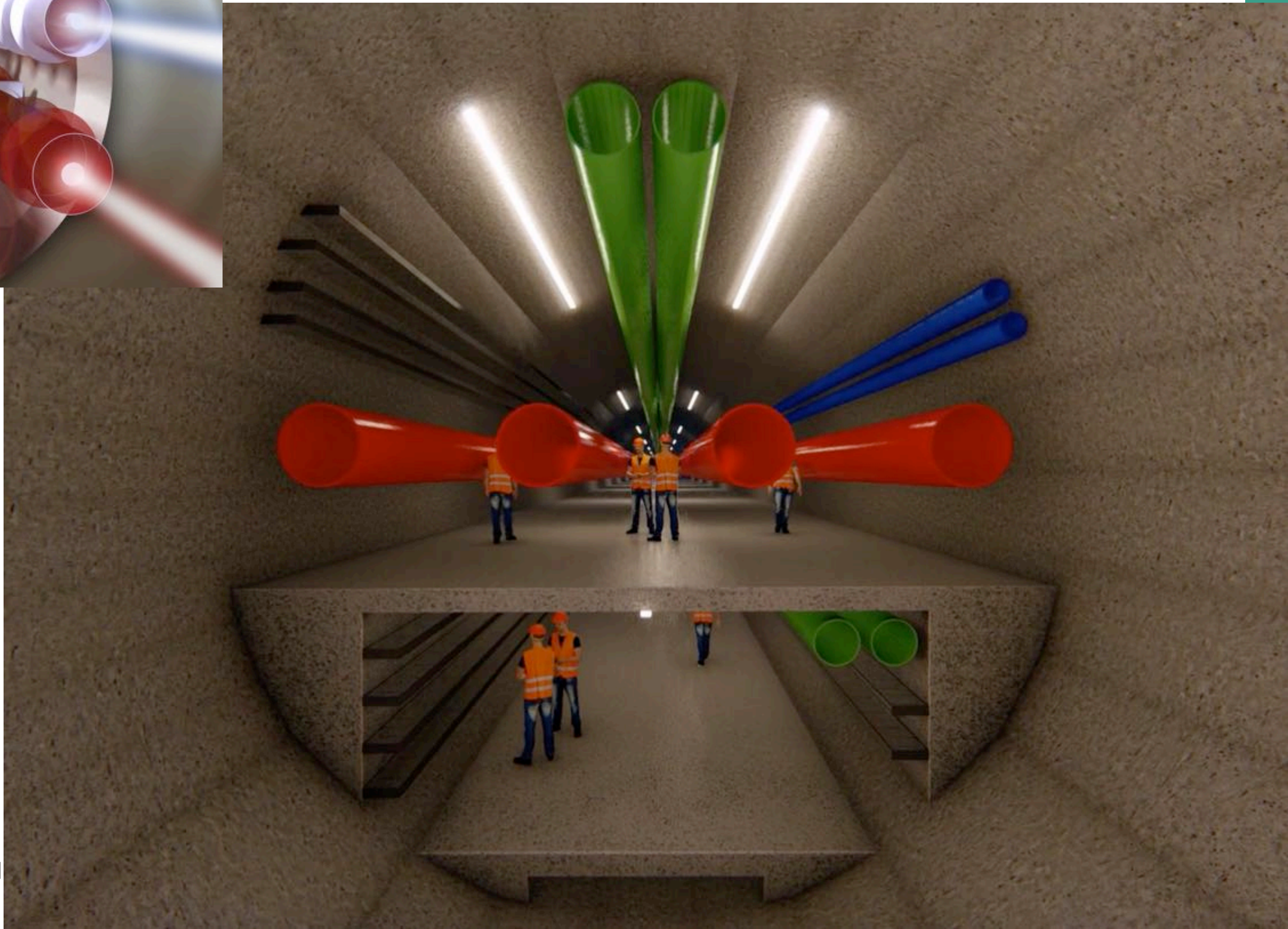
ET INFRASTRUCTURE FEASIBILITY STUDIES

TUNNEL

- Golden rules:
  - a new (and expensive) infrastructure must not be born short in space
  - avoid as much as possible complex arrangements
- We tried to fit the ET xylophone configuration in a underground infrastructure making realistic assumptions
  - space required for working around the pipes (e.g. welding the modules)
  - avoid vertical arrangement of the ITF
  - include realistic tower footprint
  - **WARNING:** things might get even more complex (e.g. space required by cryogenics)
- To further offload the tunnel we have moved the filter cavities into shorter (1 km), dedicated tunnels
  - this is a working hypothesis, to be discussed by the detector design teams
- The resulting tunnel diameter is **~2x larger** wrt ET book

TUNNEL - $\oslash_{in}$ 10m



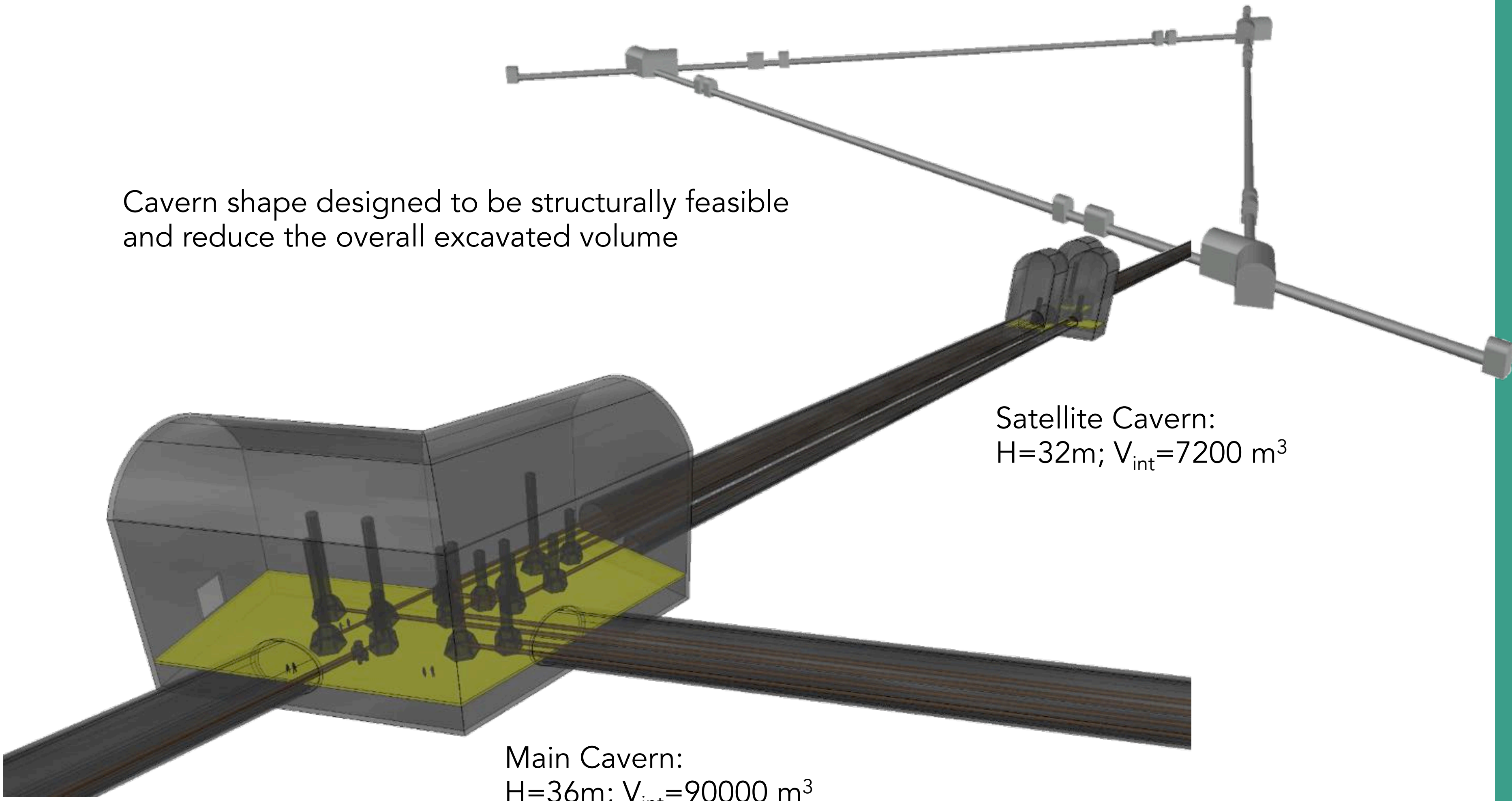


CAVERNS AND ACCESS

- Big caverns are a challenge
  - structure stability
  - atmospheric NN
- 65m diameter (ET concept) would be the largest cavern in the world
  - We have studied solutions to reduce the volume while maintaining the infrastructure flexibility and development potential
- Big shafts are expensive and challenging for civil engineering
  - We have designed downhill accesses to the infrastructure and smaller diameter shafts for safety accesses

ET Triangle
Underground Base Infrastructure
Heights are not to scale

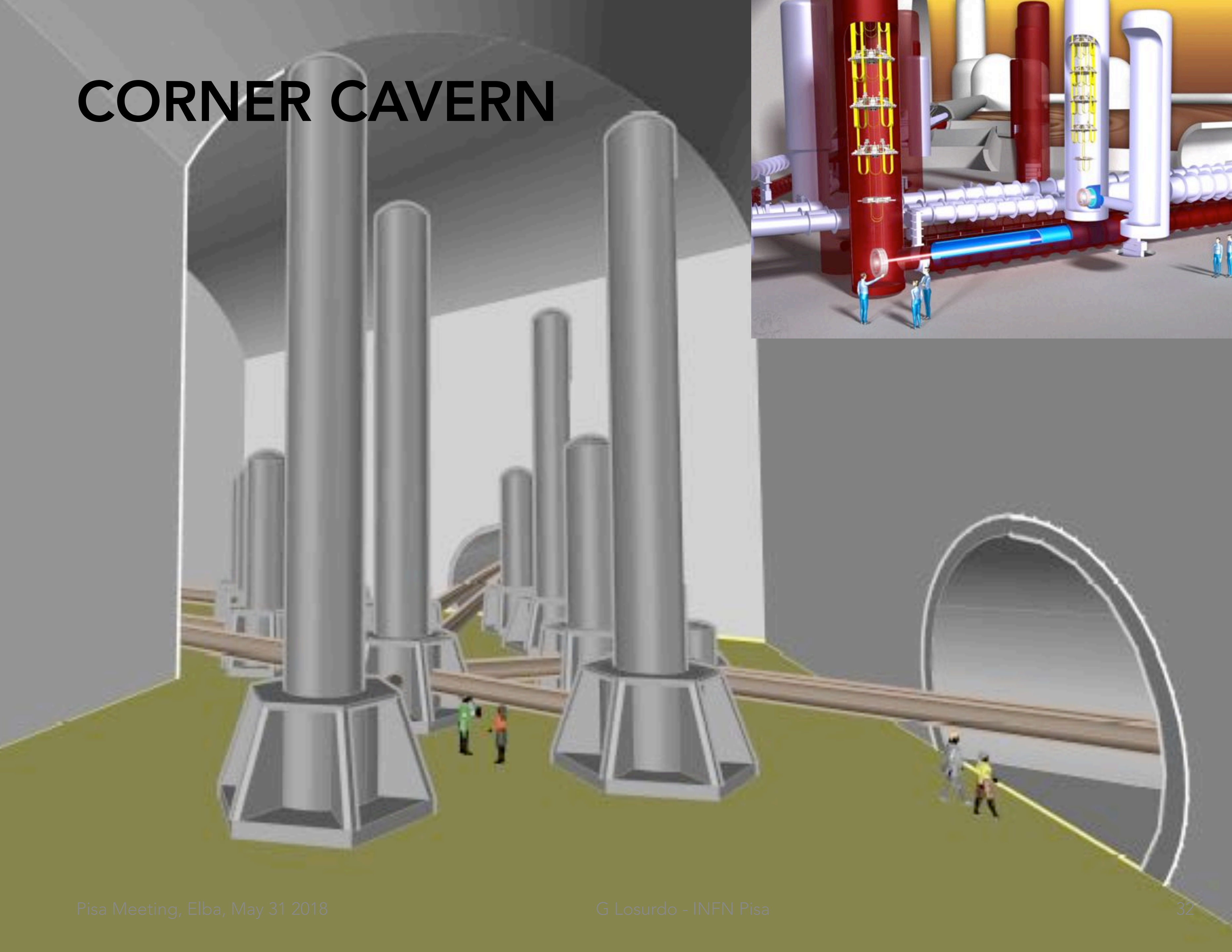
Cavern shape designed to be structurally feasible and reduce the overall excavated volume



Satellite Cavern:
H=32m; V_{int}=7200 m^3

Main Cavern:
H=36m; V_{int}=90000 m^3

CORNER CAVERN

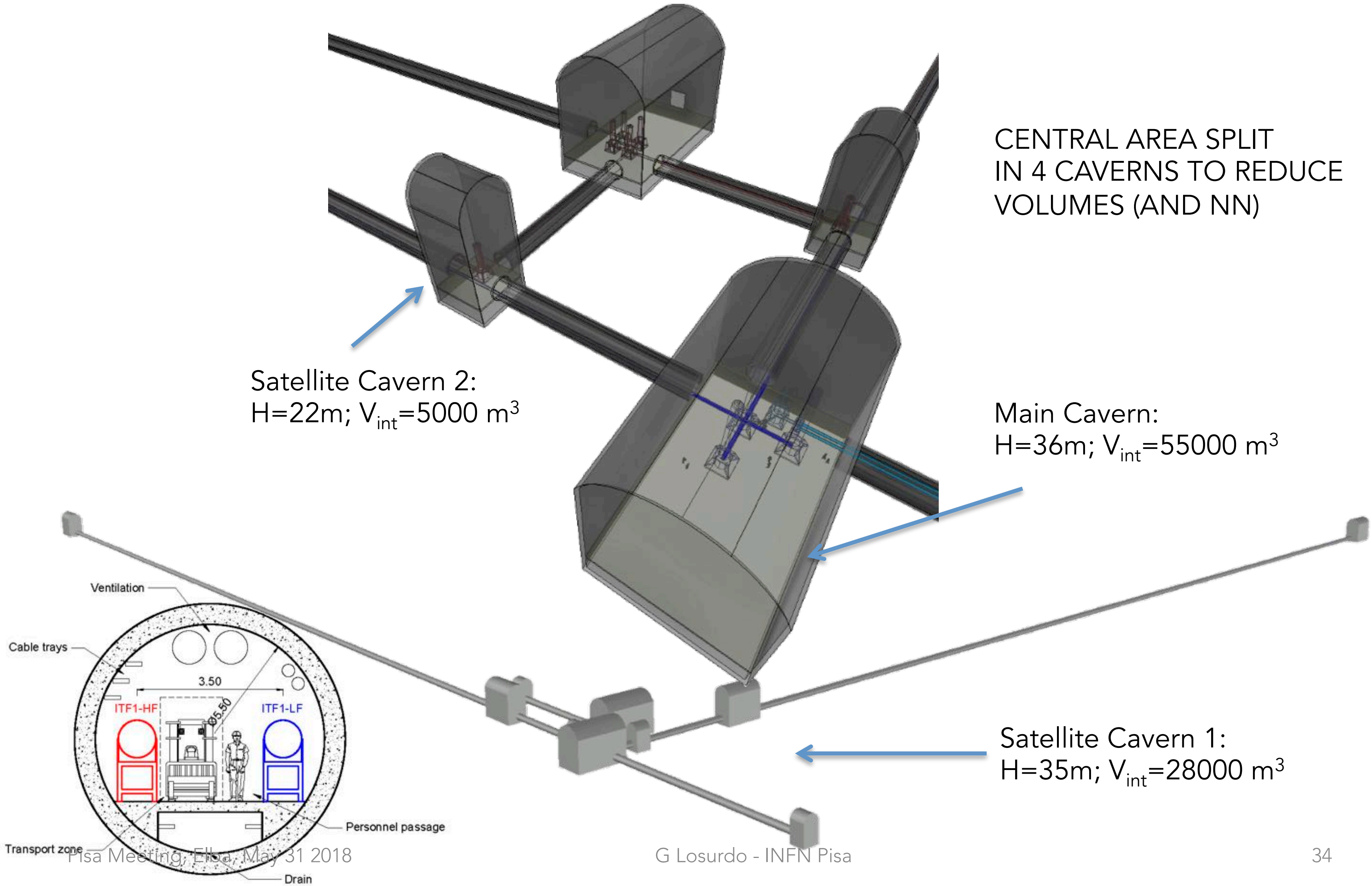


THE "L" GEOMETRY OPTION

- There are top-level arguments which may push towards changing the baseline topology
  - ET was conceived as a stand-alone observatory
  - The ideal perspective is to have a 3G network
  - We are working for a global governance of a 3G effort
- We have studied the scenario of a 15 km L-shaped ET
  - smaller tunnel diameter (5.5 instead of 10 m)
  - smaller caverns
  - less complexity
- Overall, in this scenario the cost of the infrastructure would be about one half of the full triangle

ET L Topology – Main Infrastructure

Heights are not to scale



CENTRAL AREA SPLIT IN 4 CAVERNS TO REDUCE VOLUMES (AND NN)

Satellite Cavern 2:
H=22m; V_{int}=5000 m^3

Main Cavern:
H=36m; V_{int}=55000 m^3

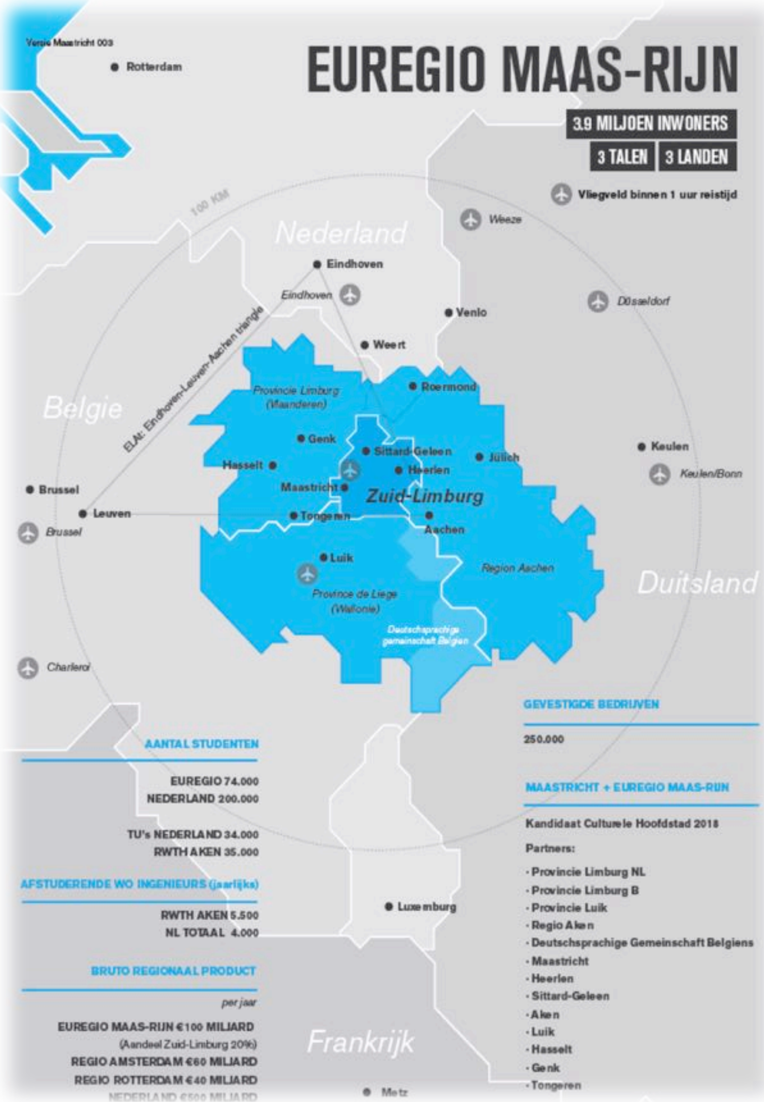
Satellite Cavern 1:
H=35m; V_{int}=28000 m^3

SITE OPTIONS

Limburg (NL)
Matra (HU)
Sos Enattos (I)

EUREGIO MEUSE-RHINE

- A proposal to realize ET in the Limburg area
- A strong asset: a detector hosted by 3 countries (B-D-NL)



APPEARING ON NATIONAL ROADMAPS

39 | Domein – Bèta/Techniek

ET

'Luisteren' naar het universum

ET (*Einstein Telescope*) is het Europese initiatief voor een ondergronds zwaartekrachtsgolfobservatorium van de derde generatie, bedoeld voor het waarnemen van zwaartekrachtgolven uit de ruimte. Zuid-Limburg geldt als mogelijke kandidaat voor de vestiging van deze Europese faciliteit.

Zwaartekrachtgolven zijn minieme rimpelingen in de ruimtetijd. Albert Einstein voorspelde het bestaan ervan al in 1916. Honderd jaar later werden ze daadwerkelijk direct waargenomen door de LIGO-detector in de VS. De ontdekking opent een geheel nieuw onderzoeksveld waar astrofysica, kosmologie en fundamentele fysica bij elkaar komen.

Eeuwenlang bestudeerde de mens het universum door elektro-magnetische straling zoals licht te bestuderen. Maar niet ieder kosmisch object zendt straling uit, en niet alle straling bereikt onze detectoren, bijvoorbeeld omdat het wordt tegengehouden door ruimtestof. Zwaartekrachtgolven reizen echter haast ongehinderd door het universum. De ET kan daarom signalen opvangen uit de verste uithoeken van het heelal.

Zwaartekrachtgolven verraden zich door minieme vervorming van de twee kilometerslange armen van een zwaartekrachtgolfdetector, die daardoor verschillend van lengte worden. Om dit lengteverschil (10^{-19} m, kleiner dan de doorsnede van een atoomkern) te meten, maken onderzoekers gebruik van heen en weer kaatsende laserlichtbundels. De ET krijgt zes van dergelijke interferometers, elk met een lengte van 10 kilometer. Daarmee is de ET vele malen gevoeliger dan de huidige generatie detectoren en in staat om het aantal observaties met ongeveer een factor 1.000 te vergroten. Om storende trillingen van buitenaf zoveel mogelijk te voorkomen, wordt de telescoop aangelegd op een diepte van ongeveer 200 meter.

Met zijn grote meetnauwkeurigheid en trillingsfrequentiebereik maakt de ET het mogelijk om de krachtigste verschijnselen in het heelal te bestuderen. De ET zal ook waarnemingen leveren voor onderzoek op het gebied van kwantumgravitatie, waar Einsteins algemene relativiteitstheorie samenkomt met quantumfysica. Zo wijst de ET ons de weg naar de correcte theorie van zwaartekracht.

Het voorontwerp voor de ET is reeds afgerond; het 'programma van eisen' is in voorbereiding. In fase 1 wordt onderzoek gedaan naar de optimale locatie (definitieve keuze naar verwachting rond 2020), planning en financiering, waarna in fase 2 de telescoop wordt gebouwd.

De ET is een initiatief van een tiental Europese instituten, met Nikhef als betrokken partij vanuit Nederland. Het onderzoeksteam telt momenteel meer dan 220 onderzoekers van 57 onderzoeksinstellingen.

STRONG SUPPORT BY LOCAL POLITICIANS

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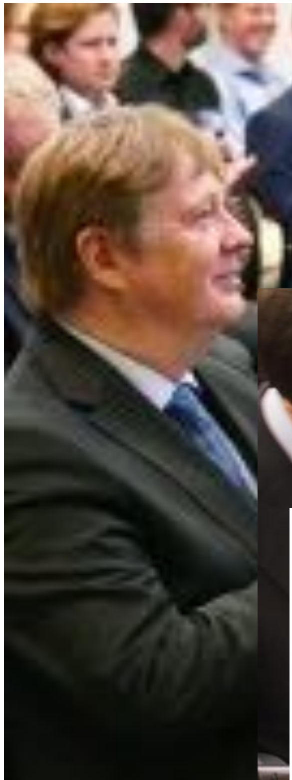
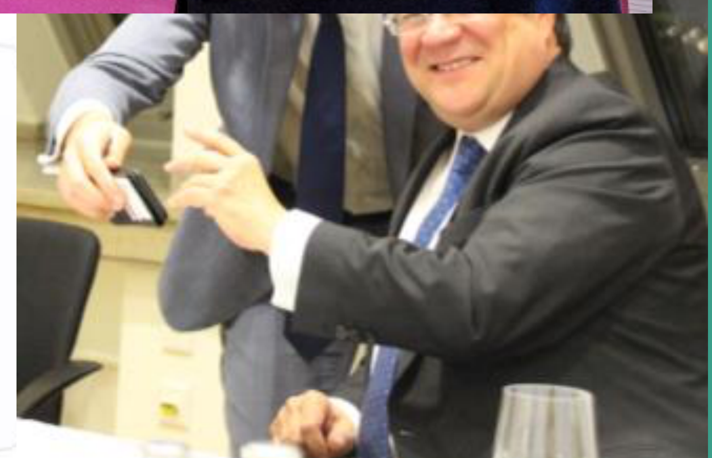
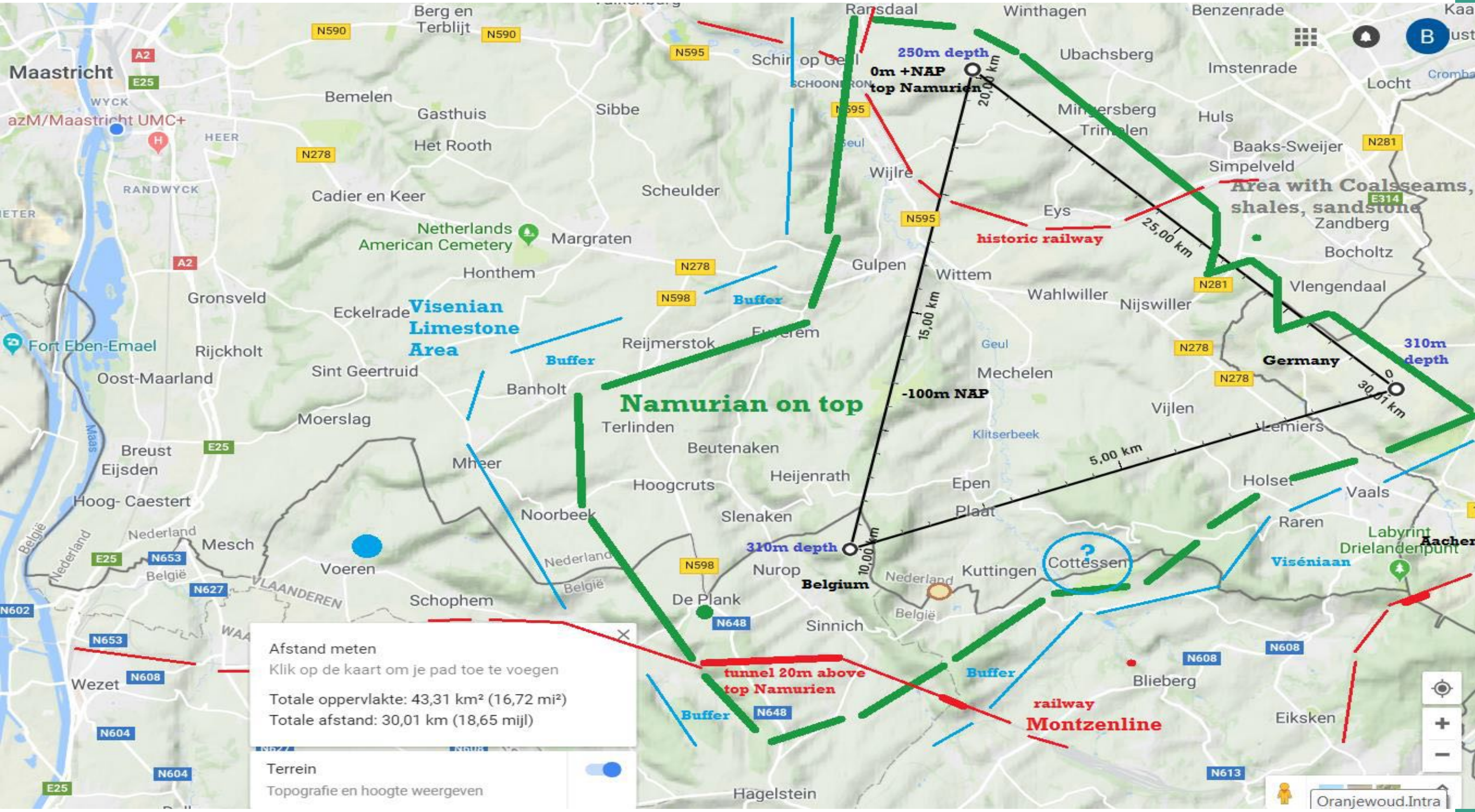


STRONG SUPPORT BY LOCAL POLITICIANS

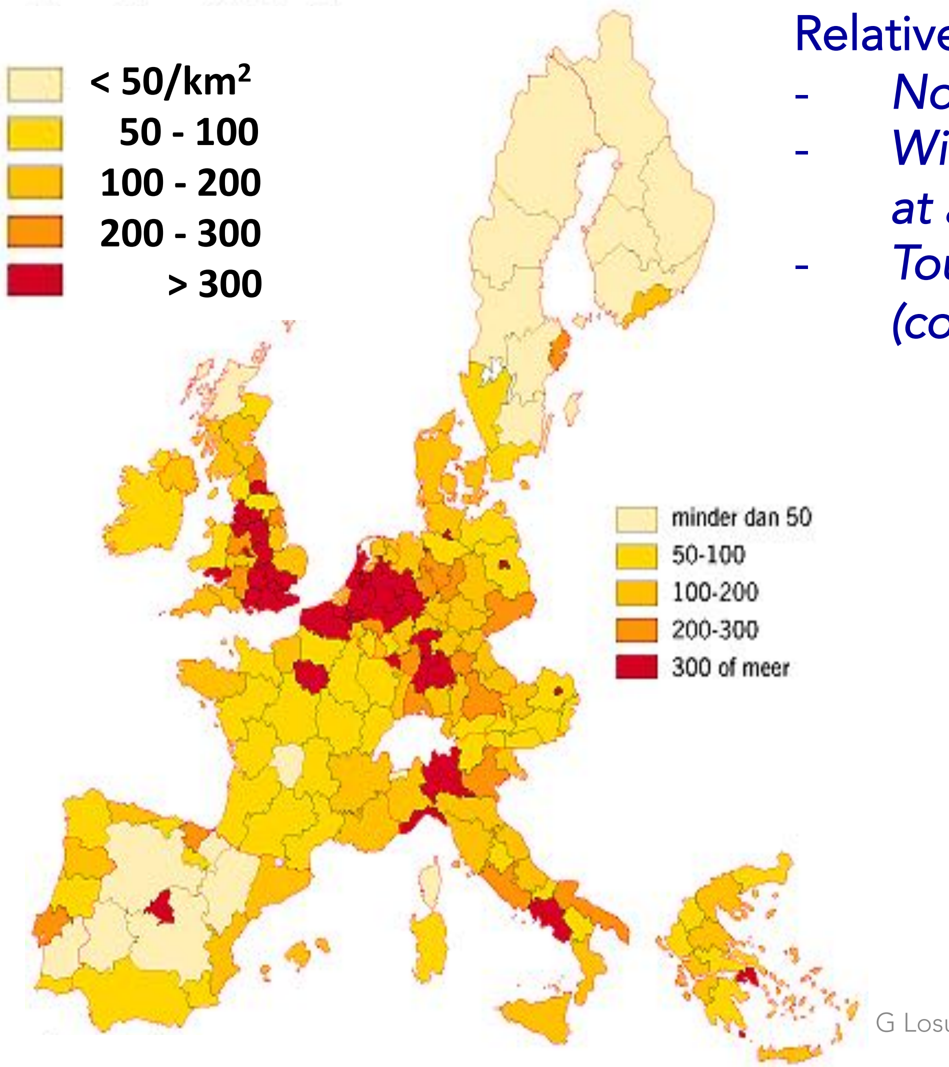


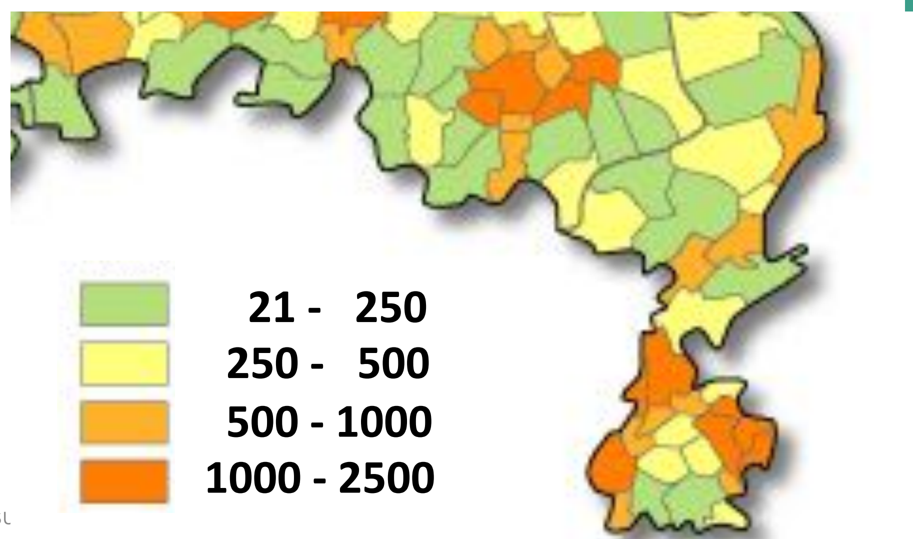


250m depth
0m +NAP
top Namurien
20,00 km
25,00 km
15,00 km
-100m NAP
5,00 km
10,00 km
30,01 km
310m depth
310m depth
Area with Coalsseams, shales, sandstone
historic railway
Germany
Visenian Limestone Area
Buffer
Buffer
Buffer
Buffer
Namurian on top
Belgium
tunnel 20m above top Namurien
railway
Montzenline
Viséniaan
Afstand meten
Klik op de kaart om je pad toe te voegen
Totale oppervlakte: 43,31 km² (16,72 mi²)
Totale afstand: 30,01 km (18,65 mijl)
Terrein
Topografie en hoogte weergeven

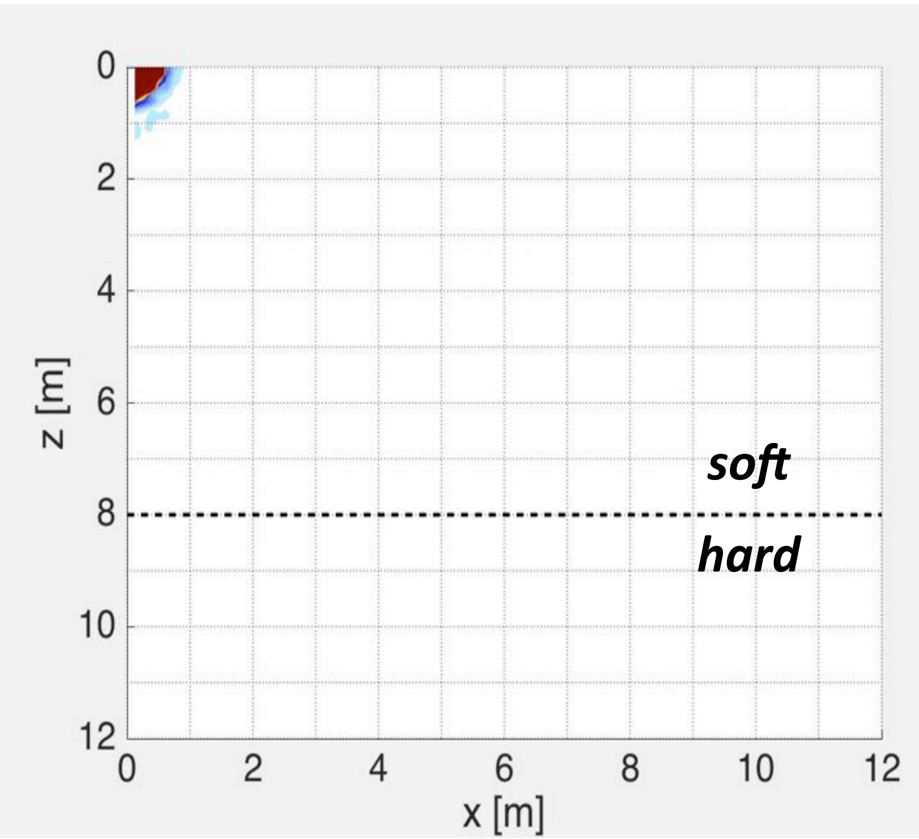
Modest population density (200/km^2)
Relatively ‘quiet’ in view of:

- *No heavy industry;*
- *Windmills, highways, railroads at a distance;*
- *Tourism earmarked as a priority (complicates our drilling activity …)*

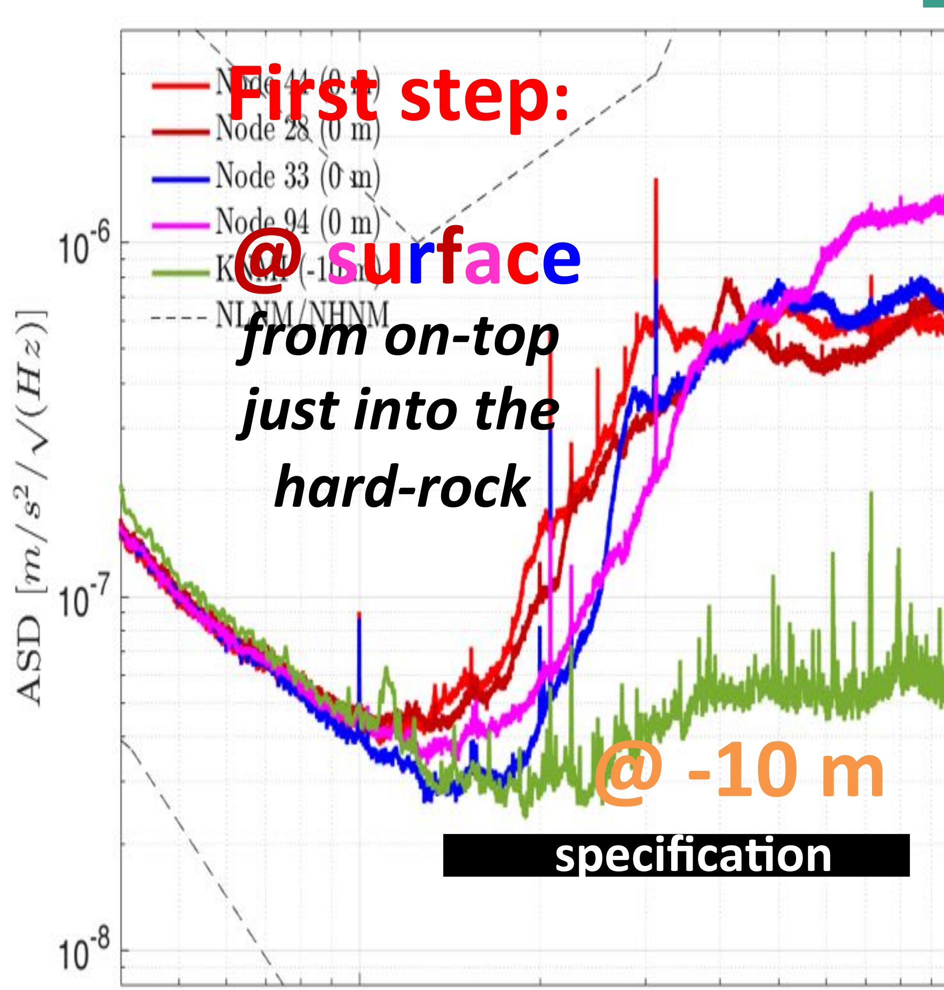




Soft top layer on top of hard rock ..

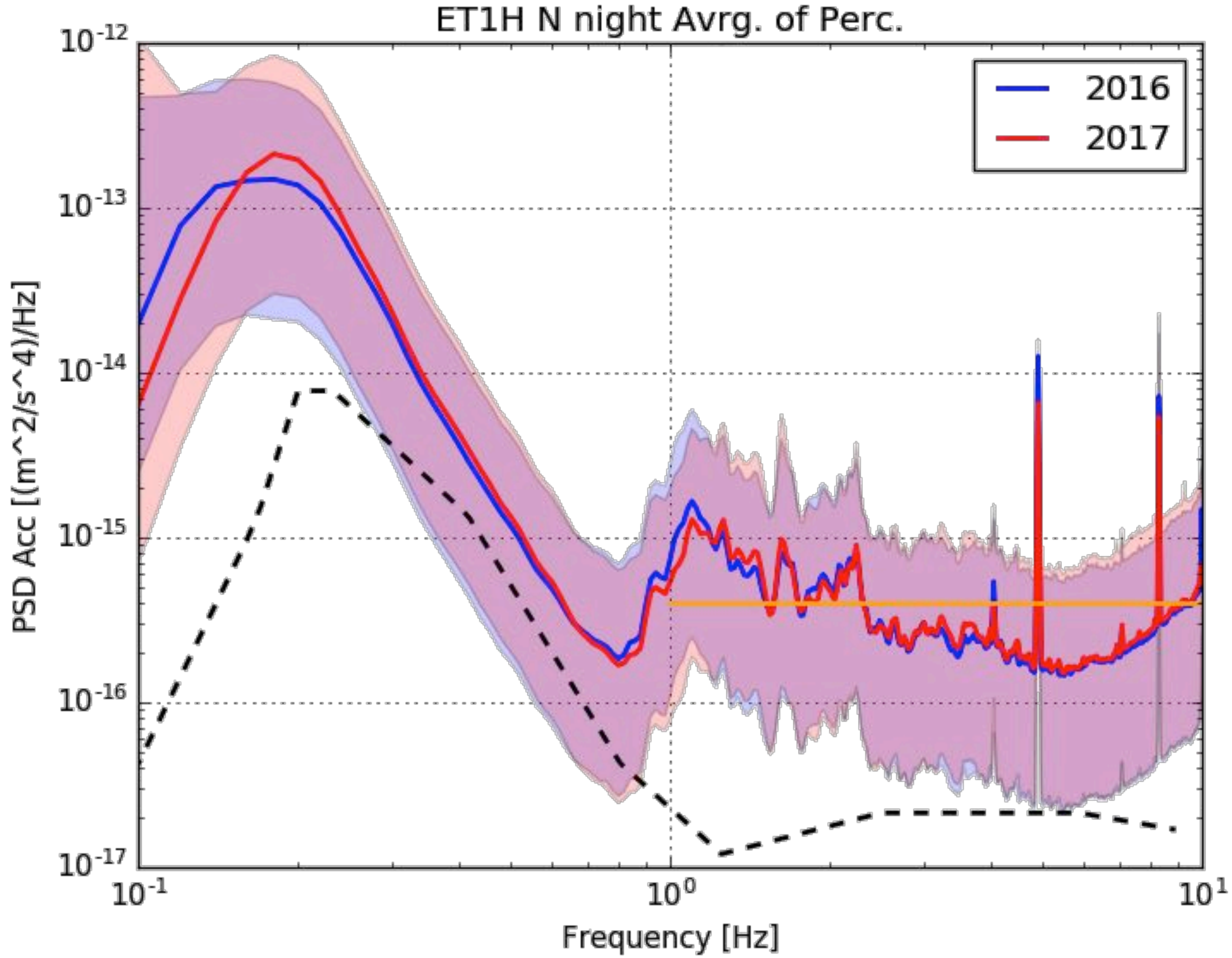


Only measurement so far …



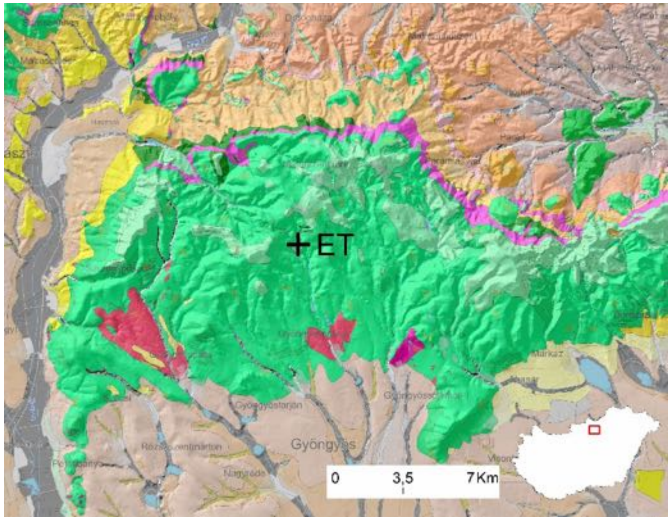
MATRA MOUNTAINS

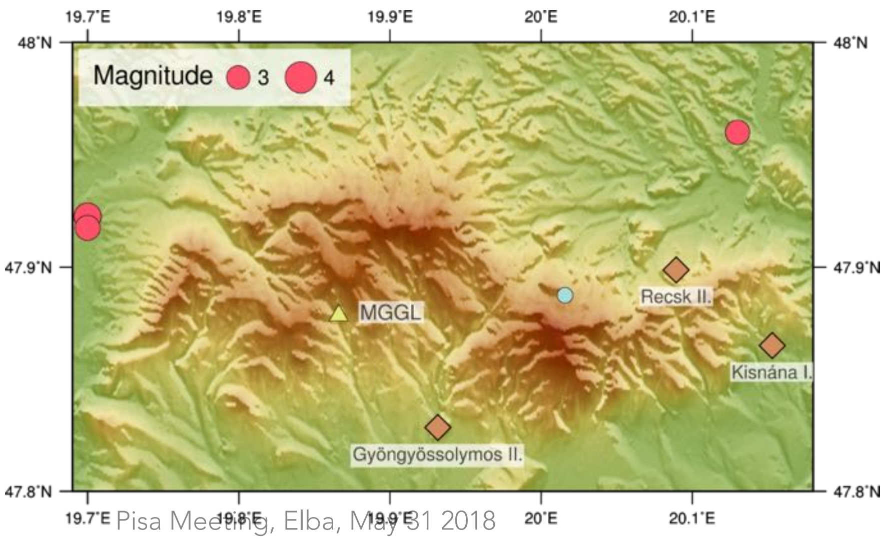
- Small underground lab (-88m) realized and used for seismic measurements
- Two years of seismic data available

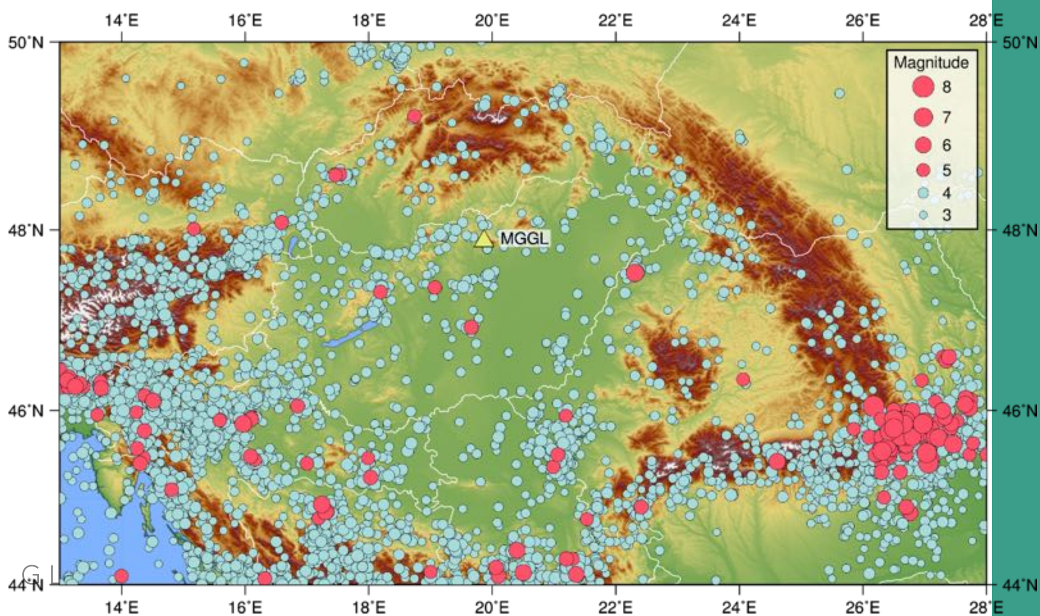


ET1H N night Avrg. of Perc.
2016
2017
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
PSD Acc [(m^2/s^4)/Hz]
10^{-1}
10^{0}
10^{1}
Frequency [Hz]

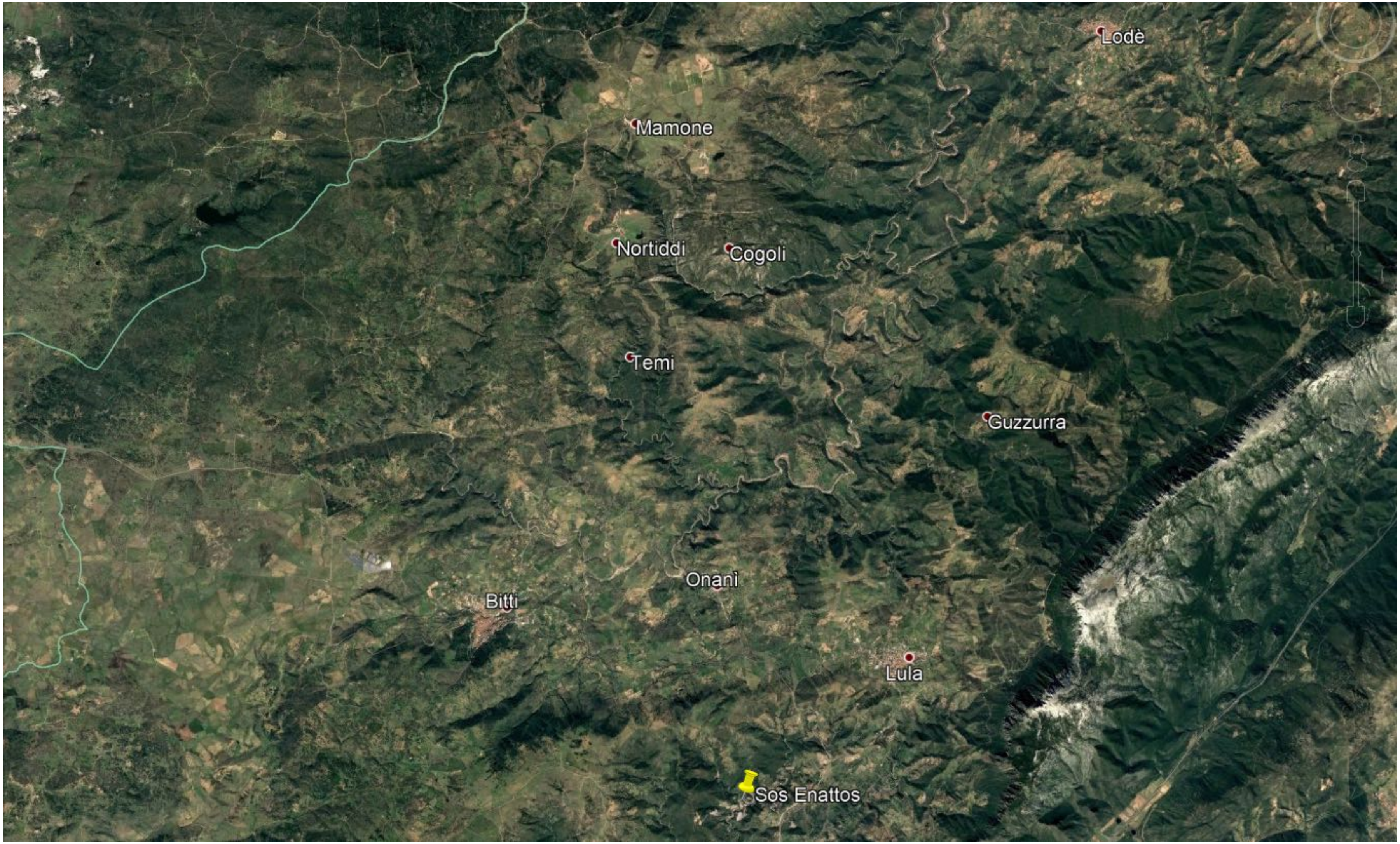
- Various andesite types from same geological era, limestone basis
- Local seismicity level
  - 3 earthquakes in the last 200 yrs
  - M = 3.5 (1879), 3.2 (1895), 3.1 (1980)
- Explosions nearby
  - 91 between 03.2016 – 12.2017







SOS ENATTOS

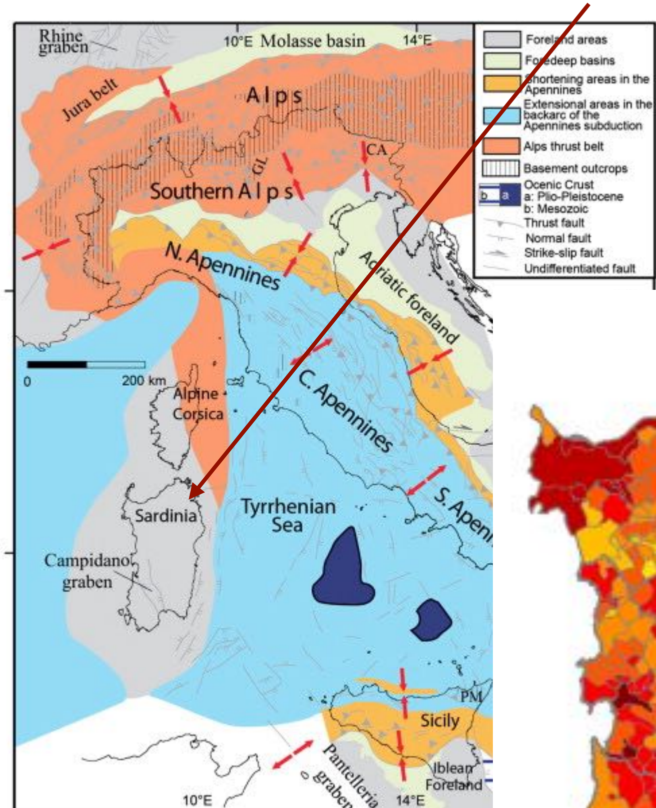


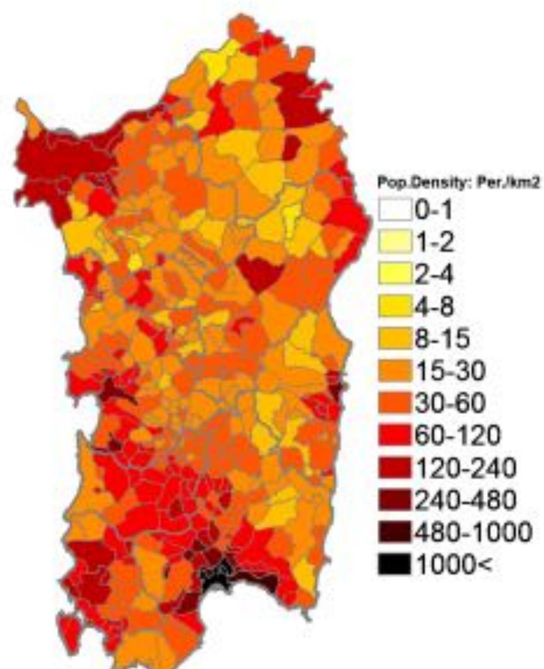
Lodè
Mamone
Nortiddi
Cogoli
Temi
Guzzurra
Onanì
Bitti
Lula
Sos Enattos

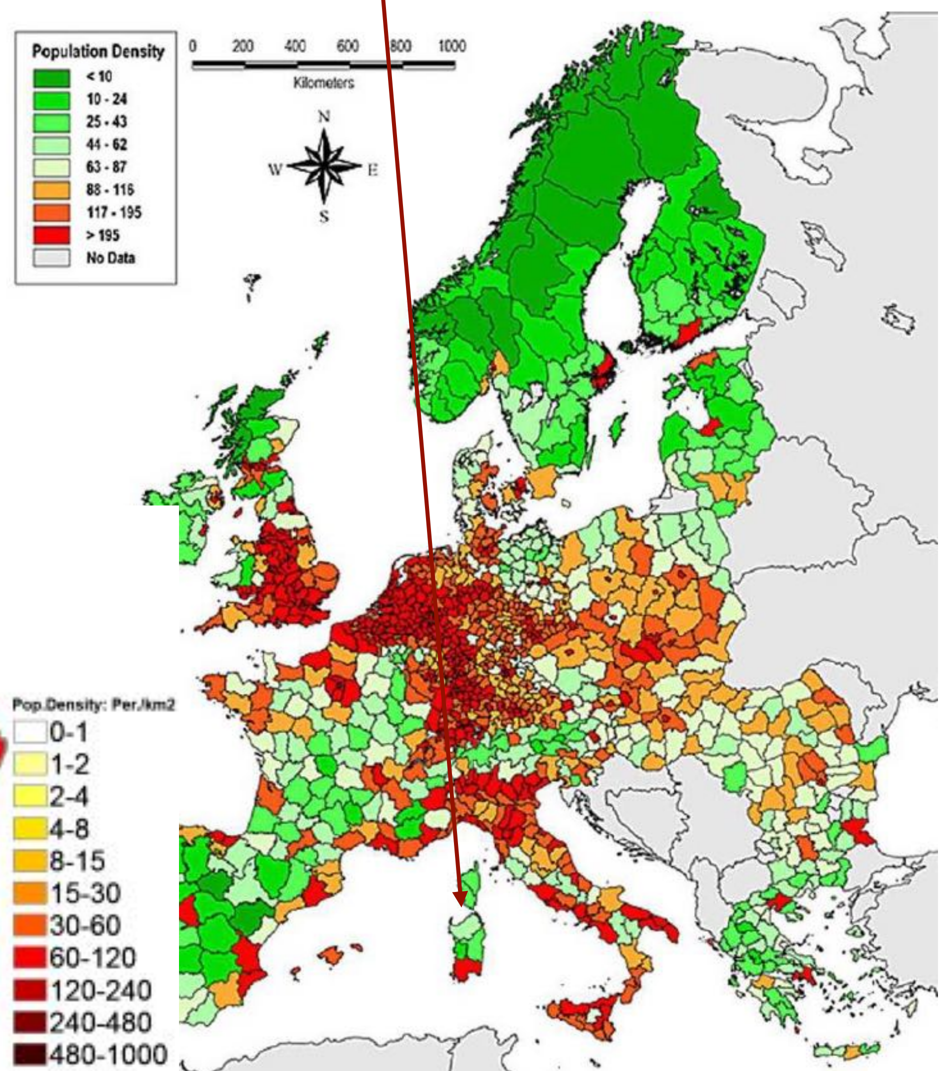
AREA ASSETS

One of the least populated areas in EU

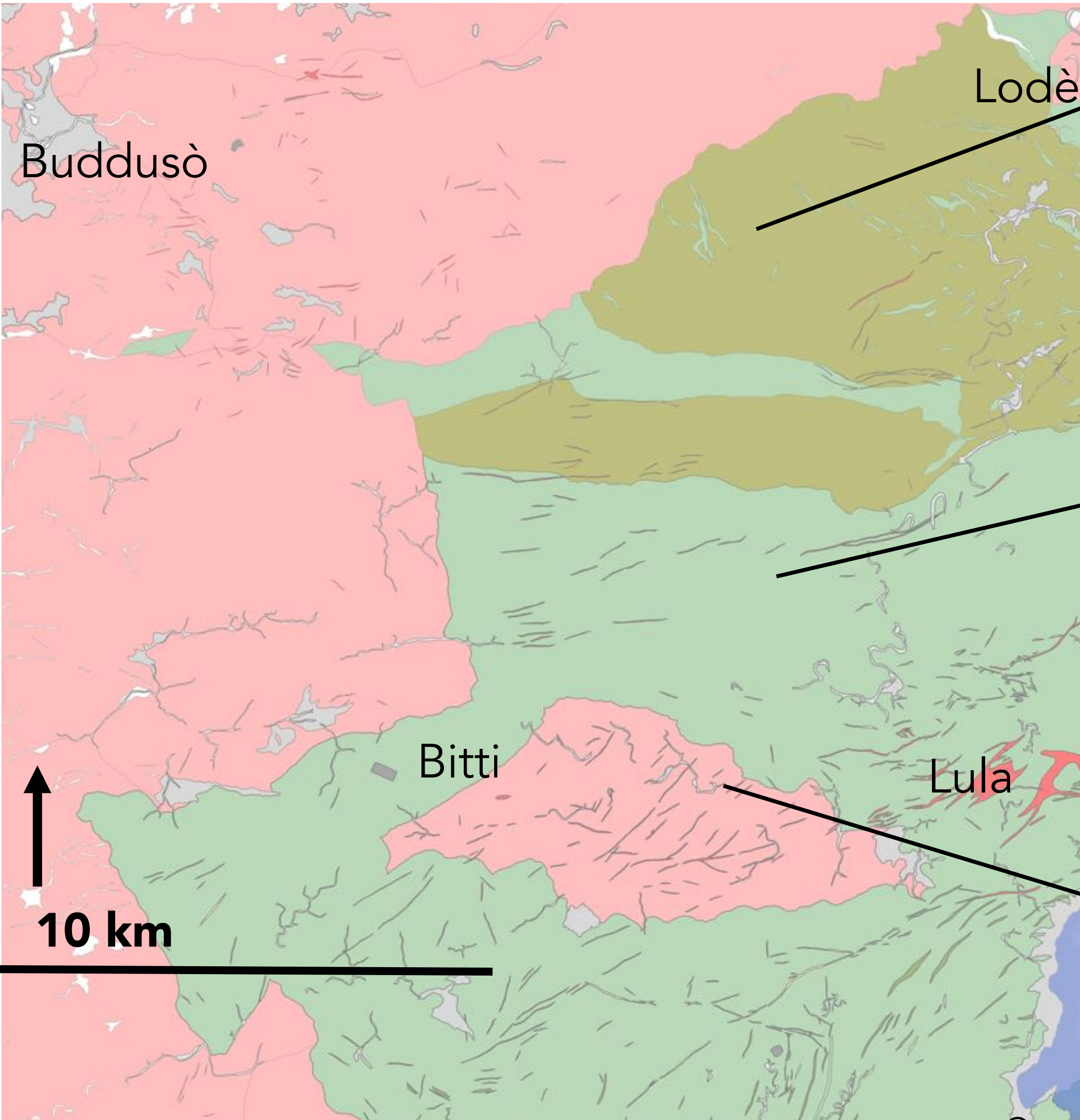
Ancient rocks, European continental landmass: <u>seismically quiet</u>





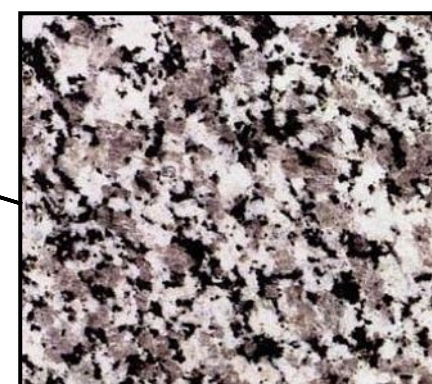


LOCAL GEOLOGY



Orthogneiss “Lodè type”
UCS: 92.6/60.8 MPa

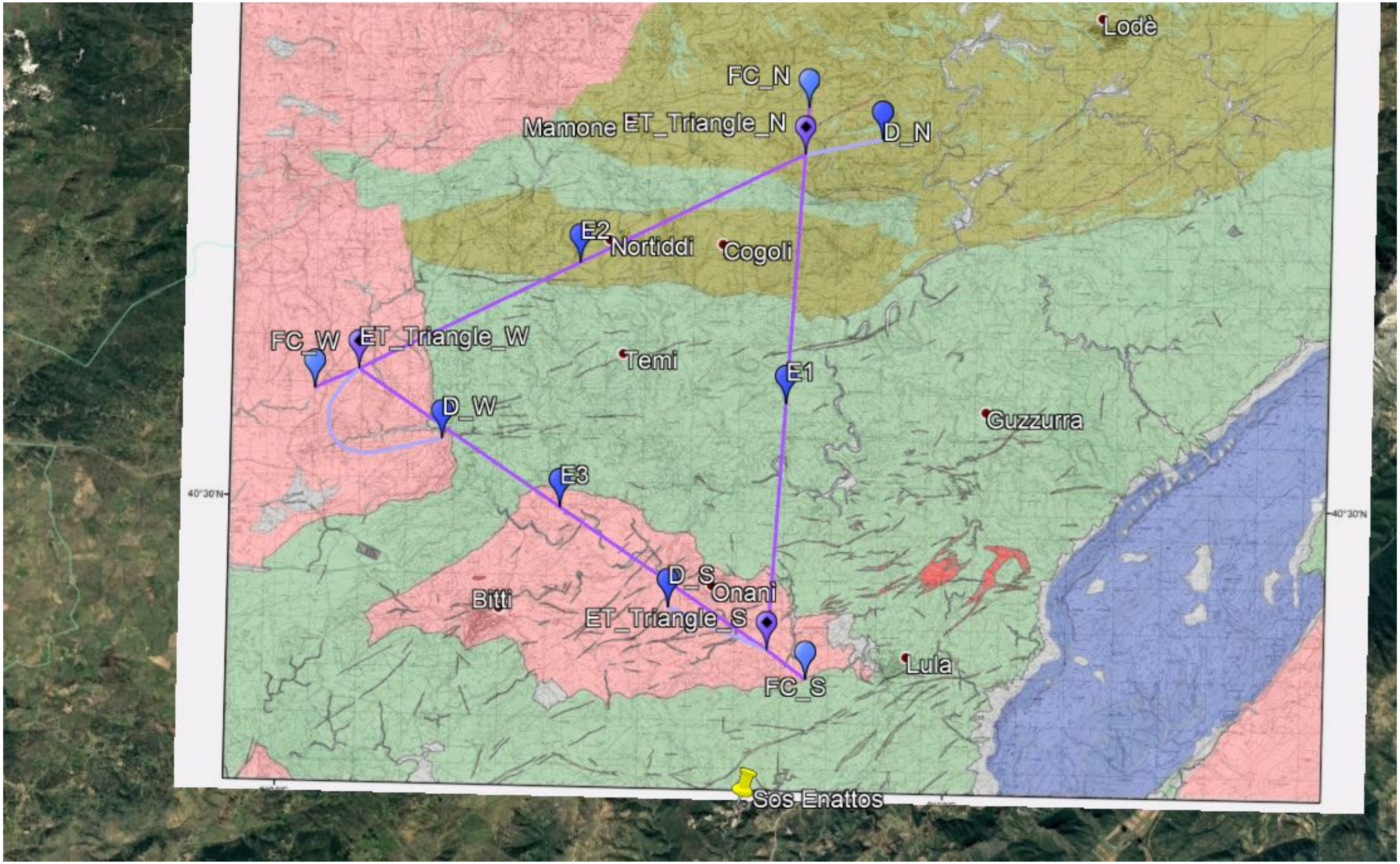
Micaschist – Paragneiss - Quartzite
UCS: 9.9/8.8 MPa



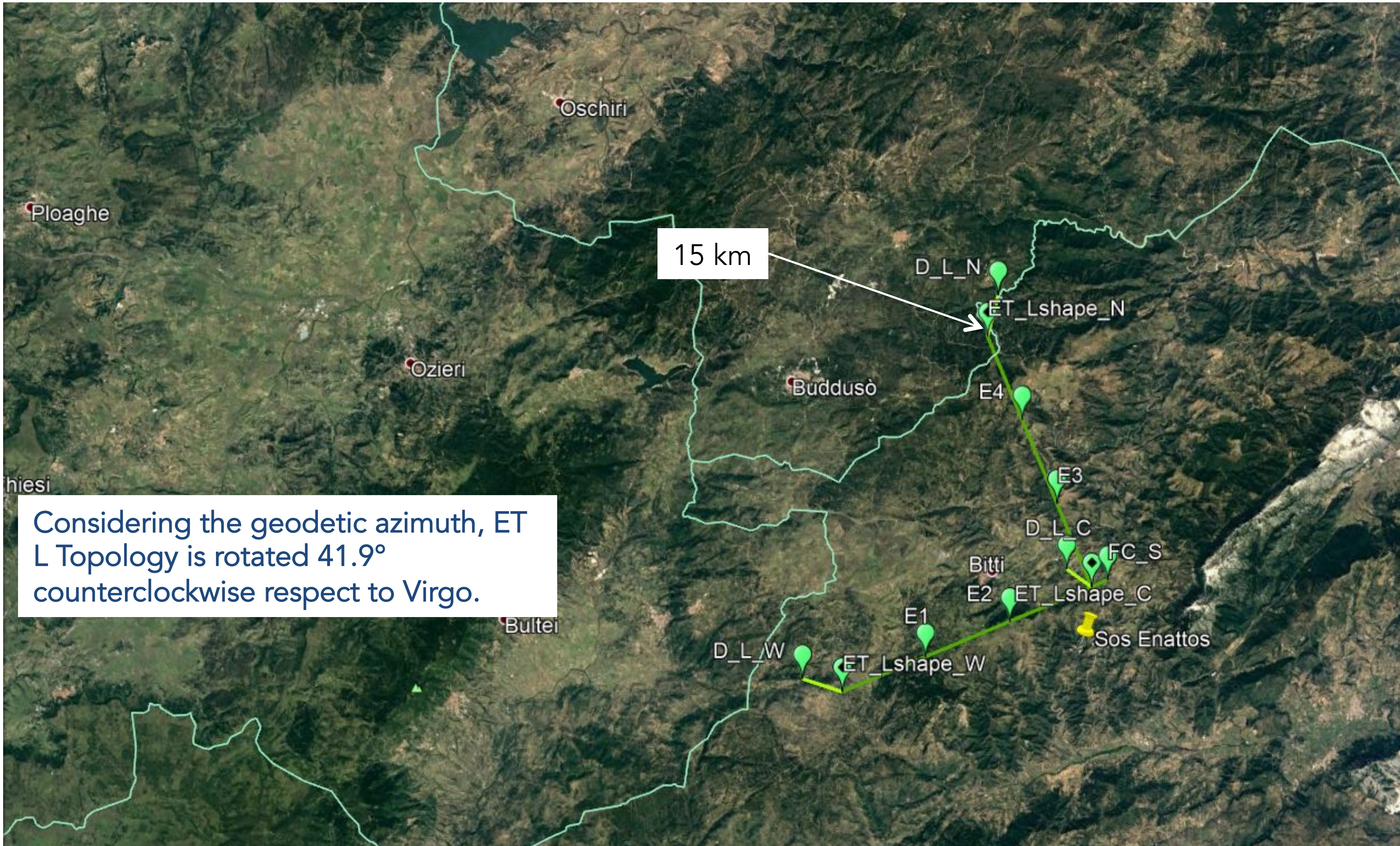
Granodiorite “Bitti type”
UCS: 72.1 MPa

*UCS: Uniaxial Compressive Strength

LOCATION - TRIANGLE

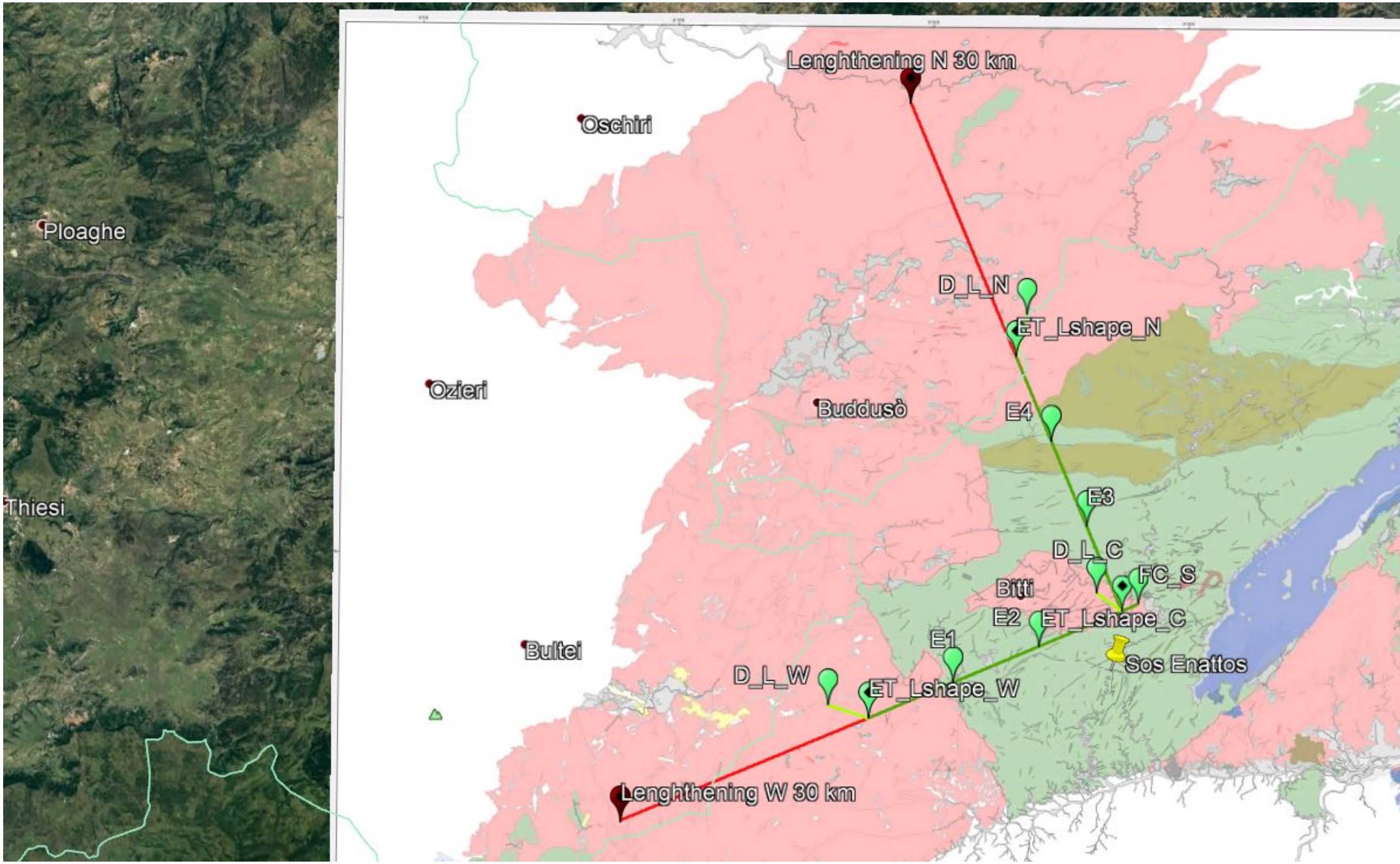


LOCATION - L



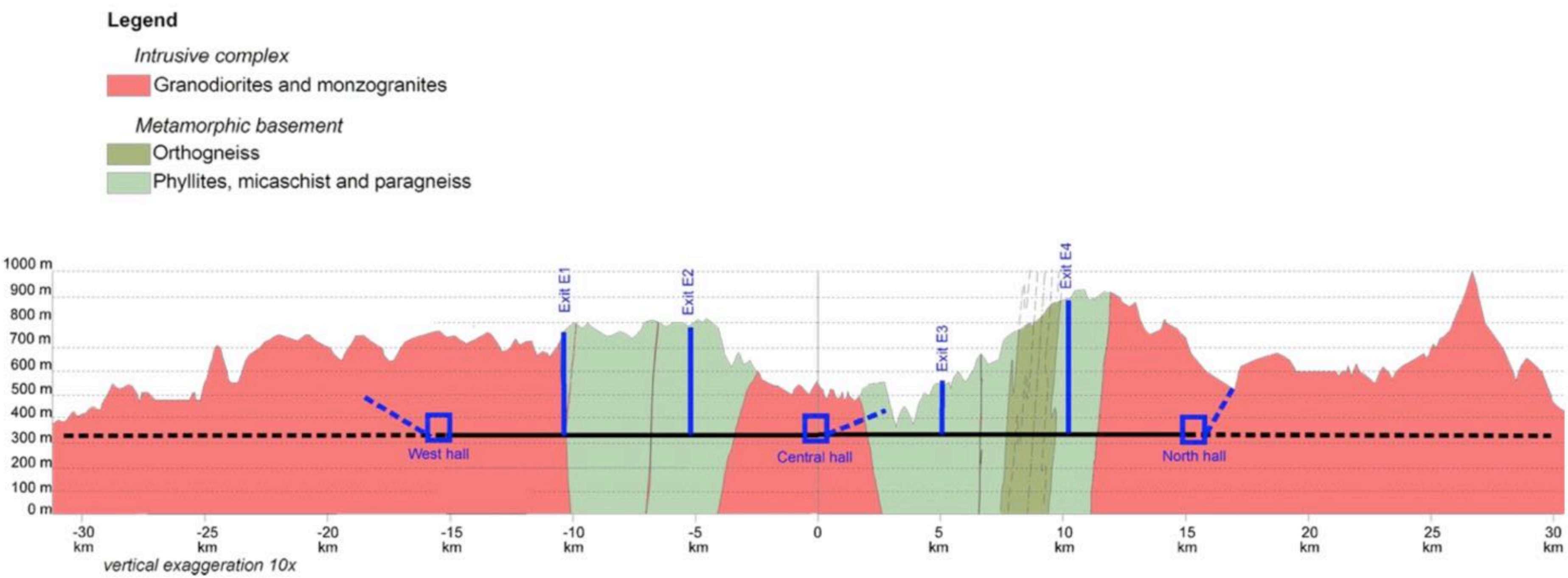
Considering the geodetic azimuth, ET L Topology is rotated 41.9° counterclockwise respect to Virgo.

LOCATION - L



Lenghthening N 30 km
Oschiri
Ploaghe
Ozieri
Buddusò
Thiesi
D_L_N
ET_Lshape_N
E4
E3
D_L_C
FC_S
Bitti
E2
ET_Lshape_C
E1
Sos Enattos
D_L_W
ET_Lshape_W
Bultei
Lenghthening W 30 km

GEOLOGICAL SECTIONS - L

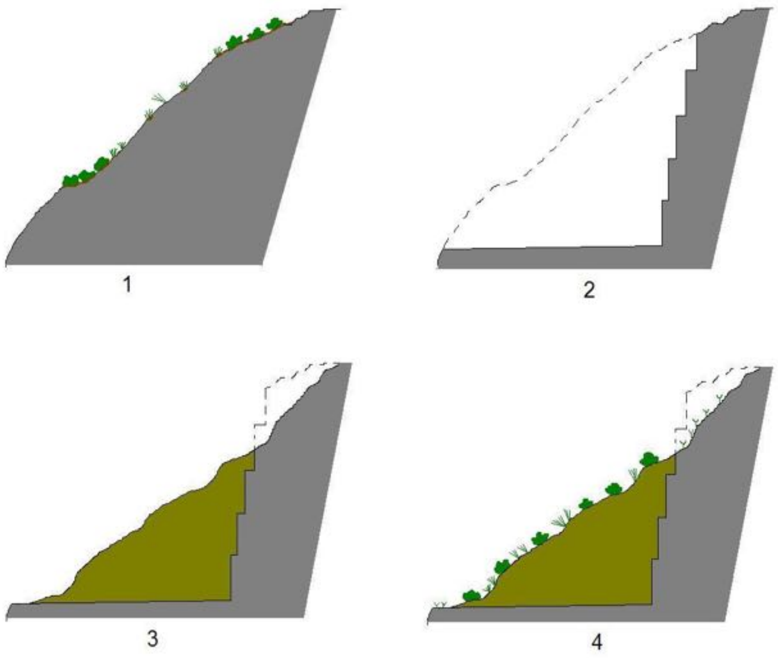


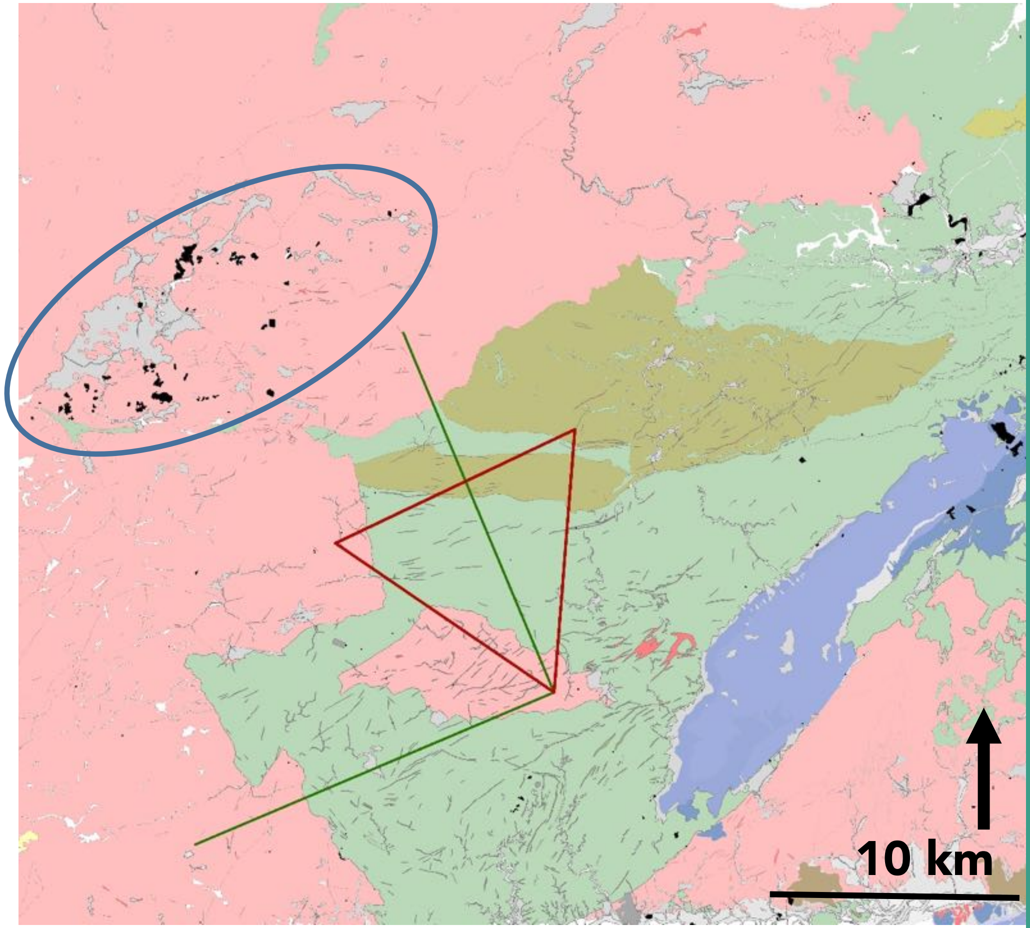
ET@SosEnattos L Topology could be lengthned untill arms of ~30 km with the present height.

Lowering the interferometer further would allow length up to 40 km.

ENVIRONMENTAL ISSUES

The excavated rock could be employed in the recovery of the nearby quarry sites.
The quarried surfaced in the Buddusò District (granite extraction) covers ~2 Mm^2.
The muck produced by the excavations could be used for landscape rehabilitation.





ITALY GOVERNMENT SUPPORT

ET EINSTEIN TELESCOPE

17 Meuros for AdV+, ET R&D and support of the Sos Enattos candidature

ONDE GRAVITAZIONALI: MIUR, INFN E UNISS CANDIDANO LA REGIONE SARDEGNA A OSPITARE IL FUTURO OSSERVATORIO INTERNAZIONALE

Pubblicato: 22 Febbraio 2018

COMUNICATO CONGIUNTO MIUR/INFN/REGIONE SARDEGNA/UNISS_Il Ministero dell'Istruzione, dell'Università e della Ricerca sosterrà la candidatura della Regione Sardegna a ospitare un Centro europeo per l'Osservatorio delle onde gravitazionali nella miniera di Sos Enattos a Lula. Il MIUR, la Regione, l'Istituto Nazionale di Fisica Nucleare e l'Università di Sassari hanno firmato un Protocollo d'intesa finalizzato a mettere in atto ogni iniziativa utile a favorire l'insediamento della infrastruttura Einstein Telescope nell'Isola, anche con lo scopo di entrare nella lista delle infrastrutture di ricerca riconosciute a livello europeo. Il progetto era stato presentato lo scorso 7 febbraio a Roma alla ministra Valeria Fedeli dal presidente della Regione Francesco Pigliaru e dall'assessore della Programmazione

Ministero dell'Istruzione dell'Università e della Ricerca

REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA

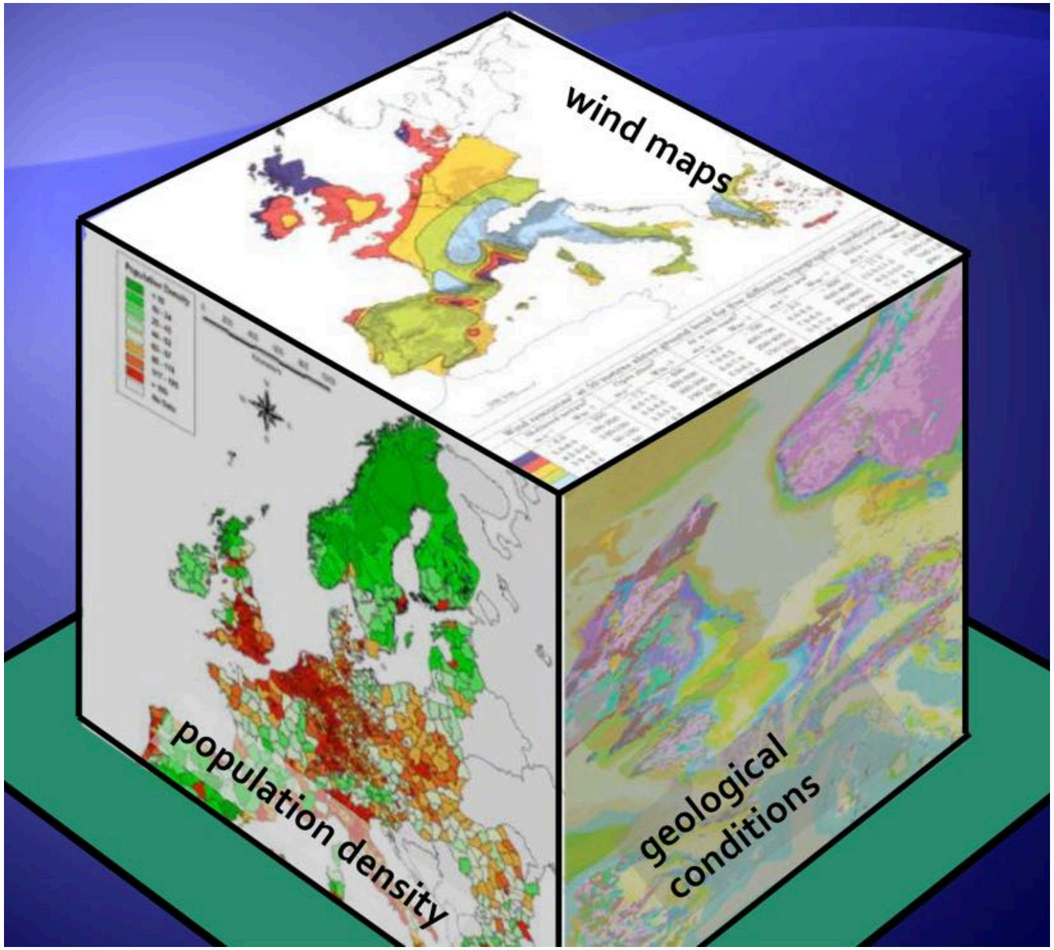
INFN Istituto Nazionale di Fisica Nucleare

uniss UNIVERSITÀ DEGLI STUDI DI SASSARI

SITE SELECTION

POLITICAL SUPPORT

FUNDING AGENCIES PRIORITIES



LOGISTICS

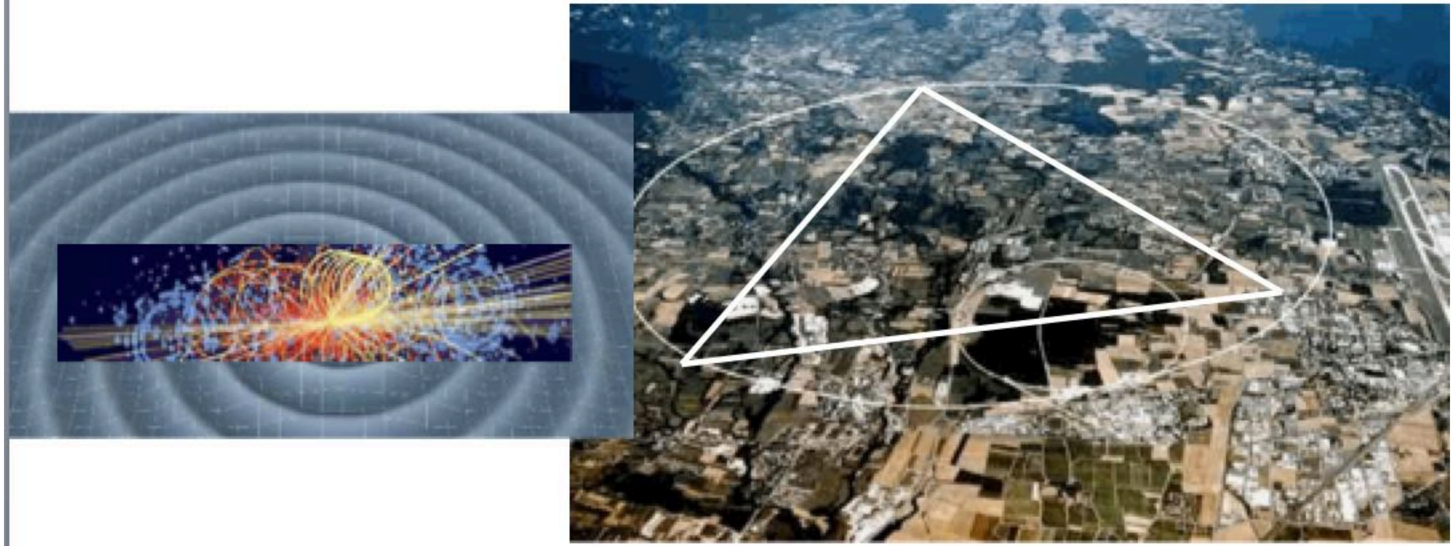
...

CERN

NOT THE BEST SITE FOR ET BUT….

The Great Unification…in Europe

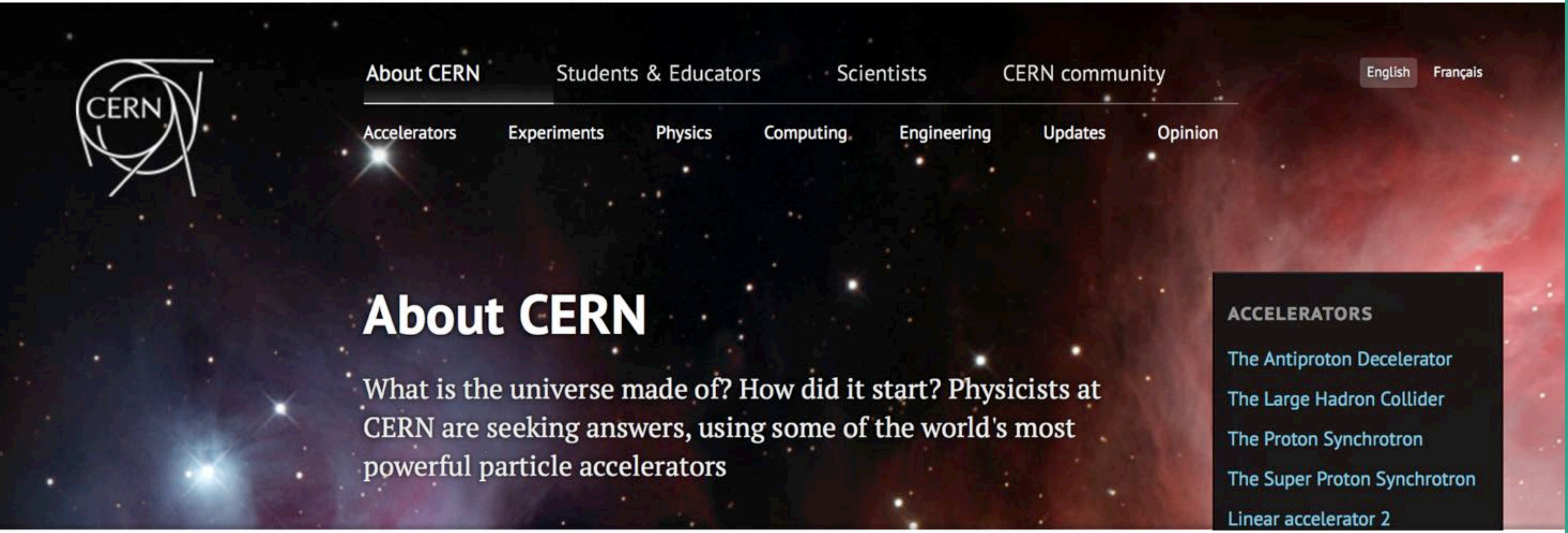
If we cannot put the fundamental interactions into the same theory…
we can at least put them in the same place!



EAP Town Meeting – Munich, Nov. 23, 2005 G.Losurdo – Firenze-Urbino 24

THE POSSIBLE ROLE OF CERN

- The GW community looks at CERN as a model to many extents
- We have a lot to learn from CERN:
  - Model of governance
  - Management of big projects
  - Technology: underground infrastructure, vacuum, cryogenics



GF Giudice, CERN 9/2017

- GW physics is awesome
- Our sciences have much in common
- More than ever, particle physics needs exchange with other sciences
- GW physics has much to offer to particle physics and CERN

(tests of GR, search for ECOs, primordial BH as DM, early-universe phase transitions, cosmological stochastic bkgrd, search for light particles through superradiance, QCD in extreme conditions, ...)

CONCLUSIVE REMARKS

- The science case for ET is compelling
- **If not now…**: a great window of opportunity has been opened by recent discoveries
- A world wide coordination effort on 3G detectors is being pursued
  - Europe is ahead
- CERN can play a crucial role

SPARE SLIDES

TECHNOLOGIES

- HF DETECTOR
  - “standard” superattenuators
  - large fused silica mirrors (for large beams)
  - high power, frequency dependent squeezing
  - standard laser (1064 nm)
- LF detector
  - “extreme” superattetuators (1 Hz goal)
  - newtonian noise subtraction
  - large silicon mirrors, silicon suspensions, cryogenics (test mass @10 K)
  - new wavelength (1550 nm)
  - low power, frequency dependent squeezing)

- Aggressive R&D program needed

GWIC 3G COORDINATION

With the recent first detections of gravitational waves by LIGO and Virgo, it is both timely and appropriate to begin seriously planning for a network of future gravitational-wave observatories, capable of extending the reach of detections well beyond that currently achievable with second generation instruments.

Gravitational Wave International Commitee

GWIC 3G

Planning for a 3rd Generation Ground-based Gravitational-wave Observatory Network

Committee Members

Michele Punturo, University of Florence, Italy (Co-Chair)
David Reitze, Caltech, USA (Co-chair)
Stavros Katsanevas, European Gravitational Observatory
Takaaki Kajita, University of Tokyo, Japan
Vicky Kalogera, Northwestern University
Harald Lueck, Albert Einstein Institute, Germany
Jay Marx, Caltech, USA
David McClelland, Australian National University
Sheila Rowan, University of Glasgow
B.S. Sathyaprakash, Penn State University, USA and Cardiff University, UK

David Shoemaker, MIT (secretary)

SUBCOMMITTEES:

- SCIENCE CASE
- R&D COORDINATION
- GOVERNANCE

FEASIBILITY MATRIX

	Conceptual Design (ET-0106C-10) Triangle				ET Triangle “realistic”				L shape			
Rock Mass Classes	Good rock	Fair rock	Weak rock	Soft Soil	Good rock	Fair rock	Weak rock	Soft Soil	Good rock	Fair rock	Weak rock	Soft Soil
Uniaxial compression strengh [MPa]	100÷250	50÷100	25÷50	≤ 25	100÷250	50÷100	25÷50	≤ 25	100÷250	50÷100	25÷50	≤ 25
RMR (Rock Mass Rating)	61÷80	41÷60	21÷40	0÷20	61÷80	41÷60	21÷40	0÷20	61÷80	41÷60	21÷40	0÷20
Tunnels	3	3	3	2	2	3	2	1	3	3	3	2
Auxiliary Tunnel	3	3	2	1	2	3	2	1	3	3	3	2
Main Caverns	0	0	0	0	3	2	1	0	3	3	2	0
Auxiliary Caverns	3	2	1	0	3	2	1	0	3	3	2	0
Access	3	3	3	2	3	3	2	2	3	3	3	2
Safety Exits	3	3	3	2	3	3	2	2	3	3	3	2
Shaft	3	2	0	0	3	3	2	1	3	3	2	1
sum:	18	16	12	7	19	19	12	7	21	21	18	9

Grade	Highlight
Easy	3
Hard	2
Challenging	1
Extremely hard	0

The *caverns are the critical issues*: the location of these elements in rock mass characterized by high resistances makes possible to reduce the excavation problems (as previously illustrated).
The flexibility of the tunnel excavation is greater, as there are available equipment that can excavate both in rock and soft soils.