TWEPP 2023
EINSTEIN TELESCOPE - ITALY
CANDIDATE SITE IN SARDINIA

Alberto Masoni

National Institute of Nuclear Physics - INFN

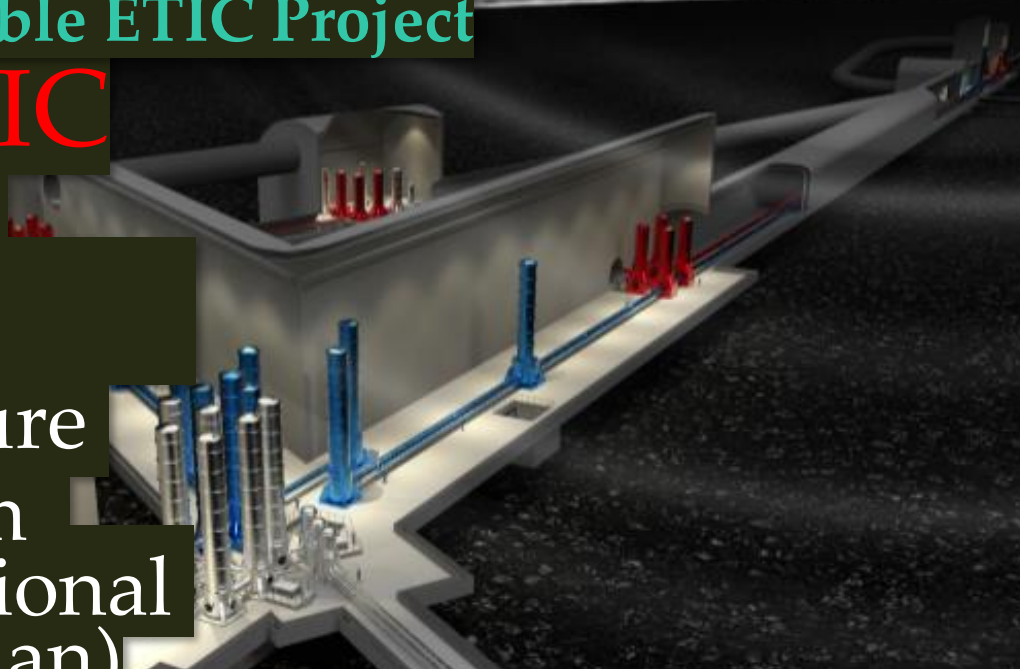
Local Responsible ETIC Project

INFN
Istituto Nazionale di Fisica Nucleare

ET ITALY
Einstein Telescope

ETIC

Einstein
Telescope
Infrastructure
Consortium
(Italian National Recovery Plan)

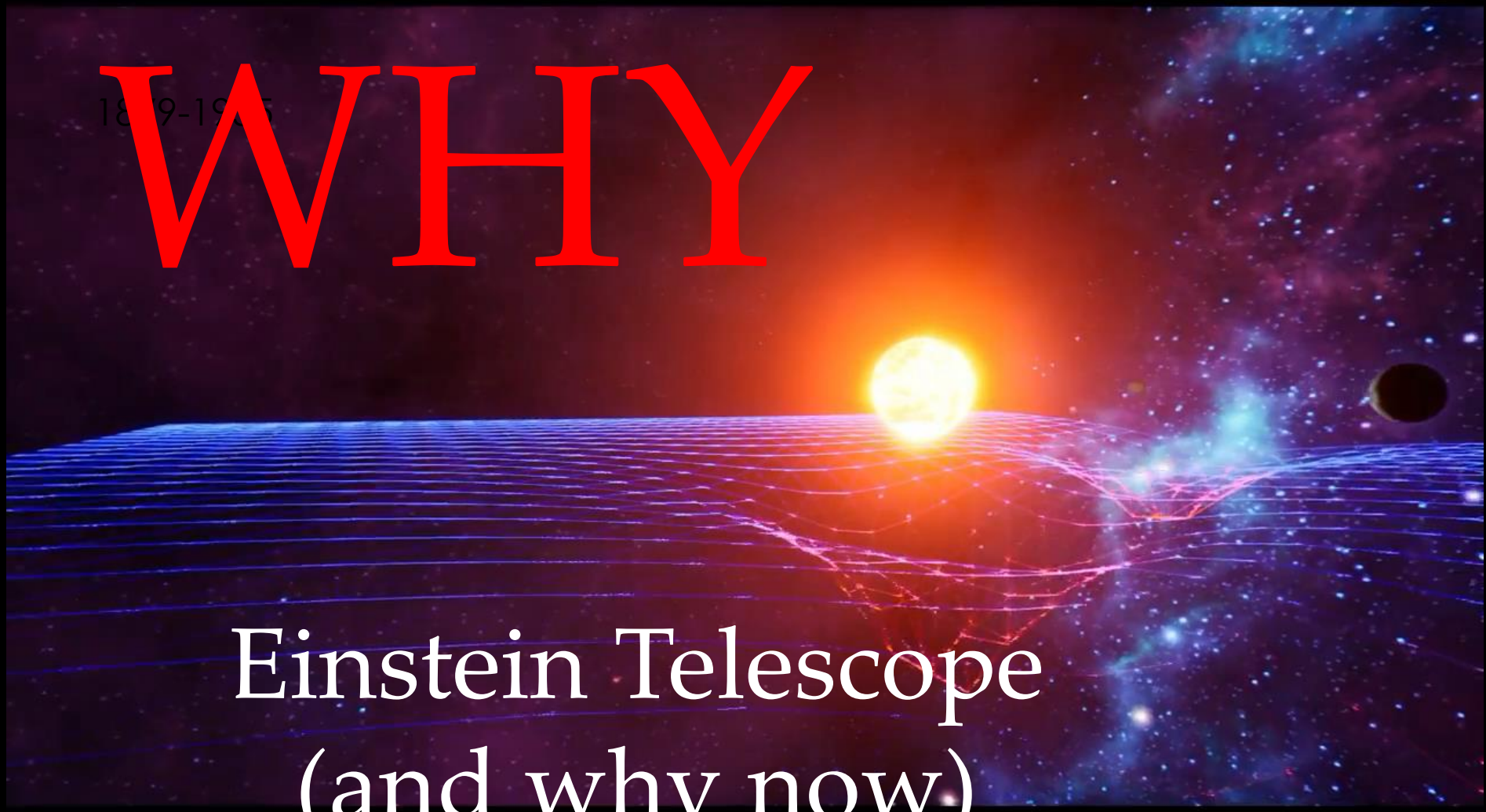


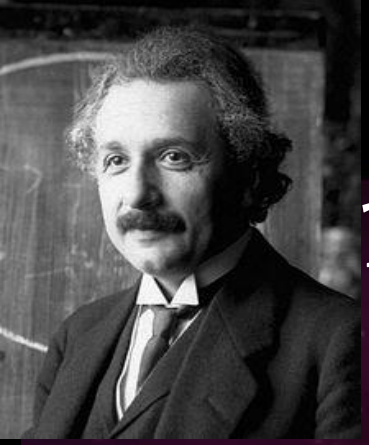
Acknowledgments

Pia Astone
Marica Branchesi
Alessandro Cardini
Michele Punturo

EINSTEIN TELESCOPE IN 5 W

- WHY Einstein Telescope (and why now)
- WHO (and why INFN)
- WHAT (The Detectors)
- WHERE (and WHY there)
- WHEN (present status & timescale)


WHY
Einstein Telescope
(and why now)



The Beginning of Everything
1915 GENERAL RELATIVITY

Gravity as curvature of space and time

matter tells spacetime how to curve, and curved spacetime tells matter how to move (J.A. Wheeler)

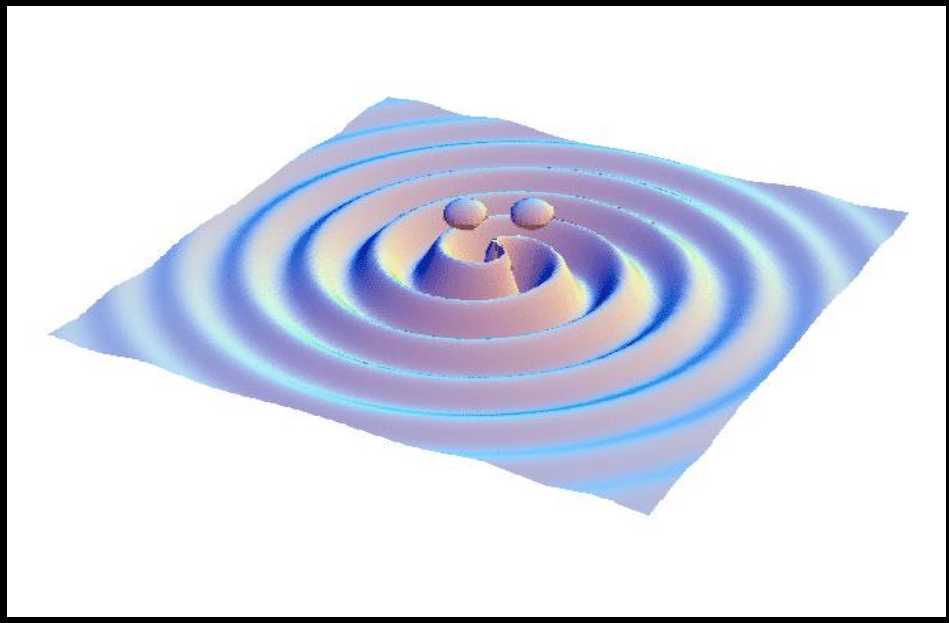
and….

Näherungsweise Integration der Feldgleichungen der Gravitation.

Von A. Einstein.

Bei der Behandlung der meisten speziellen (nicht prinzipiellen) Probleme auf dem Gebiete der Gravitationstheorie kann man sich damit begnügen, die $g_{\mu\nu}$ in erster Näherung zu berechnen. Dabei bedient man sich mit Vorteil der imaginären Zeitvariable $x_4 = it$ aus denselben Gründen wie in der speziellen Relativitätstheorie. Unter »erster Näherung« ist dabei verstanden, daß die durch die Gleichung

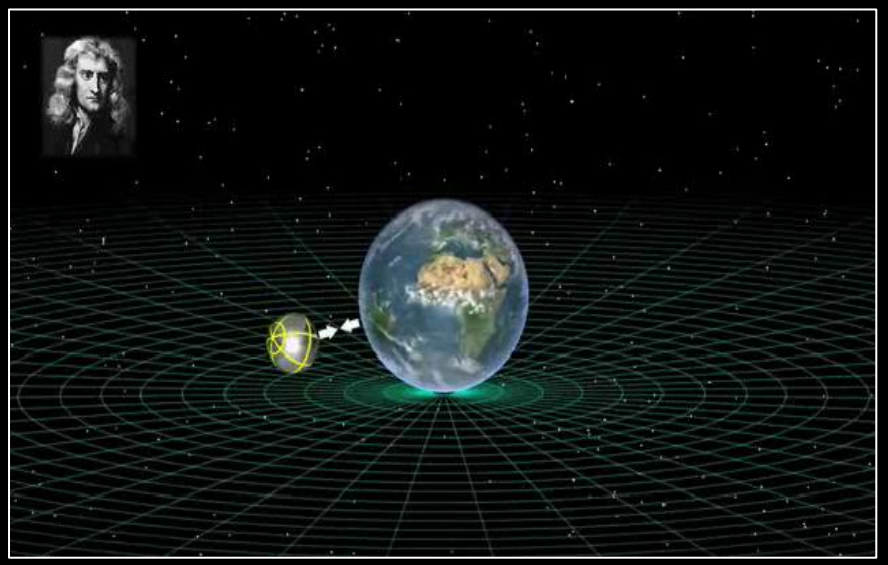
$$g_{\mu\nu} = -\delta_{\mu\nu} + \gamma_{\mu\nu} \qquad (1)$$



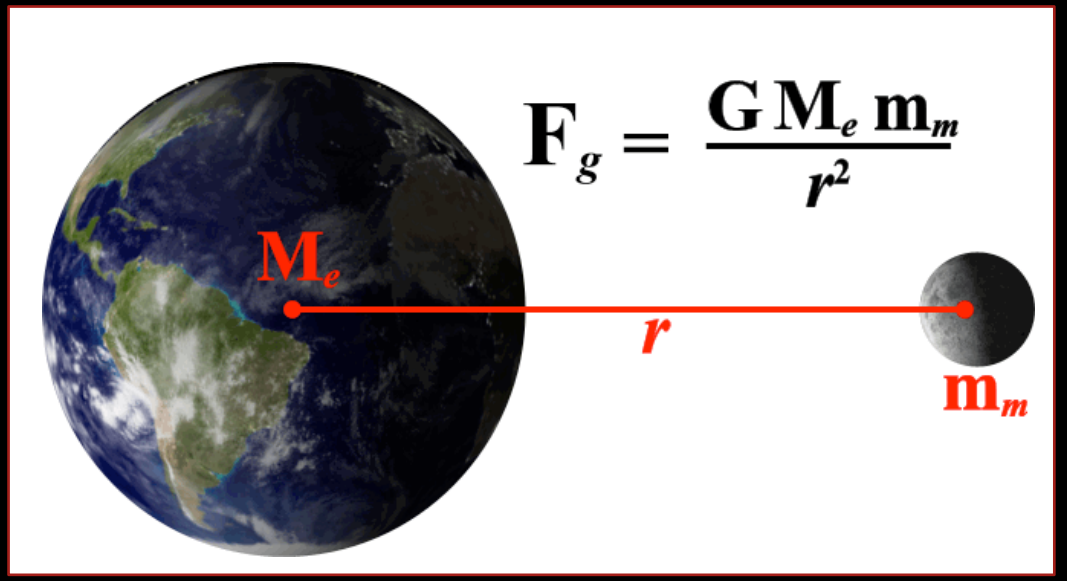
GRAVITATIONAL WAVES

Do we really need General Relativity?

Newton's Gravity is still teached in High School and University textbooks



- Gravity as a force
- Space and time are absolute, separate entities



ACTUALLY…. YES

If, for example, you do want GPS working

Credit NASA

The usefulness of useless knowledge

WHY

EINSTEIN TELESCOPE **NOW**

- *Are we humans because we gaze at stars or do we gaze at them because we are humans?*
  (Stardust, Incipit)

- Certainly for thousands years we gazed at stars as a silent movie

- **In the last 8 years:**

- Gravitational Waves provided the soundtrack

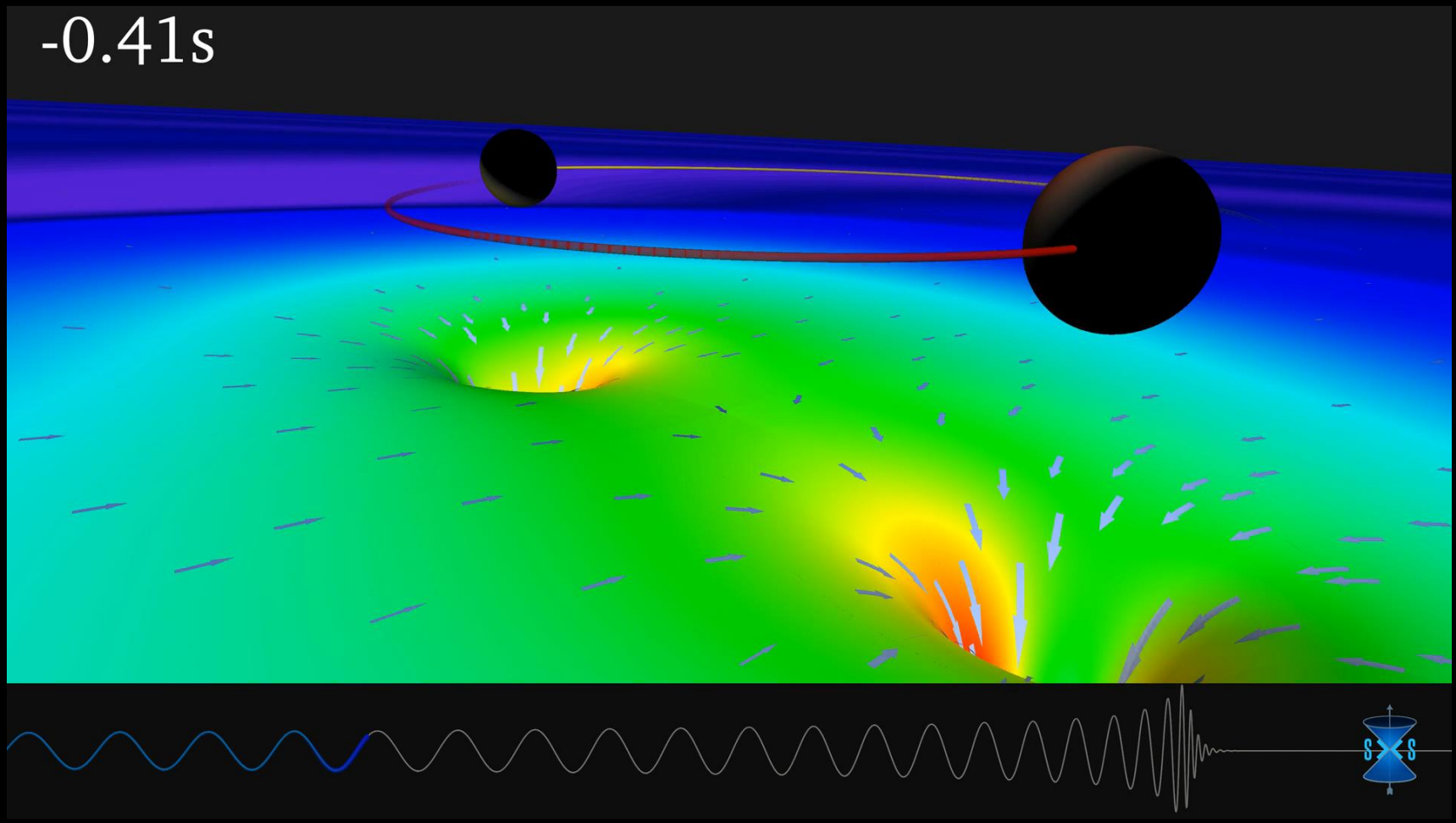
- *The scream of the universe* (Dario Menasce's book title)

- And more…

LET'S GO BACK

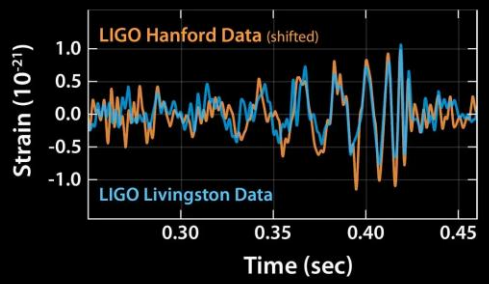
actually over 1 billion years
(in time and space)

TWO BLACK HOLES



$E = Mc^2$

M=☺☺☺

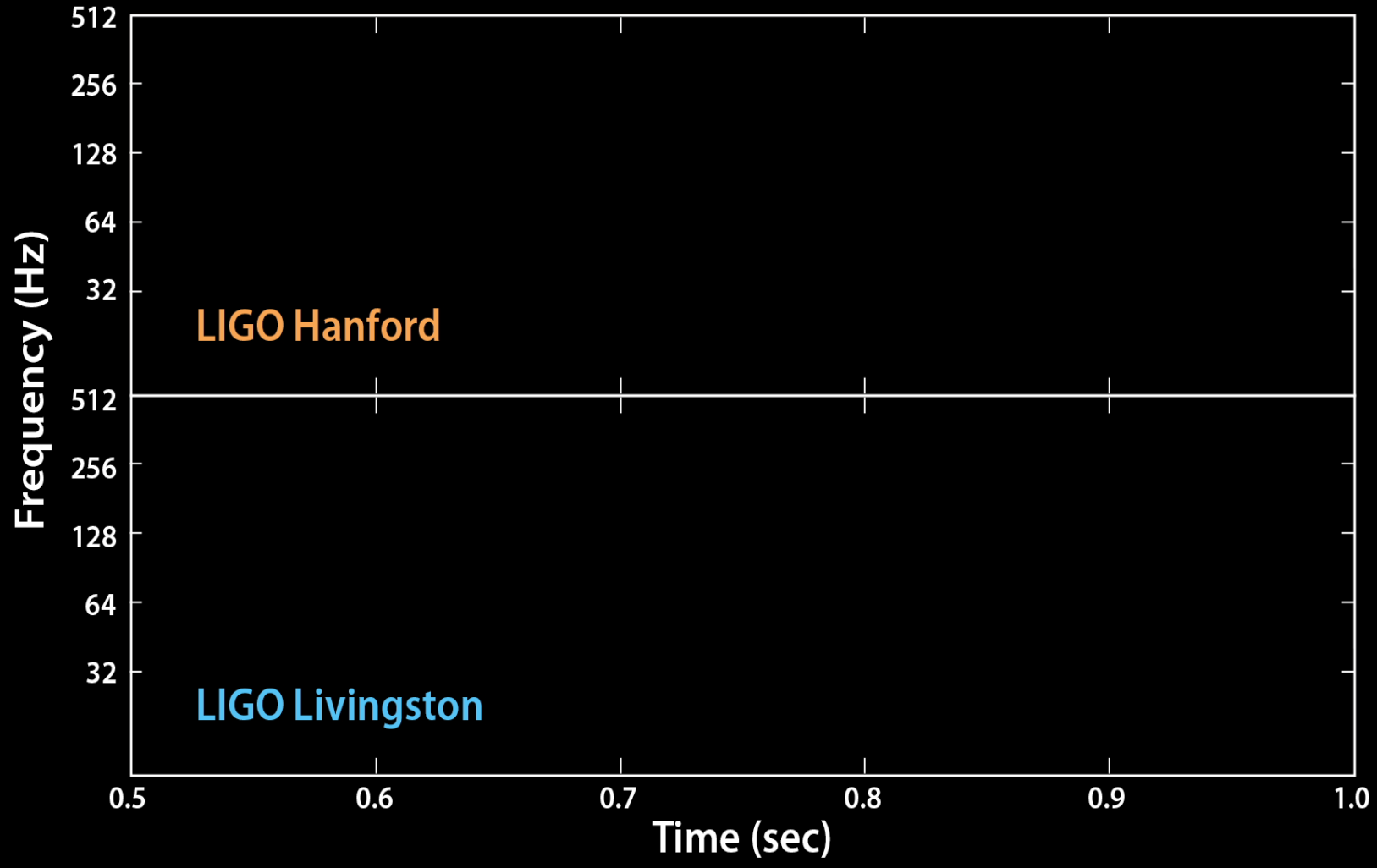


The energy of 3 Sun masses converted in Gravitational Waves

An energy capable to satisfy human needs for over 10^{18} years

The GW reach Earth on September 14 2015 after a journey longer than a billion years

FIRST DETECTION OF A BH-BH COALESCENCE, SEPT. 14, 2015



August 1st, 2017: Virgo !

GEOMETRY SHAPES LIGHT AND GETS AN ACADEMY

ACADEMY AWARD 2015 "BEST VISUAL EFFECTS"

INTERSTELLAR

Interstellar, Paramount Pictures
Directed by Christopher Nolan
Image based on calculations by Kip Thorne and Double Negative Co.

PRL 116, 061102 (2016) Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS
week ending
12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitation[al] [sig]nal, which sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wa[ve] strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merge[r] of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed w[ith] a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 20[5] years. It corresponds to the observation of a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresp[onding] to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

WHY **From Academy Award to the Royal Swedish Academy of Science**

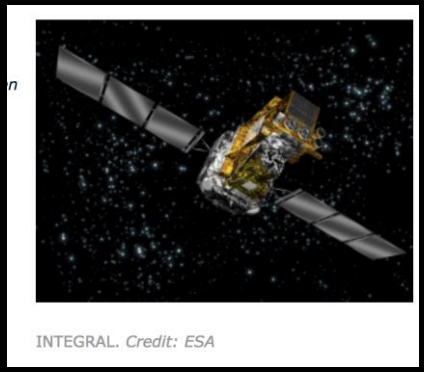
Not enough…. in 2017

A Brave New World

Multimessenger Astronomy

WHY & WHY NOW

TWO NEUTRON STARS



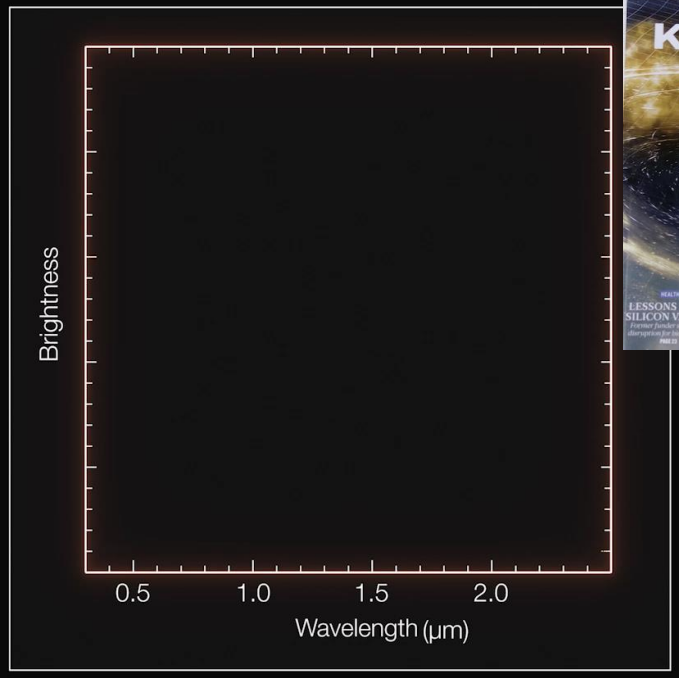
August, 17th 2017

2 neutron stars
3 GW detectors
100 telescopes

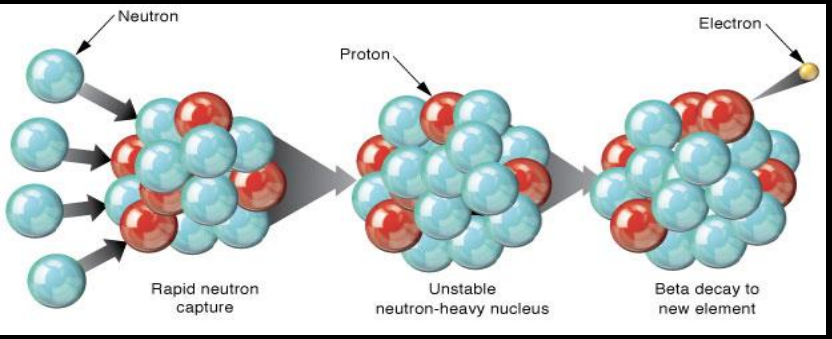
The Astrophysical Journal Letters, 848:L13
2017 October 20

KILONOVA

Credit: ESO/E. Pian et al./S. Smartt & ePESSTO/L. Calçada



Time: -1225 days




WHO
(and WHY INFN)

WHO the GW Detectors

LIGO-VIRGO Collaboration

Physics | The Nobel Prize in Physics 2017 | Rainer Weiss - Facts

The Nobel Prize in Physics 2017

Rainer Weiss
Barry C. Barish
Kip S. Thorne

Share this

Rainer Weiss
Facts

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Rainer Weiss
The Nobel Prize in Physics 2017

Born: 29 September 1932, Berlin, Germany

Affiliation at the time of the award: LIGO/VIRGO Collaboration, ; Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

Prize motivation: "for decisive contributions to the LIGO detector and the observation of gravitational waves"

Prize share: 1/2

The Nobel Prize in Physics 2017 | Barry C. Barish - Facts

Barry C. Barish
Facts

© Nobel Media AB. Photo: A.Mahmoud

Barry C. Barish
The Nobel Prize in Physics 2017

Born: 27 January 1936, Omaha, NE, USA

Affiliation at the time of the award: LIGO/VIRGO Collaboration, ; California Institute of Technology (Caltech), Pasadena, CA, USA

Prize motivation: "for decisive contributions to the LIGO detector and the observation of gravitational waves"

Prize share: 1/4

The Nobel Prize in Physics 2017 | Kip S. Thorne - Facts

© Nobel Media AB. Photo: A.Mahmoud

Kip S. Thorne
The Nobel Prize in Physics 2017

Born: 1 June 1940, Logan, UT, USA

Affiliation at the time of the award: LIGO/VIRGO Collaboration, ; California Institute of Technology (Caltech), Pasadena, CA, USA

Prize motivation: "for decisive contributions to the LIGO detector and the observation of gravitational waves"

Prize share: 1/4

INFN
Istituto Nazionale di Fisica Nucleare

WHO INFN

Edoardo Amaldi

One of the Founding Fathers of INFN CERN and ESA
Pioneer in GW research bringing Italy (and INFN) to a worldwide leading posittion

INFN developed with CNRS VIRGO, operating in Italy near Pisa.
VIRGO and LIGO are the only systems capable to detect GW
KAGRA added one year ago but still detects no signals

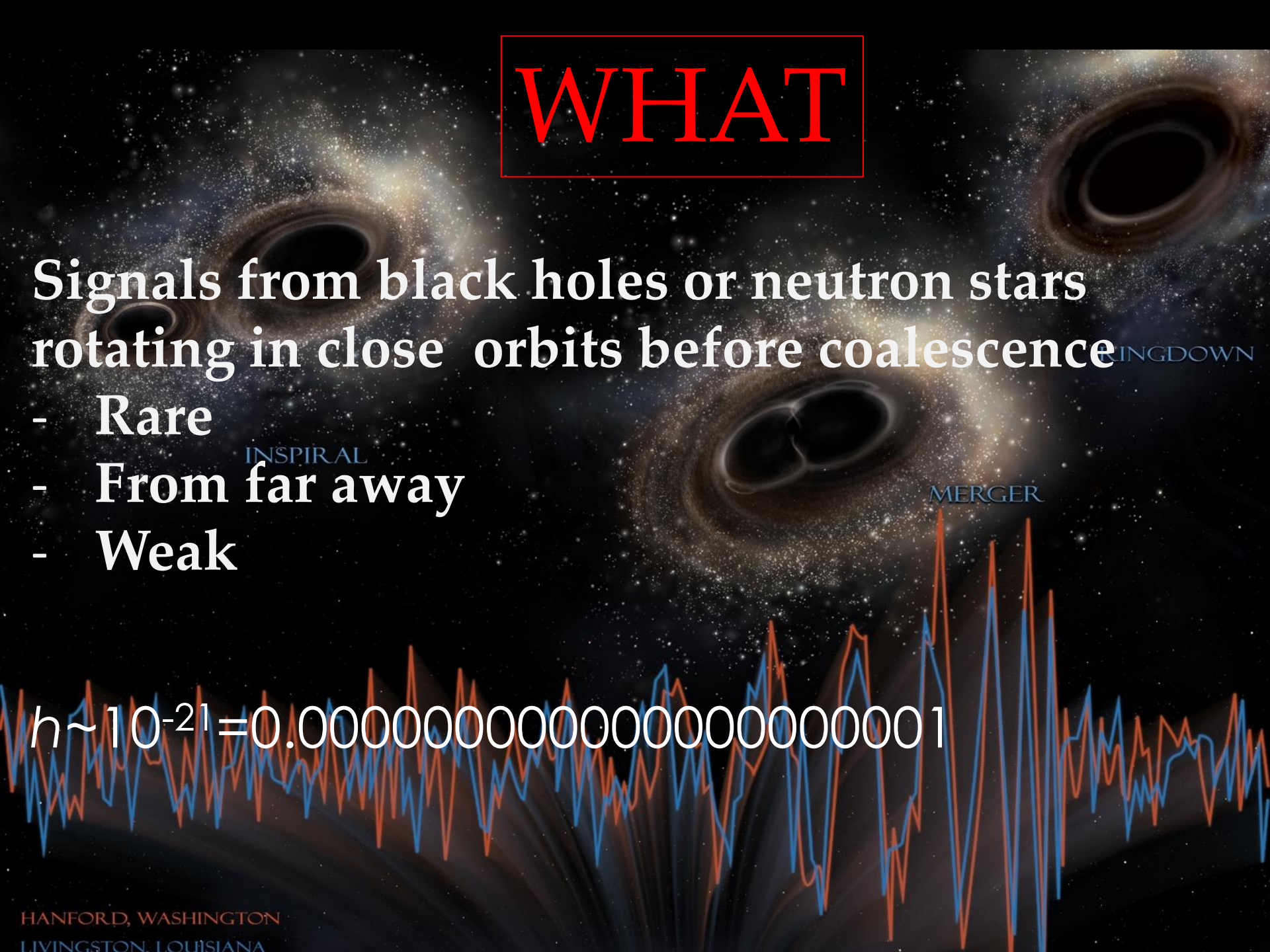
Nobel prize awarded to three scientists of
LIGO-VIRGO Collaboration


WHAT
(The Detectors)

WHAT

Signals from black holes or neutron stars rotating in close orbits before coalescence

- **Rare**
- **From far away**
- **Weak**



$h \sim 10^{-21} = 0.000000000000000000001$

Detecting Gravitational Waves represents an apparently impossible task (Albert Einstein opinion)

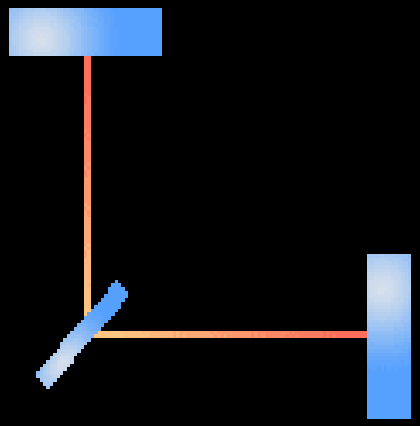
Extreme sensitivity **lowest noise**

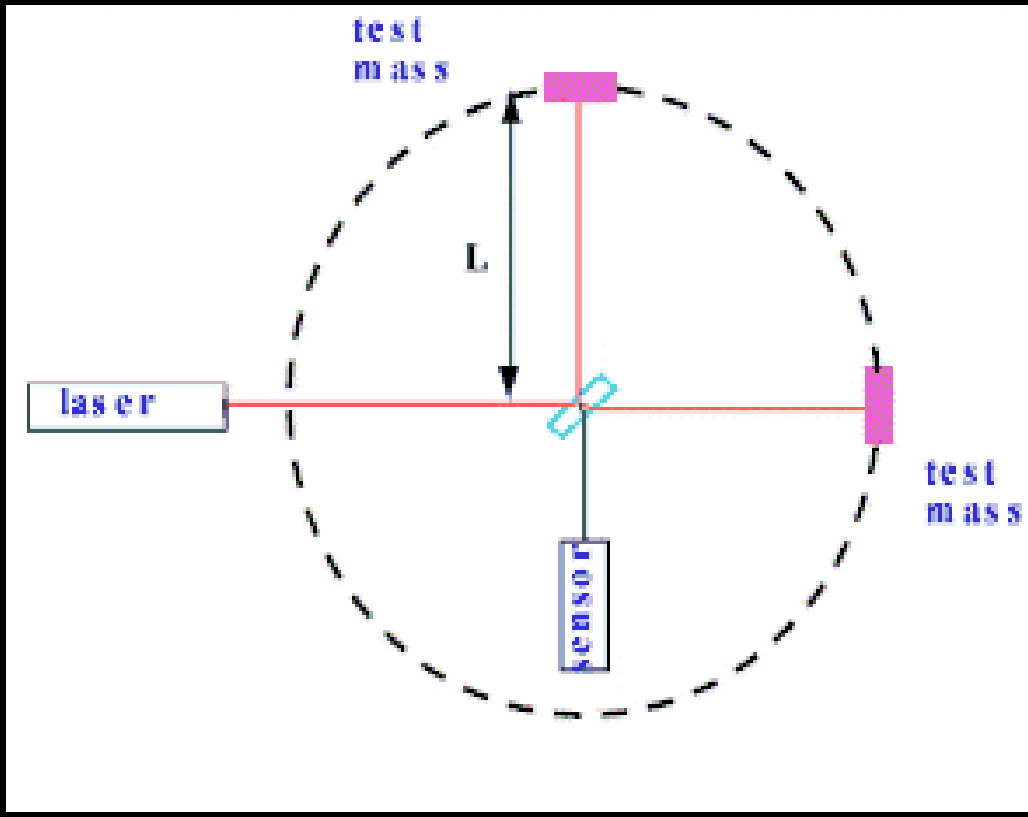
$h \sim 10^{-21} = 0.000000000000000000001$

atom~10^{-10} = 0.0000000001

nucleus ~10^{-15} = 0. 000000000000001

Detection basics

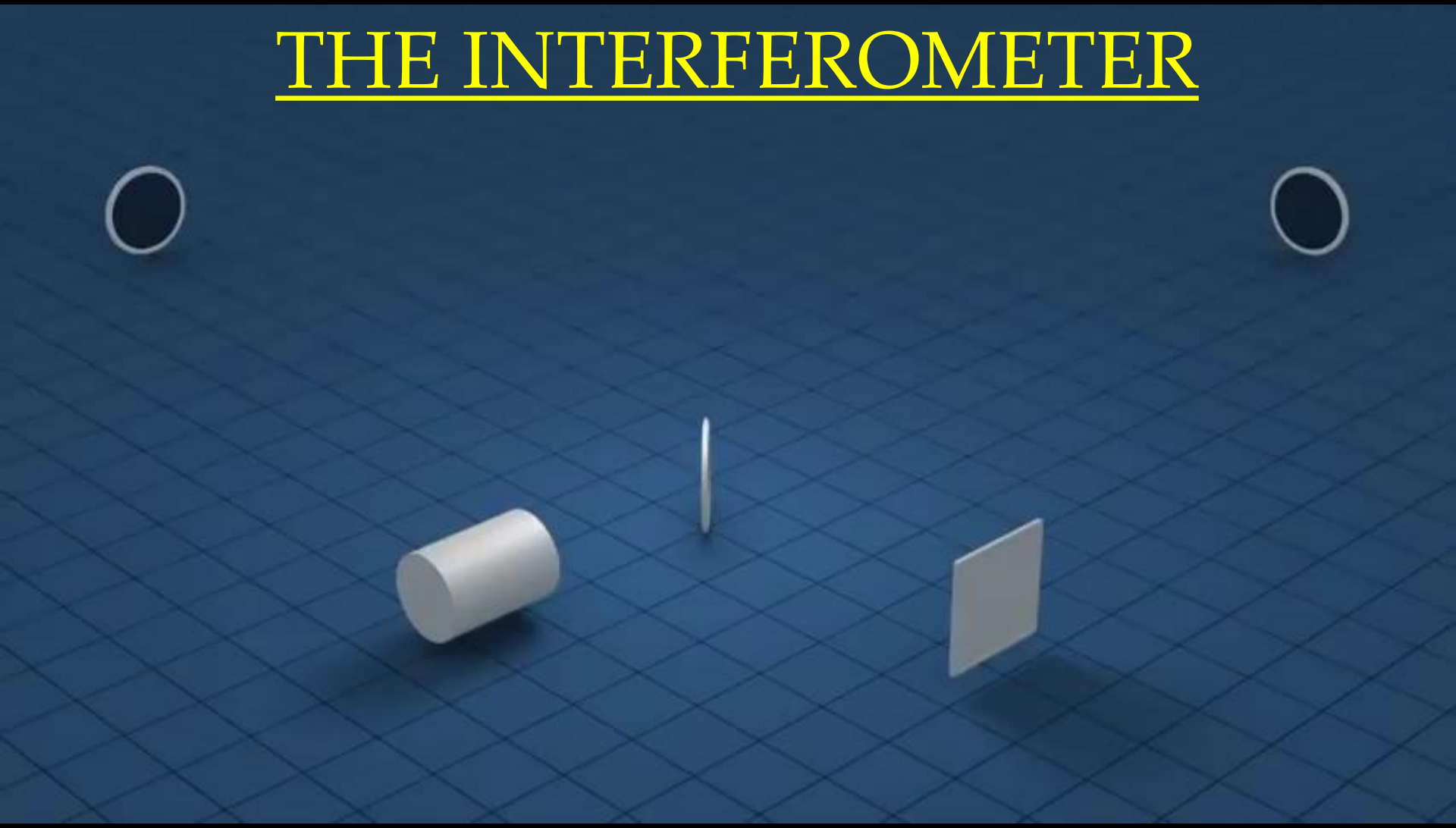


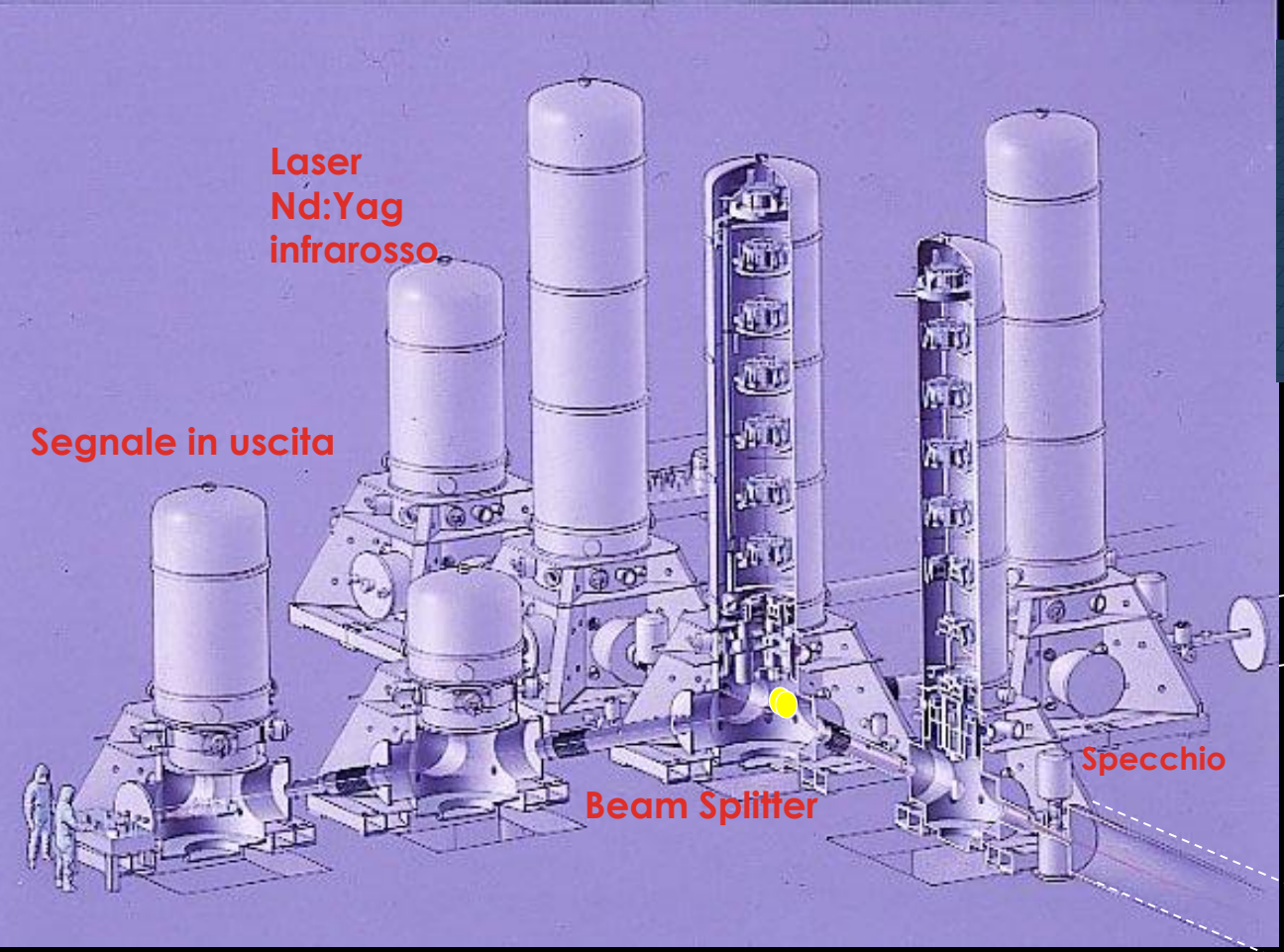


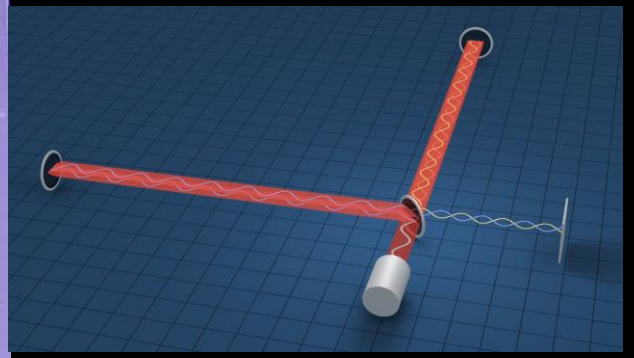
$$h = \frac{\Delta L}{L} \sim 10^{-21}$$

Main problem: the **NOISE,**
sismic (~ 10^{-8} m),
thermal vibrations (~ 10^{-12} m)

THE INTERFEROMETER







Tubo Ovest

3 km

Tubo Nord

3 km

7000 m^3 at 1 atm/10^{12} … close to interstellar vacuum

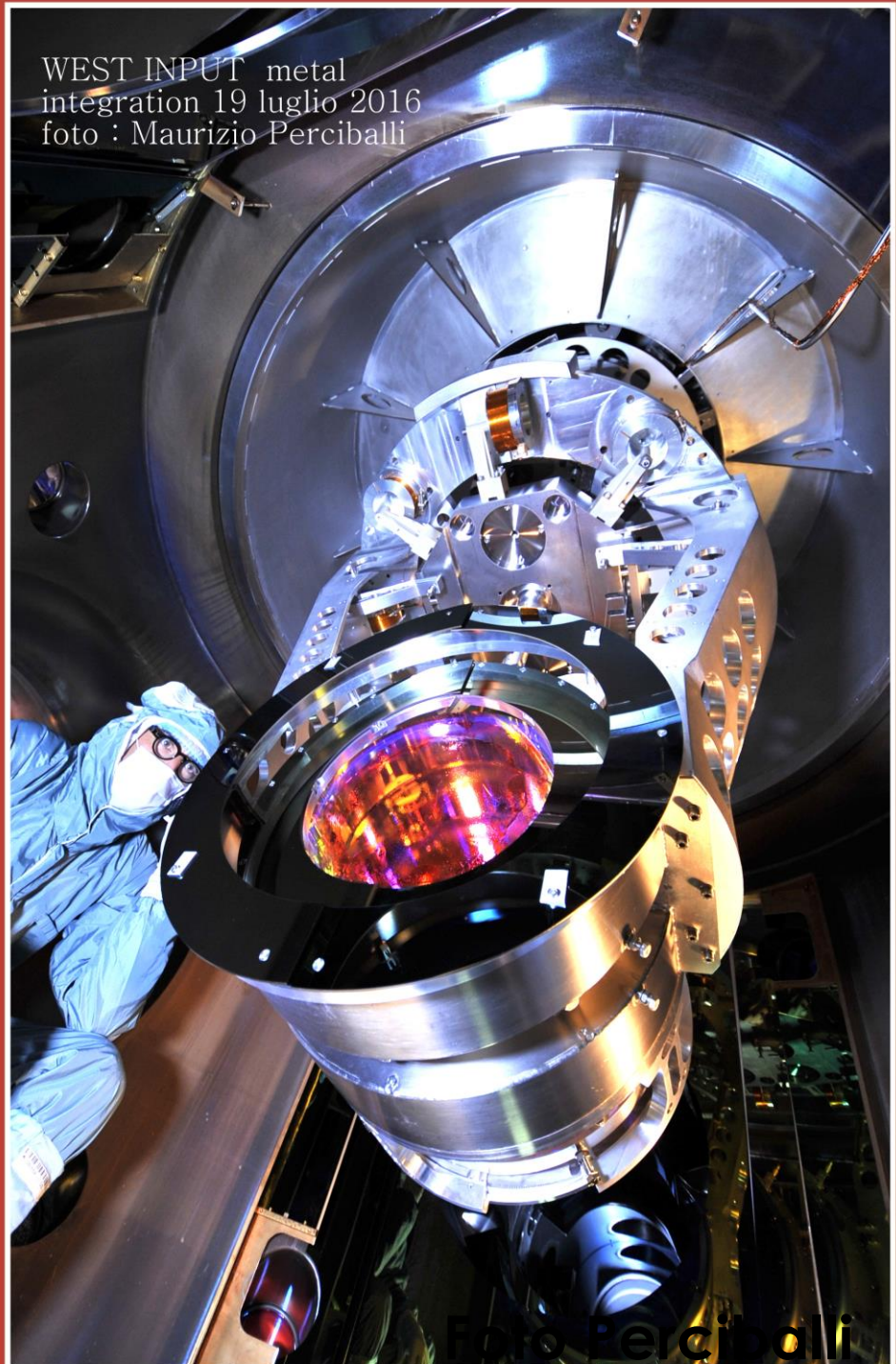
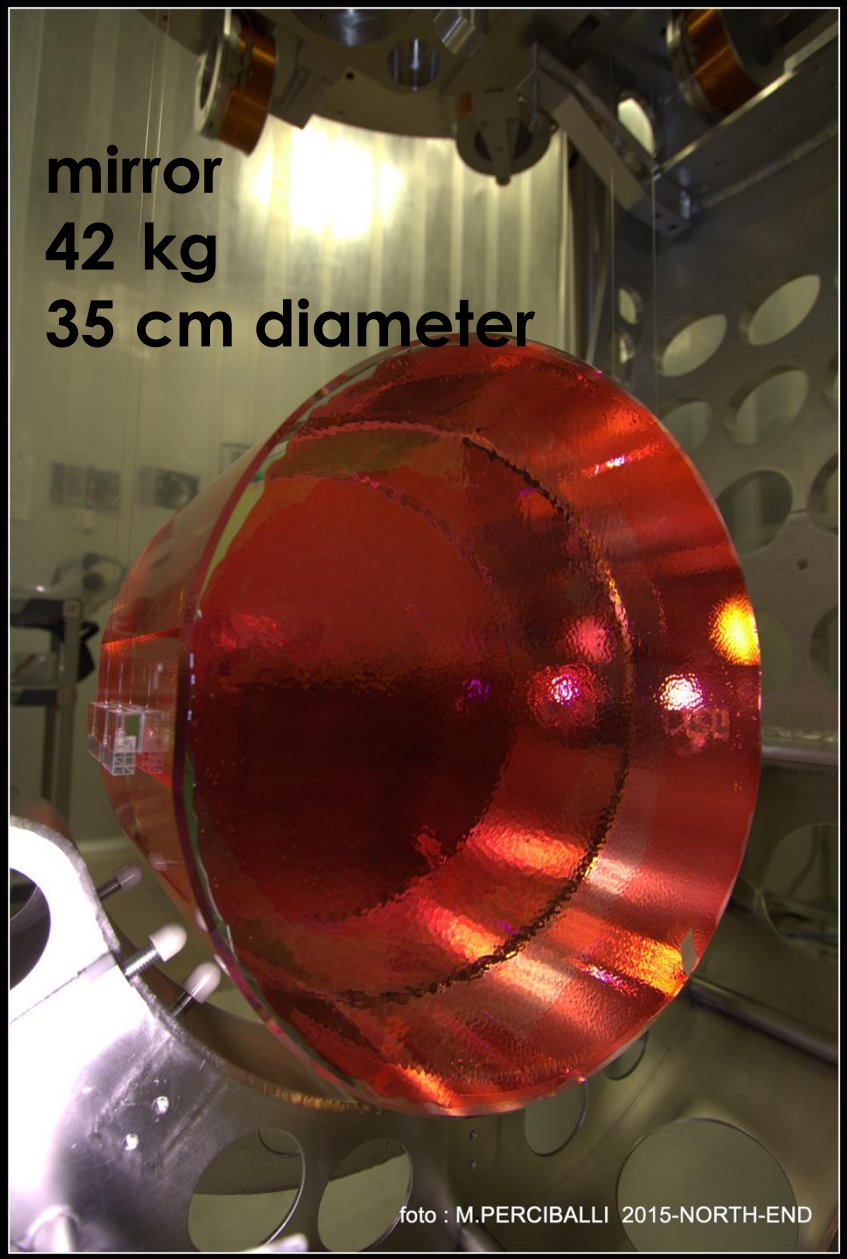
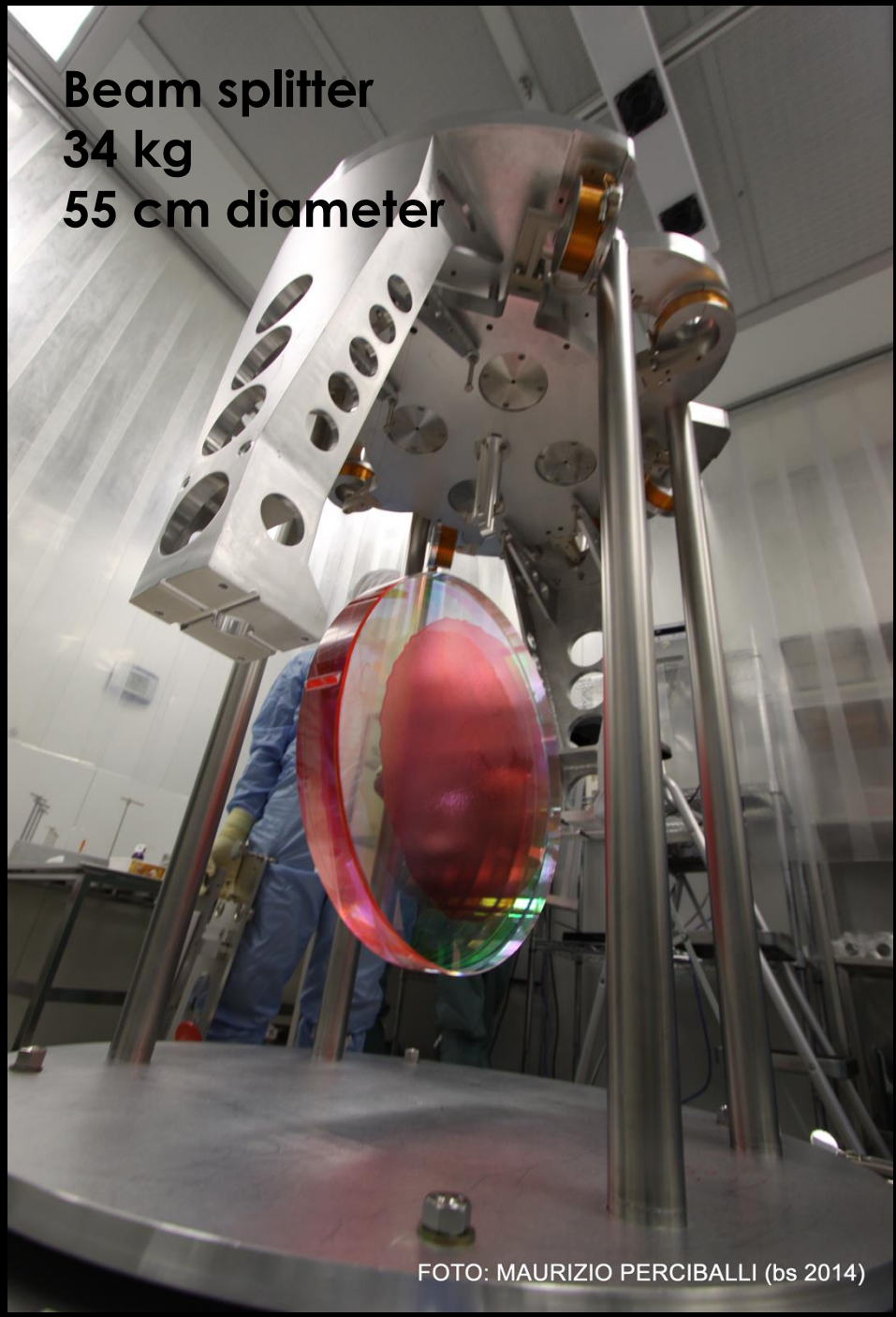
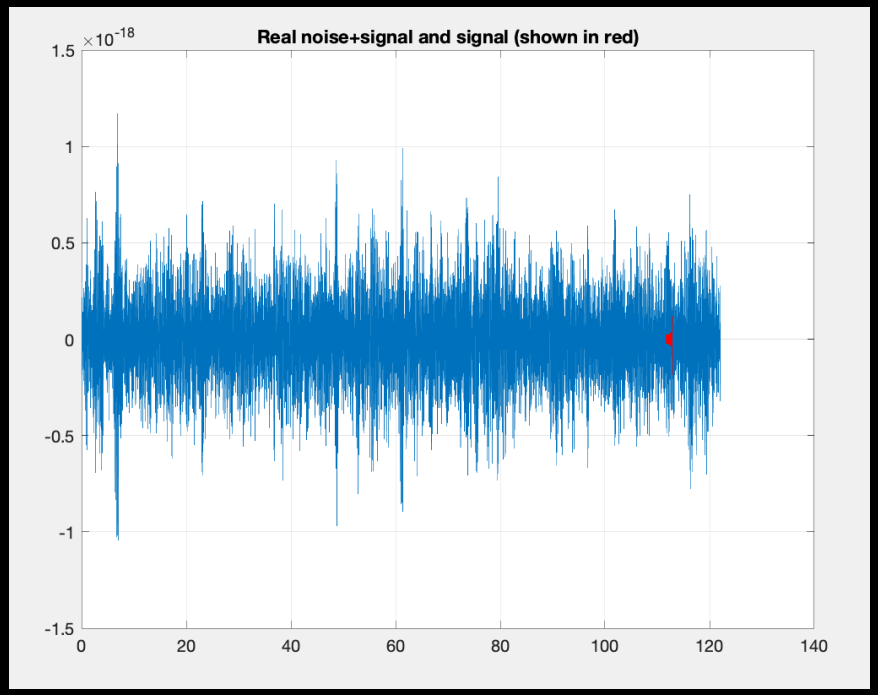


Foto Perciballi

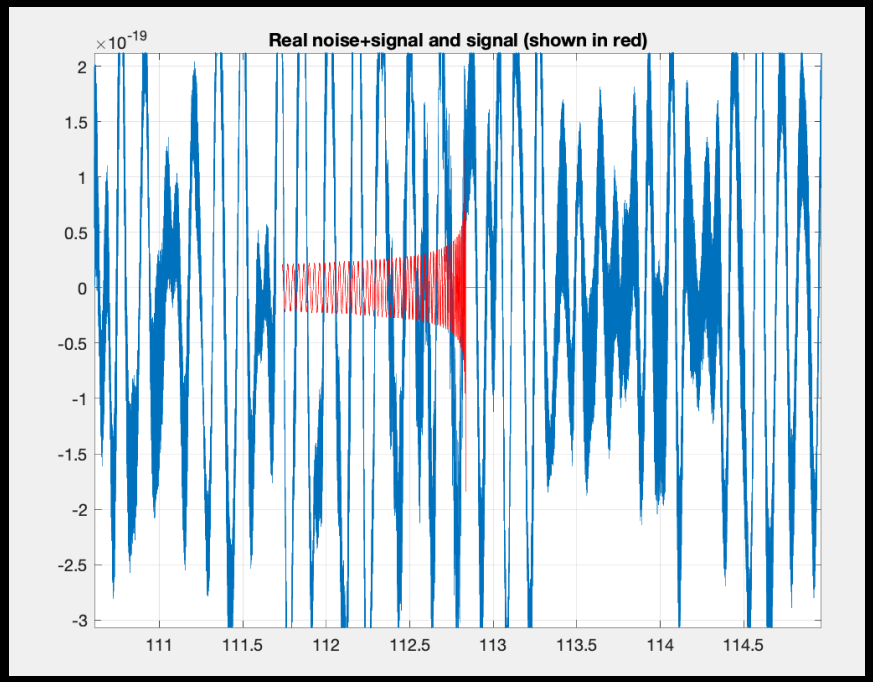

mirror
42 kg
35 cm diameter
foto : M.PERCIBALLI 2015-NORTH-END


Beam splitter
34 kg
55 cm diameter
FOTO: MAURIZIO PERCIBALLI (bs 2014)

VERY SMALL SIGNAL WITH HIGH BACKGROUND

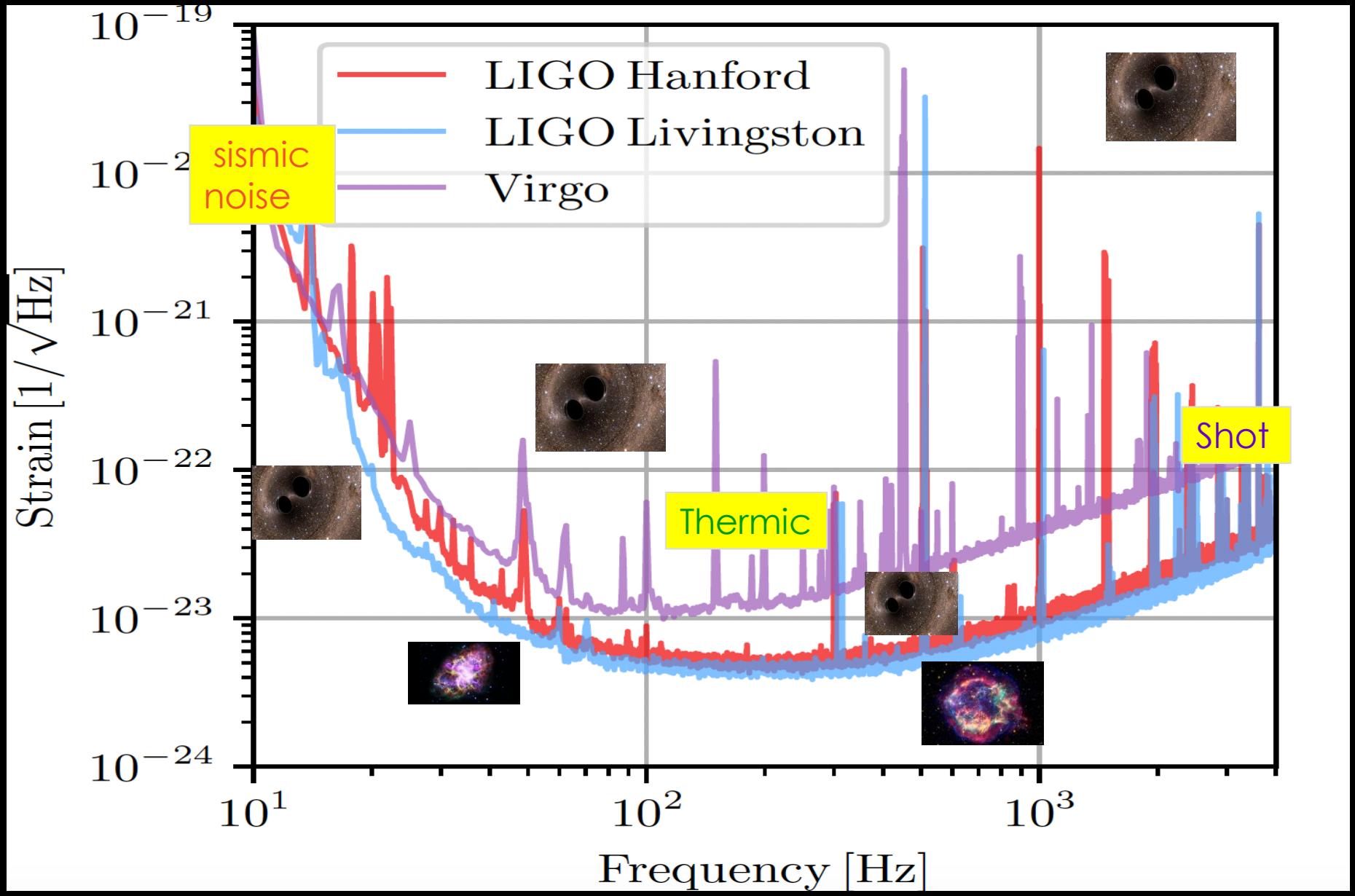


Time 0 - 140 s.



ZOOM

O3. DETECTORS SENSITIVITY



WHAT HAVE WE LEARNED?

Cosmology/fundamental physics

- speed of GWs equal to speed of light (1:10^{15})
- first measurement of the Hubble constant with GWs
- the tail of the waveform of GW150914 consistent with the prediction from General Relativity for the quasi-normal modes of the final BH
- deviations from GR (graviton mass, post-Newtonian coefficients, modified dispersion relations, etc.) could be tested and bounded

FROM 2G TO 3G DETECTORS

Still, 2G detectors lack the sensitivity to make really stringent tests of fundamental physics/cosmology

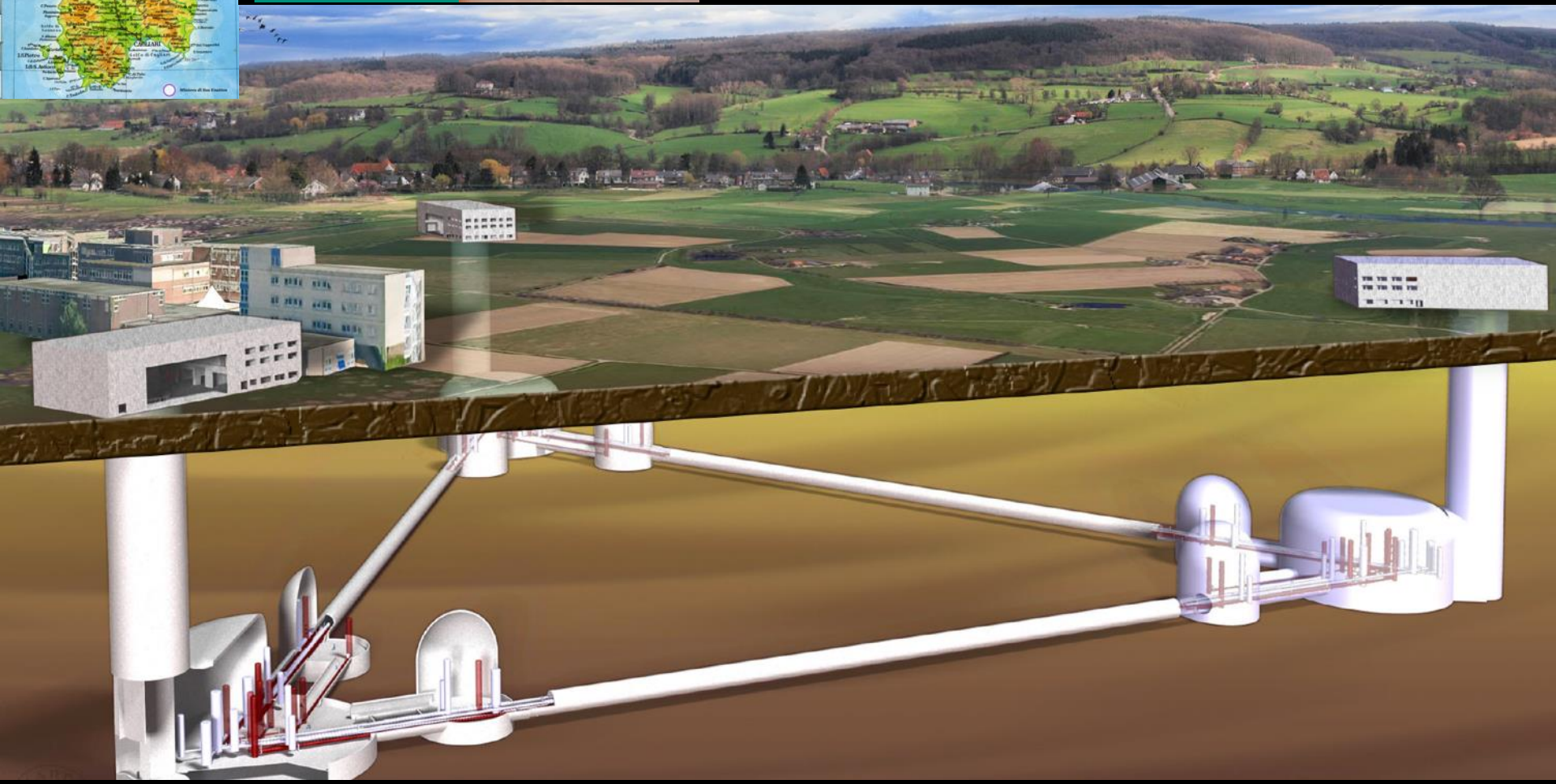
2G detectors have opened a new window

3G ground-based detectors (ET, CE) will look deeply into this window

We will focus on the science that can be done with ET

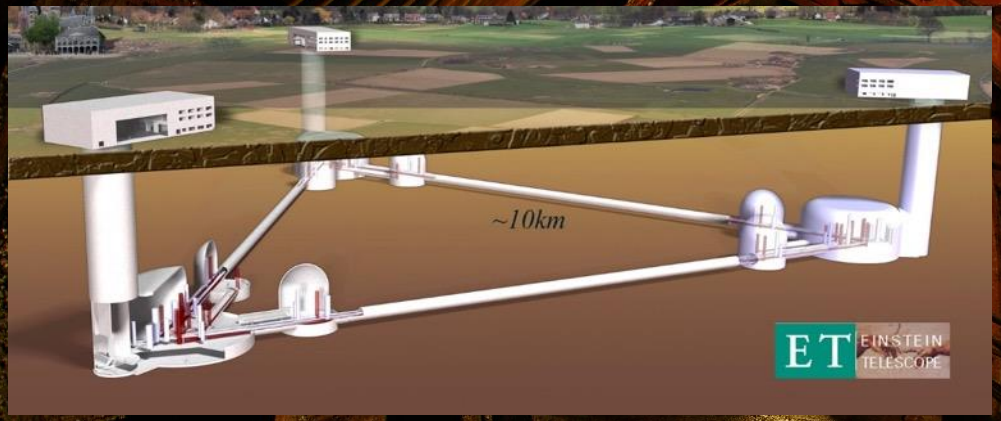
Einstein telescope

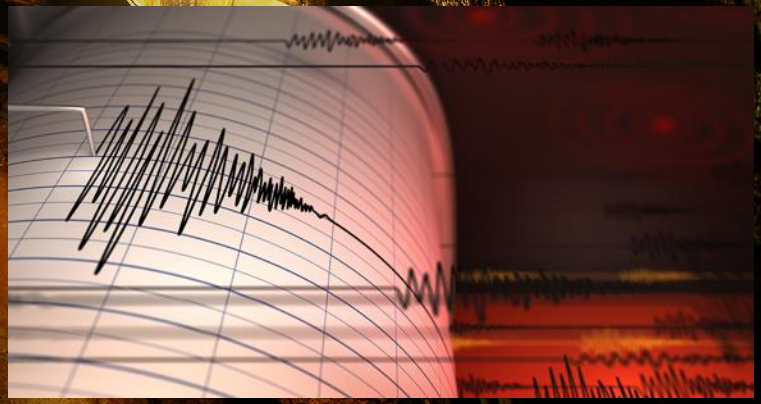
ET EINSTEIN TELESCOPE



> ~ 2030

LARGER & UNDERGROUND



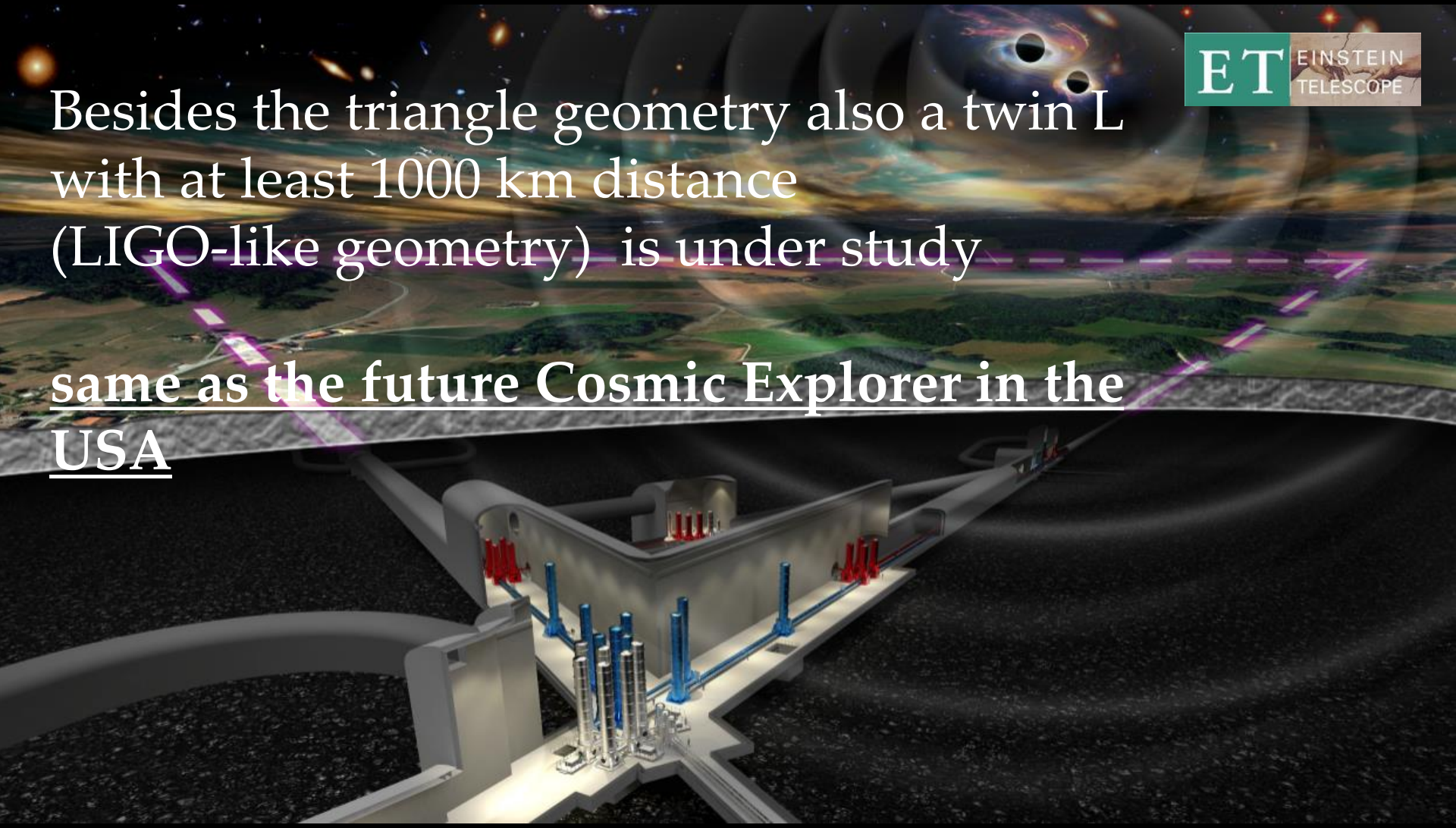


SENSITIVITY improves with arms length

→ From 3 km in VIRGO to **10 km ET**

UNDERGROUND to fight sismic and antropic noise

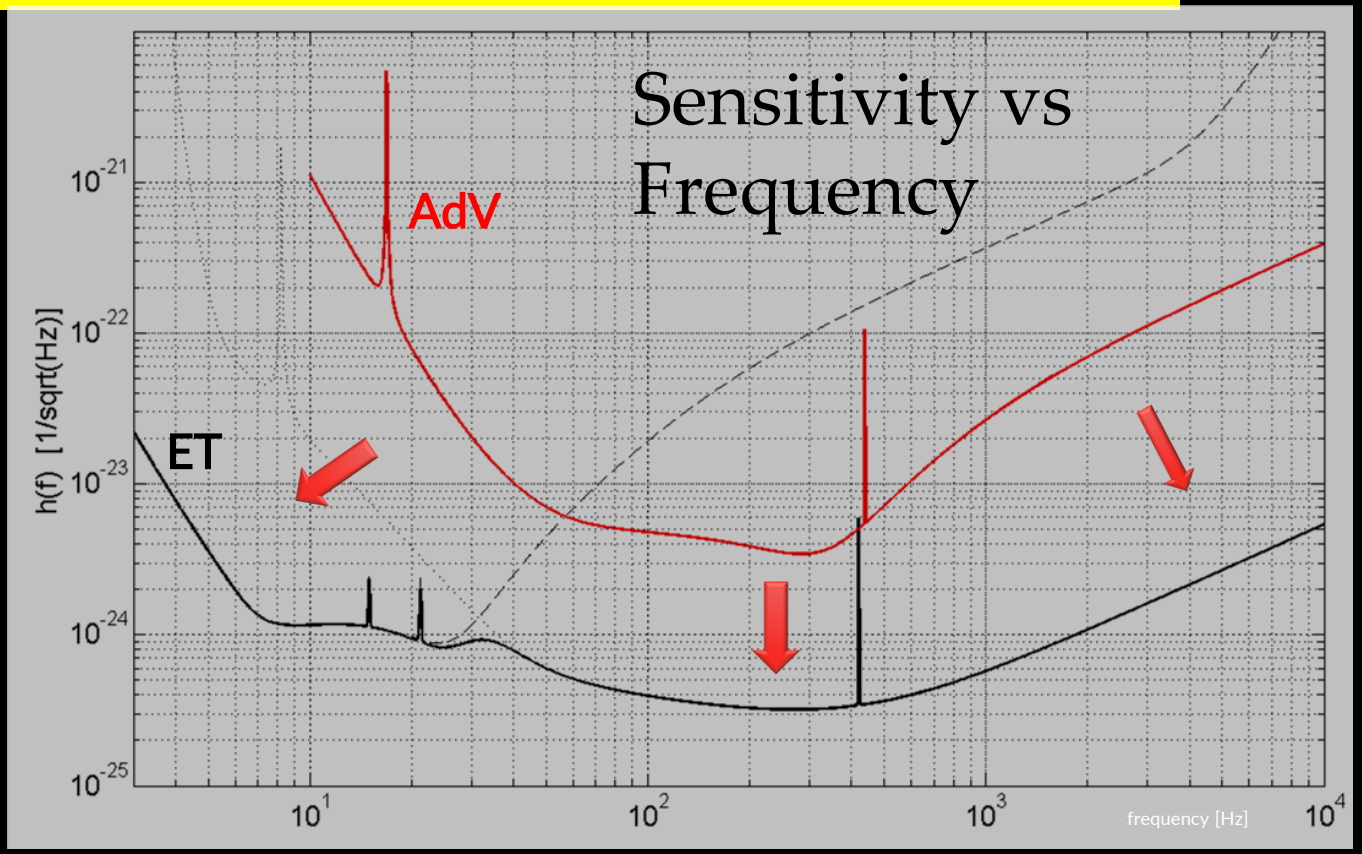
→ **200 m underground**



Besides the triangle geometry also a twin L with at least 1000 km distance (LIGO-like geometry) is under study

same as the future Cosmic Explorer in the USA

From Advanced VIRGO to ET

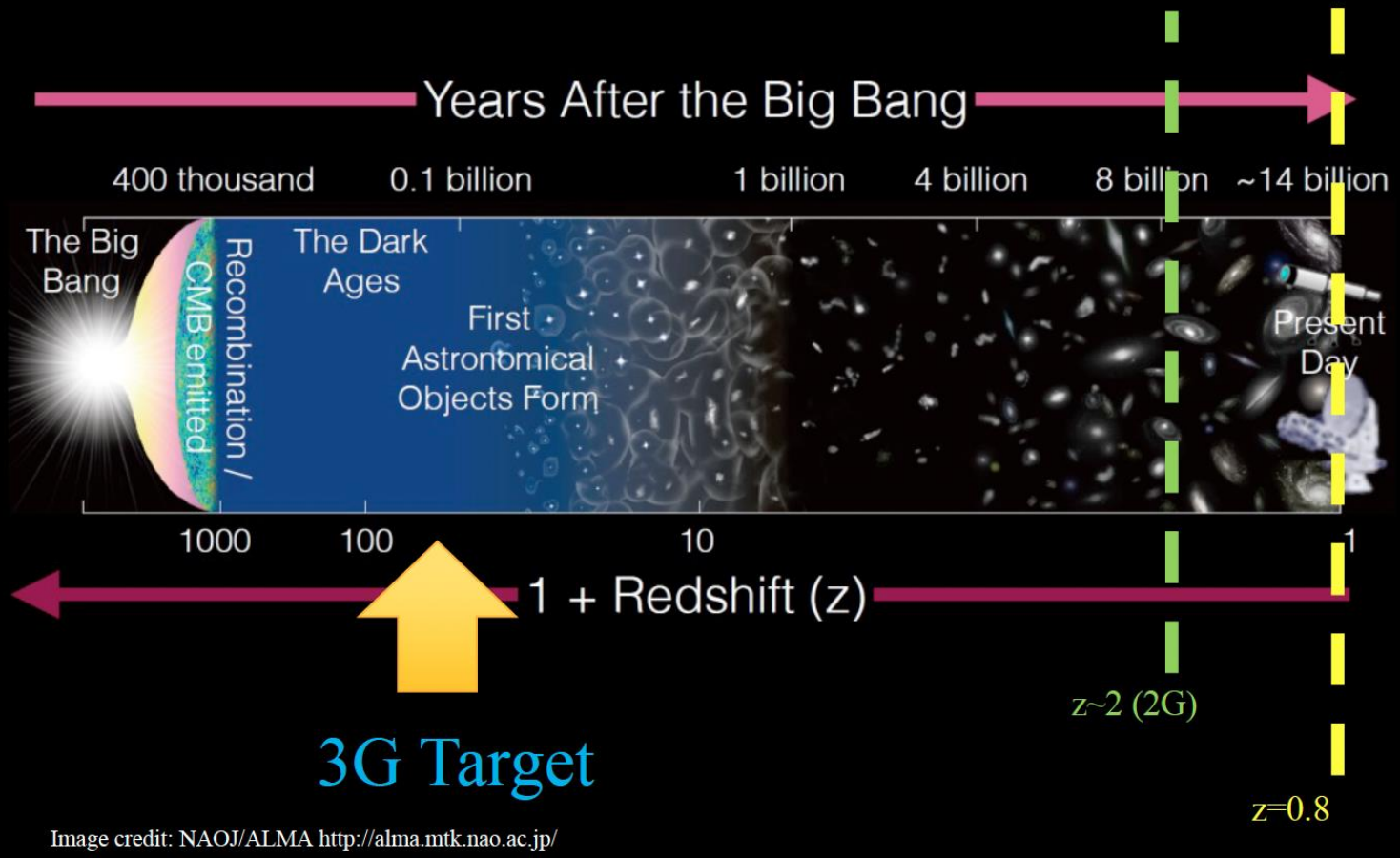


The combinations of:

- ❑ Distances and masses explored
- ❑ Number of detections
- ❑ Detections with very high SNR

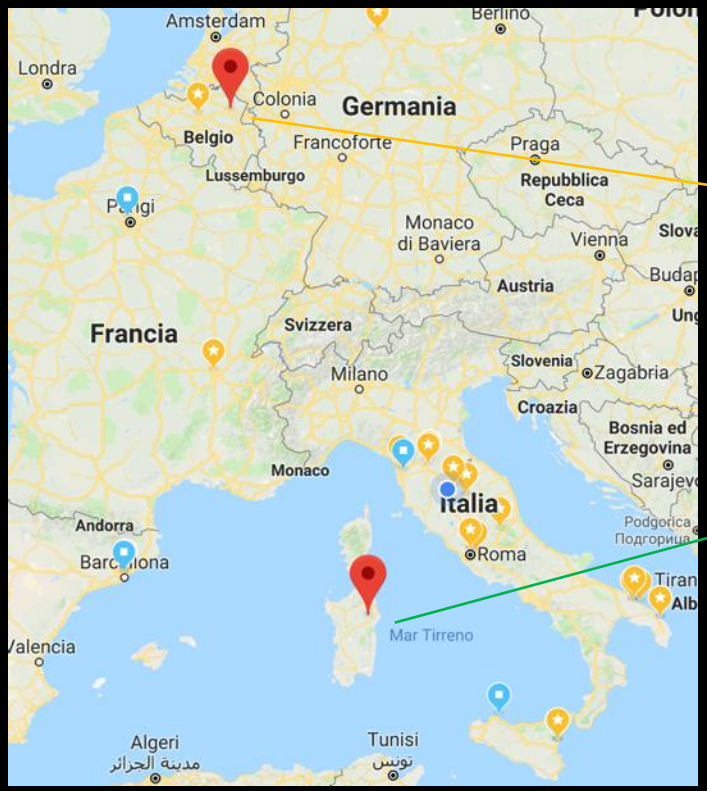
will provide a wealth of data that have the potential of triggering revolutions in astrophysics, cosmology and fundamental physics

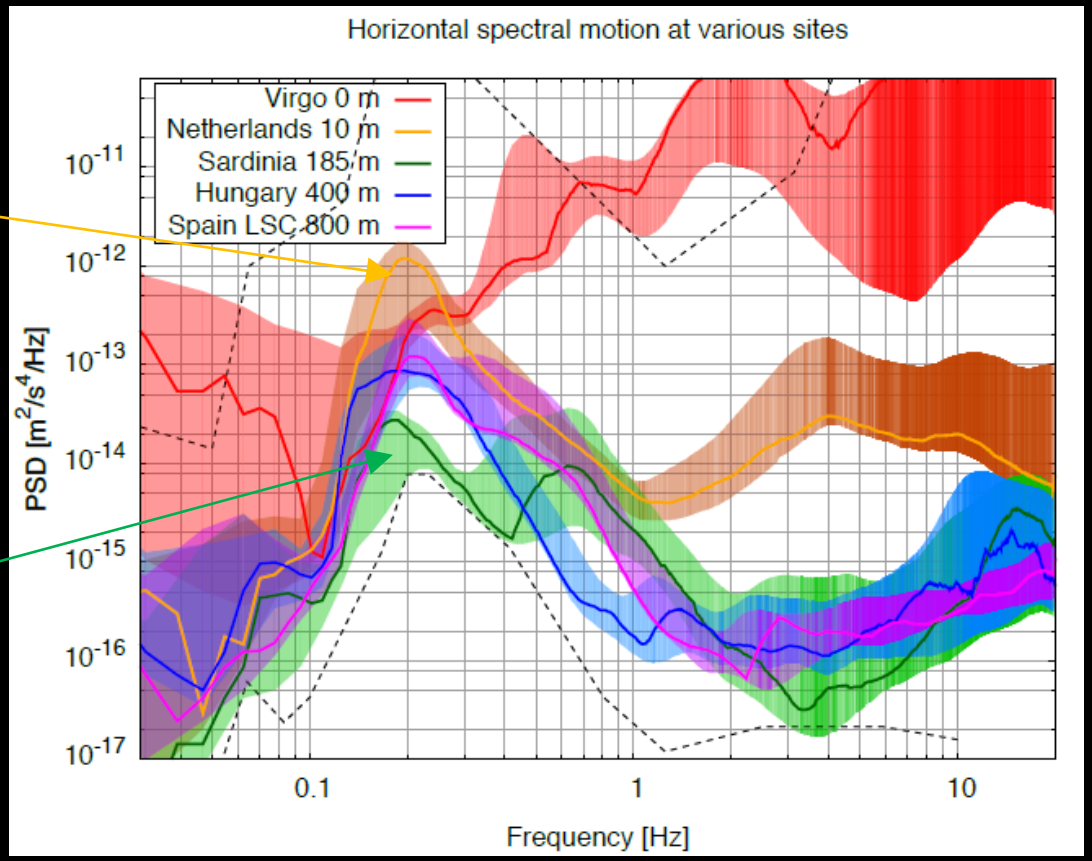
EXAMPLE: DETECTION DISTANCE OF BBHS




WHERE
(and WHY there)

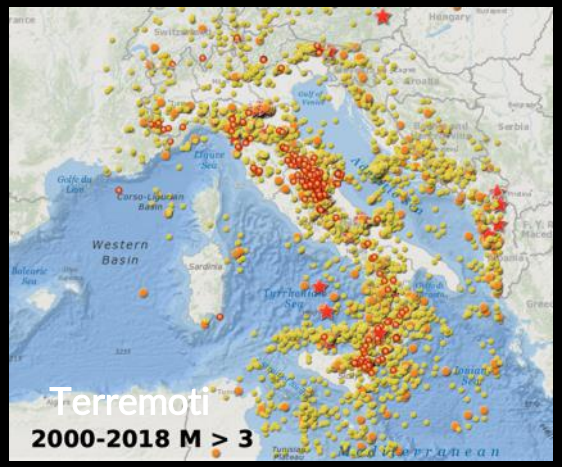
WHERE

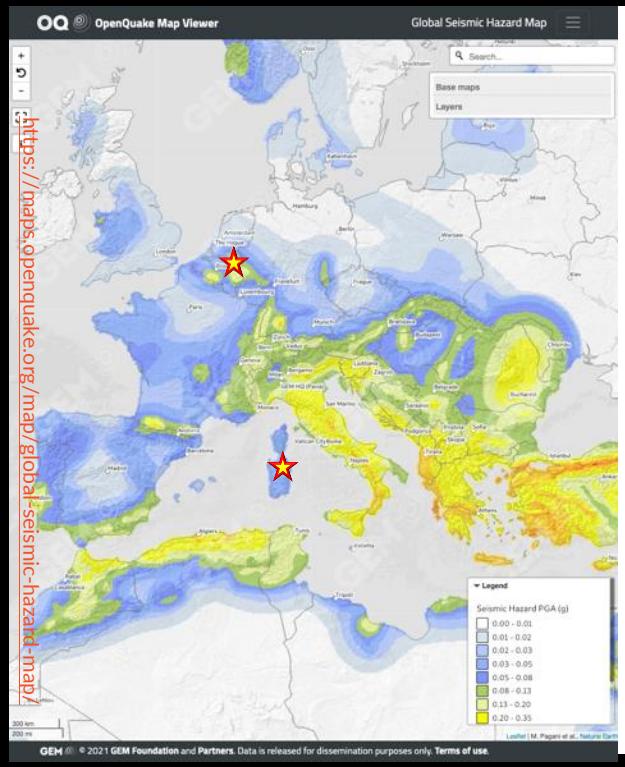


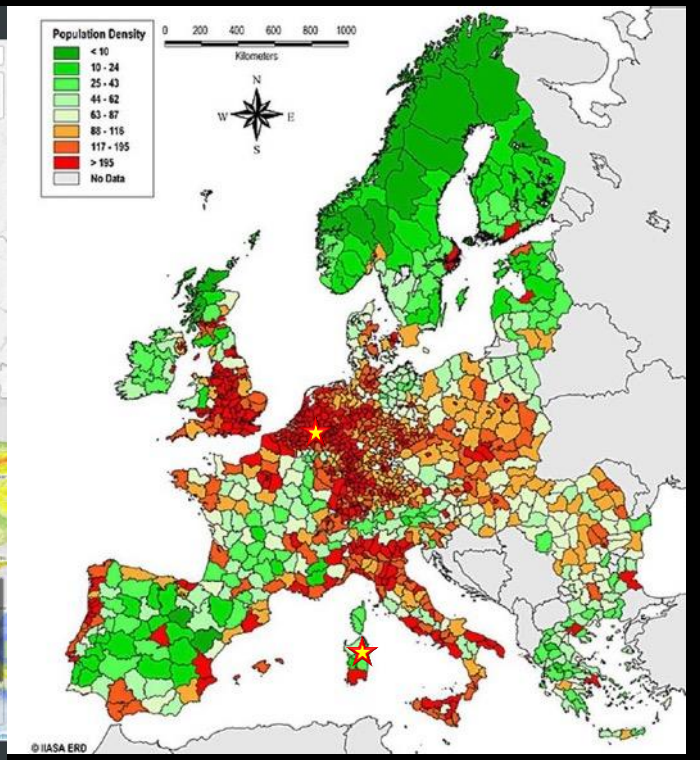


CANDIDATE SITES

SOS ENATTOS





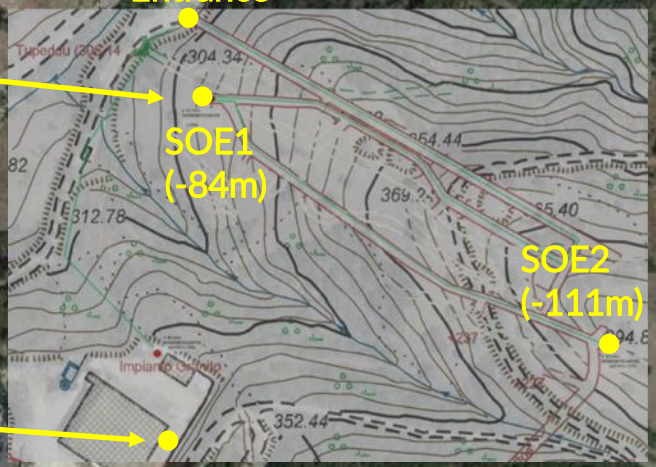


- NO RELEVANT SISMIC ACTIVITY IN SARDINIA

- Low populated area ➔ Low anthropic noise


RAMPA TUPEDDU
LABORATORIO
Sos-Enattos

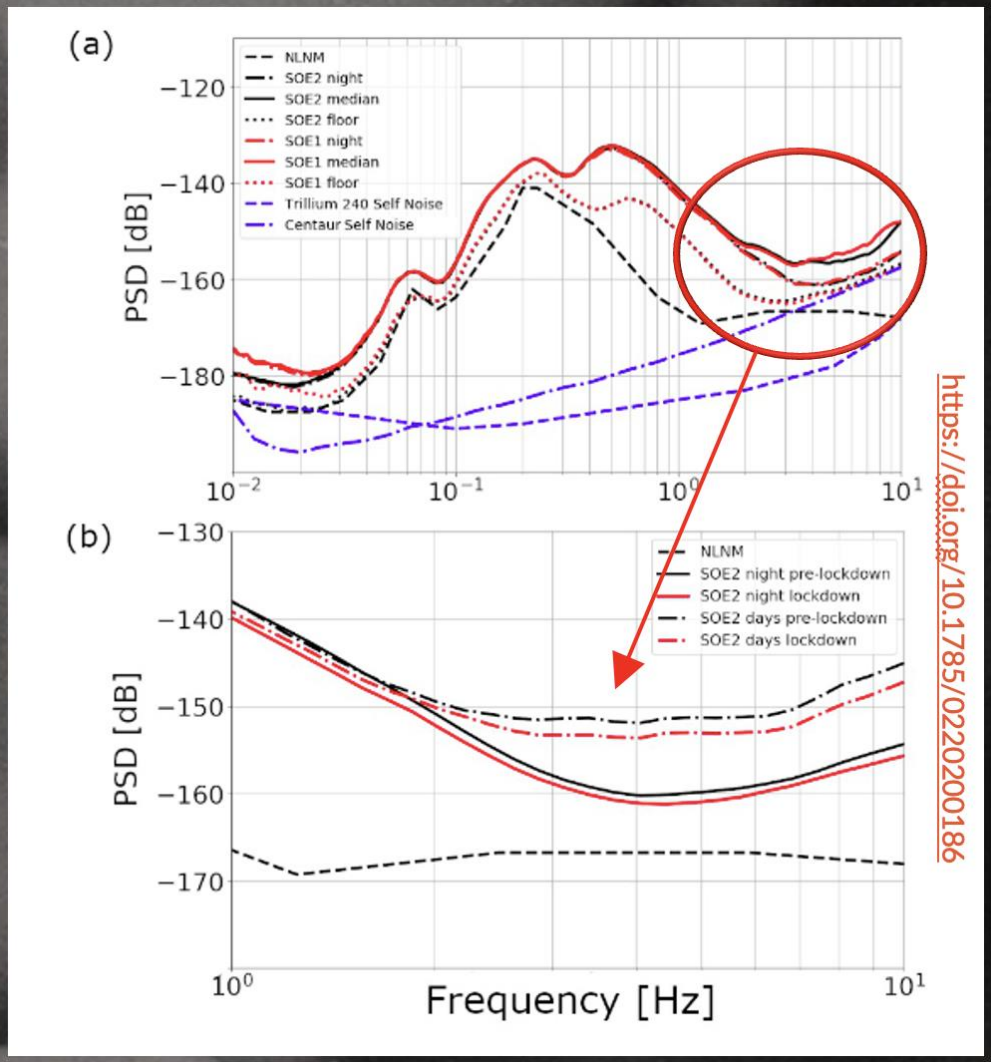
Sensors


Entrance
SOE1
(-84m)
SOE2
(-111m)
Scontrol room SarGrav
(340 m slm)
SOE3
(-130m)
SOE0
(400m slm)

Seismic monitoring 2019-20

In the region 1-10 Hz Sos Enattos is one of the best sites worldwide

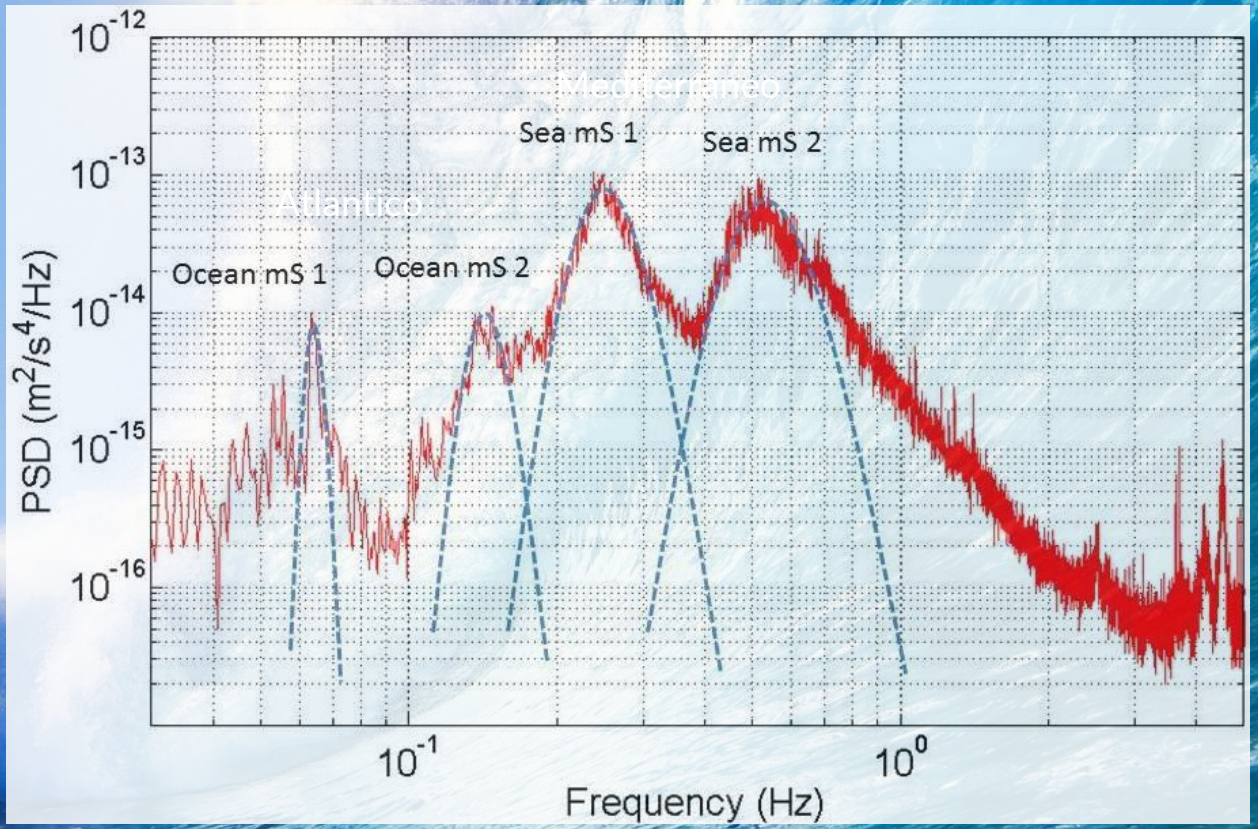
In the [1,10] Hz frequency band, noise is mainly due to anthropic activities; within the mine tunnels (≃100 m underground), its spectrum is compliant with the requirements of the ET design



PRESENT SENSORS DETECT WAVES…

FROM ATLANTIC SEA

In the [0.1,1] Hz bandwidth, seismic noise is correlated with sea wave height in the northwestern Mediterranean Sea



ET design: Δ or (2) L ?

The collaboration started the evaluation of the best configuration for ET, considering the alternative of two L configuration, to the triangle configuration

maximize the science return
reduce risks

- First detections, GTWC-3 catalog → BH population
- Science case developed;
- Know-how with advanced (L) detectors;
- International scenario (+ Cosmic Explorer in US);
- Tw


WHEN
(Present status and time scale)

WHEN

(PRESENT DEVELOPMENTS & TIMESCALE FOR DECISION AND CONSTRUCTION)

ET MILESTONES IN ITALY

- 2017- National Projects funded by Ministry of Research for studies at the Sardinan site (3 M€)
- 2017- Sardinia Regional Government provides funds for a low noise infrastructure for GW research 3.5 M€
- 2018 Ministry of Research provides fund to support studies for the Italian site 17 M€
- 2019 ET is presented to ESFRI by the Italian Minister of Research (with both IT & NL options)
- 2021 Sardinia Regional Government supports a pledge of 350M€
- 2022 Support Letter of President Draghi to INFN President

Il Presidente del Consiglio dei Ministri

Presidenza del Consiglio dei Ministri
PCM_DRAGHI 0009483 P-4.1.3
del 14/09/2022

Gentile Presidente Zoccoli,

Le scrivo per confermare il sostegno del Governo alla candidatura del sito di Sos Enattos, in Sardegna, come sede di Einstein Telescope (ET). È un'importante opportunità per l'Italia e va colta con determinazione e rapidità.

.....

.....

Nel corso della mia visita dello scorso febbraio ai Laboratori del Gran Sasso, accompagnato dal Professor Giorgio Parisi, ho avuto l'occasione di apprezzare di persona la dedizione e l'eccellenza dei ricercatori italiani dell'Istituto. Sono convinto che la scelta dell'Italia per Einstein Telescope, oltre a contribuire allo sviluppo dei territori interessati, rafforzerà ulteriormente il nostro primato nei campi della fisica delle particelle e dell'astronomia.

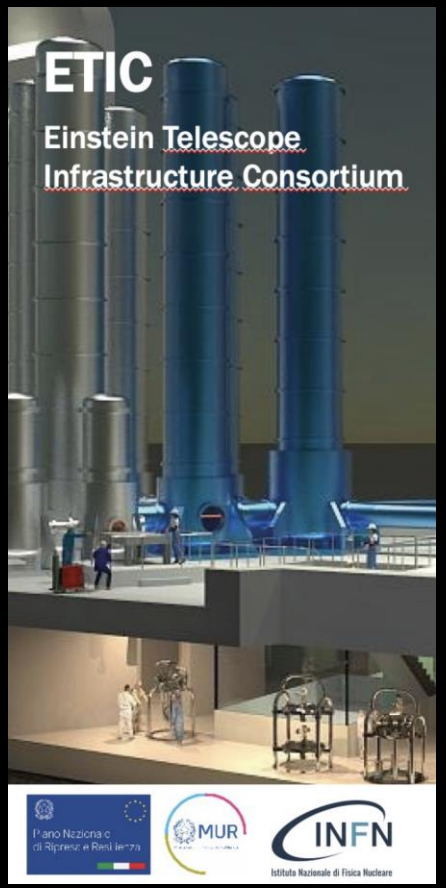
Cordiali saluti,

Mario Draghi

PROJECTS WITHIN THE ITALIAN NATIONAL RECOVERY PLAN

- **Einstein Telescope Infrastructure Consortium (ETIC) 50M€**

  - Support to Italian Candidature
  - Technology Developments
  - Site characterization



PROJECTS WITHIN THE ITALIAN NATIONAL RECOVERY PLAN

TErabit network for Research & Academic Big Data in Italy **TERABIT 41 M€**

- Network upgrade 10 Gb to 1000 Gb

Project **MEET 42 M€**

2.7 M€ dedicated to a worldwide «unique» low noise sismic observatory in the site of Sos Enattos in Sardinia

RECENT EVENTS IN CAGLIARI

INFN Istituto Nazionale di Fisica Nucleare
UNIVERSITÀ DEGLI STUDI DI CAGLIARI
uniss
REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA
COMUNE DI CAGLIARI
Fondazione di Sardegna

con il sostegno di
Finanziato dall'Unione europea NextGenerationEU
MUR
Italiadomani

progetto ETIC
EINSTEIN TELESCOPE INFRASTRUCTURE CONSORTIUM

coordinato da
INFN Istituto Nazionale di Fisica Nucleare

con la partecipazione di
ASI Agenzia Spaziale Italiana
INAF Istituto Nazionale di Astrofisica
Alma Mater Studiorum Università di Bologna
Università degli Studi di Cagliari
Università di Genova
GSSI Gran Sasso Science Institute
Università degli Studi di Napoli Federico II
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Sapienza Università di Roma
Università degli Studi della Campania Luigi Vanvitelli

L'UNIONE SARDA .it World Italy Sardinia Sardinians in the World

SARDINIA

THE APPLICATION

06 giugno 2023 alle 15:53, aggiornato il 06 giugno 2023 alle

"Fortza paris" for the Einstein Telescope. Meloni: «We believe in it, Sos Enattos is the perfect place and Italy is capable of great enterprises»

The government launches Sardinia as the site of the gravitation estimated 36,000 jobs and an "impact" of over 6 billion euros

Breaking News
6 June 2023


THANK YOU
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