From Advanced Virgo to ET Physics and Astrophysics with Gravitational Waves:

VIRGO → ET EINSTEIN TELESCOPE

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Talk Outline

The Advanced detector Network

Einstein Telescope: a 3rd generation   of gravitational wave observatories

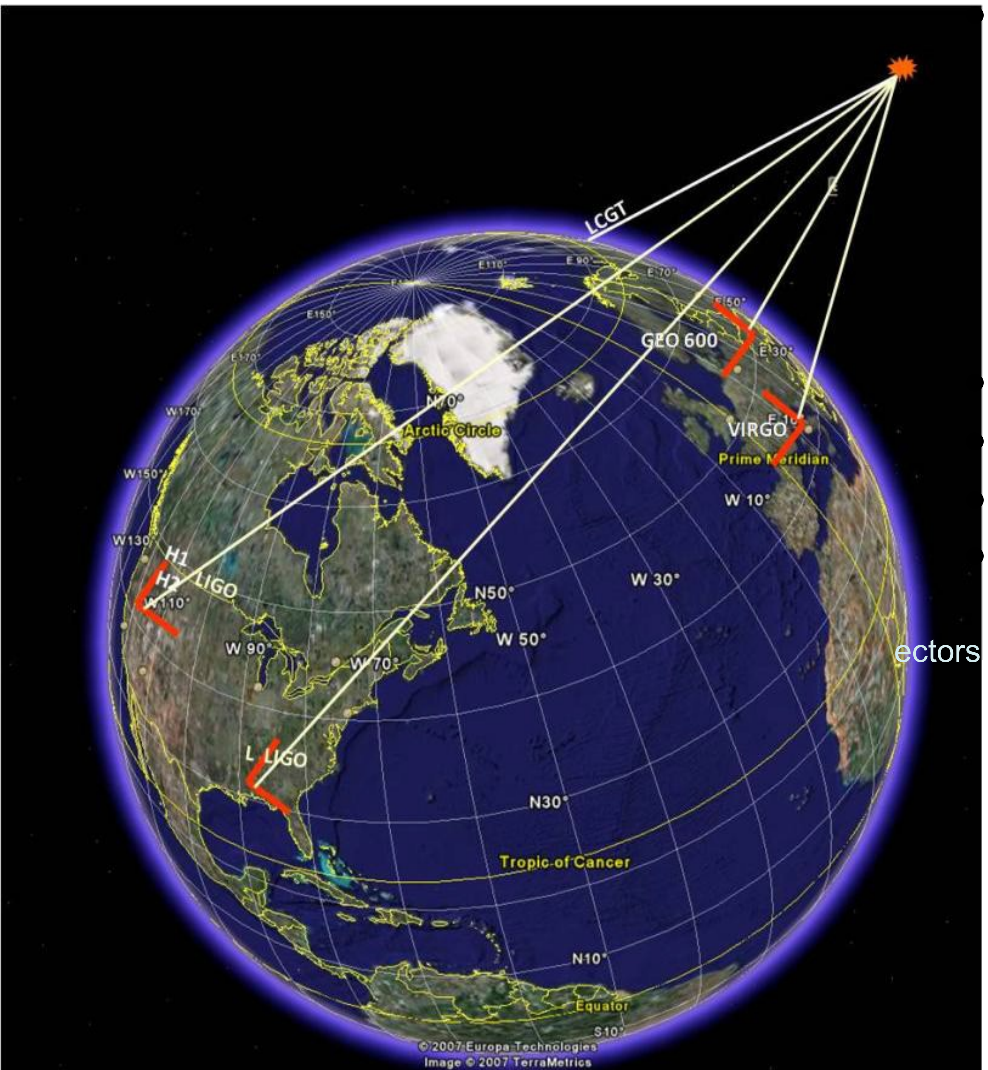
New Physics with new detectors

Conclusion

The second generation of detectors

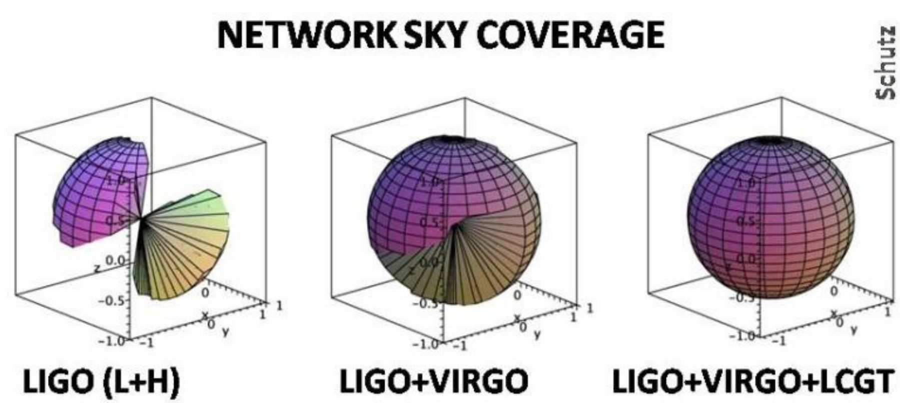
Network of GW detectors is in action again

The search for transient GW signals asks for a network of (distant) detectors

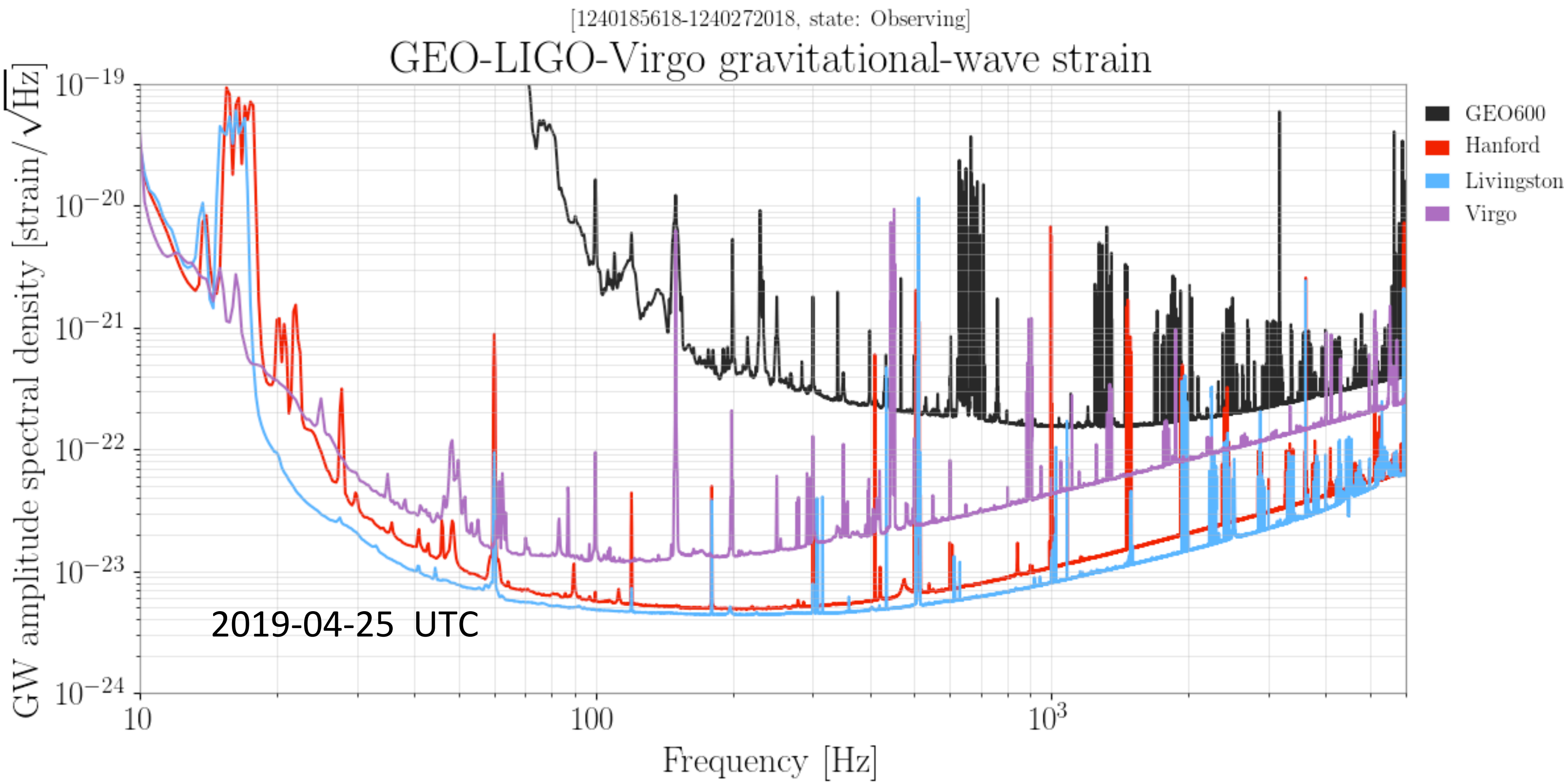


- Event reconstruction
  - Source location in the sky
  - Reconstruction of polarization components
  - Reconstruction of amplitude at source and determination of source distance (BNS)
- Detection probability increase
- Detection confidence increase
- Larger uptime
- Better sky coverage

ectors



Present status: LIGO and VIRGO in operation



The Open Alert Era: information sent to the scientific community with low latency

GraceDB — Gravitational Wave Candidate Event Database

Latest — as of 28 April 2019 14:22:00 UTC

Test and MDC events and superevents are not included in the search results by default; see the query help for information on how to search for events and superevents in those categories.

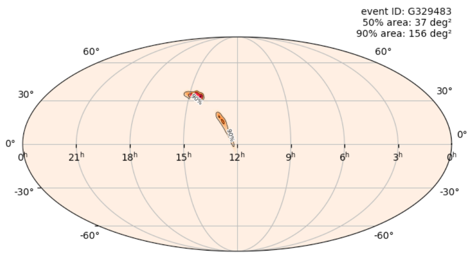
Query:

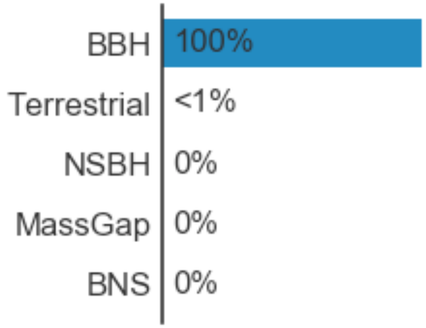
Search for: Superevent

Search

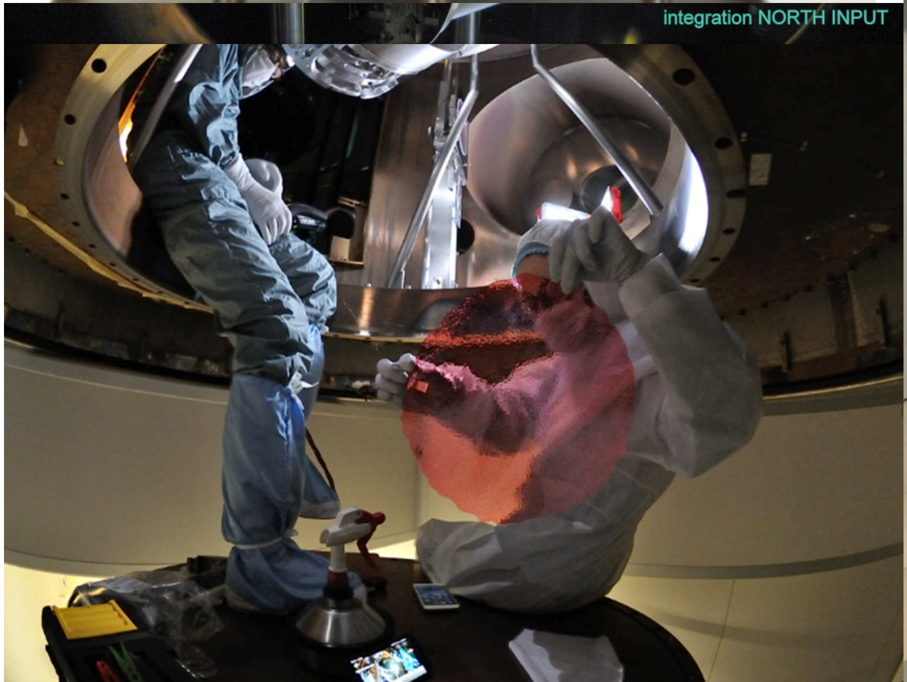
UID	Labels	t_start	t_0	t_end	FAR (Hz)	UTC Created
S190426c	DQOK EMBRIGHT_READY PASTRO_READY SKYMAP_READY ADVOK GCN_PRELIM_SENT	1240327332.331668	1240327333.348145	1240327334.353516	1.947e-08	2019-04-26 15:22:15 UTC
S190425z	DQOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY ADVOK	1240215502.011549	1240215503.011549	1240215504.018242	4.538e-13	2019-04-25 08:18:26 UTC
S190421ar	DQOK EMBRIGHT_READY PASTRO_READY SKYMAP_READY GCN_PRELIM_SENT ADVOK	1239917953.250977	1239917954.409180	1239917955.409180	1.489e-08	2019-04-21 21:39:16 UTC
S190412m	DQOK SKYMAP_READY PASTRO_READY EMBRIGHT_READY ADVOK GCN_PRELIM_SENT PE_READY	1239082261.146717	1239082262.222168	1239082263.229492	1.683e-27	2019-04-12 05:31:03 UTC
S190408an	DQOK ADVOK SKYMAP_READY PASTRO_READY EMBRIGHT_READY GCN_PRELIM_SENT PE_READY	1238782699.268296	1238782700.287958	1238782701.359863	2.811e-18	2019-04-08 18:18:27 UTC

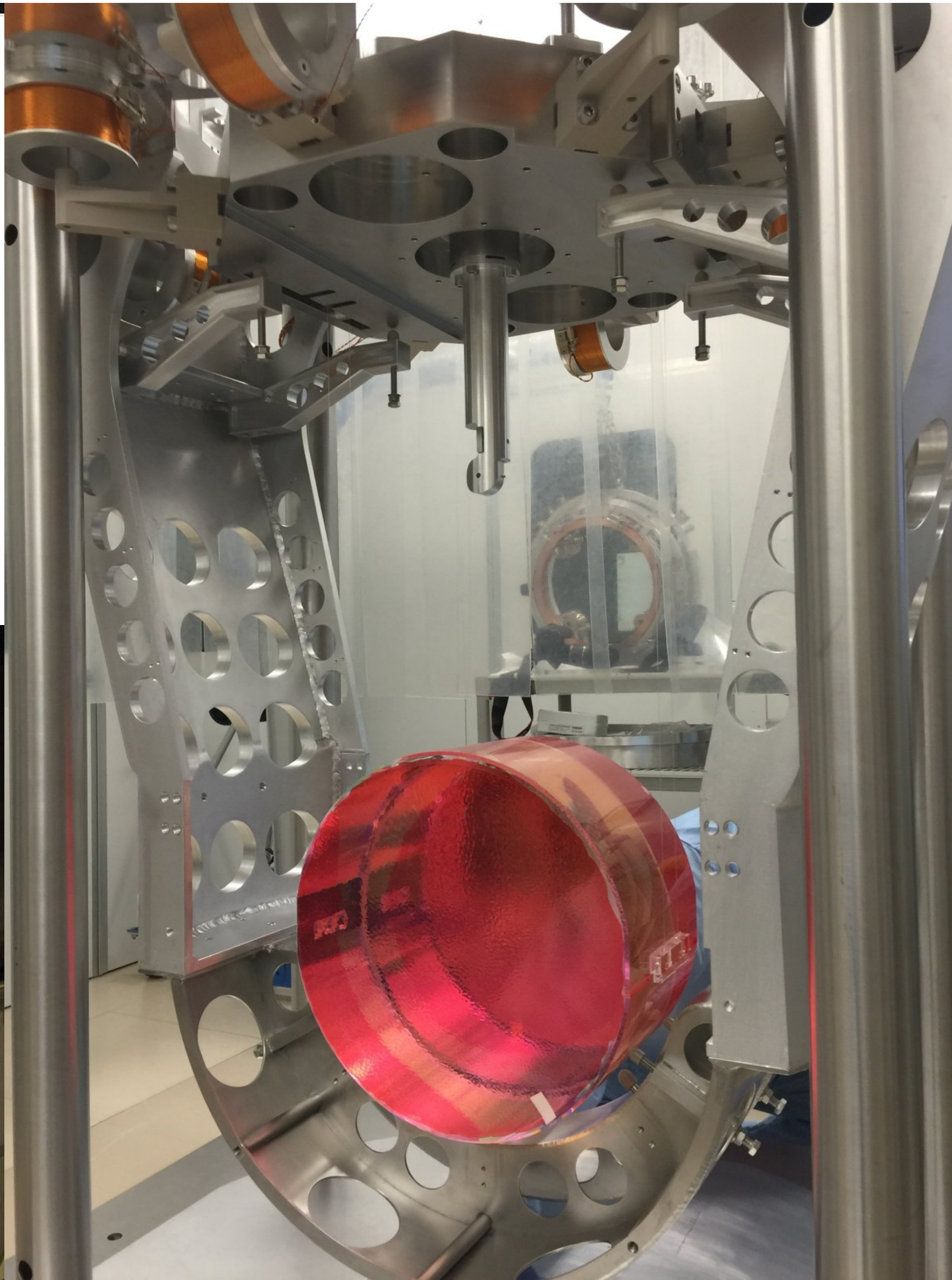
An example: S190412m





Experimental highlights: monolithic suspensions

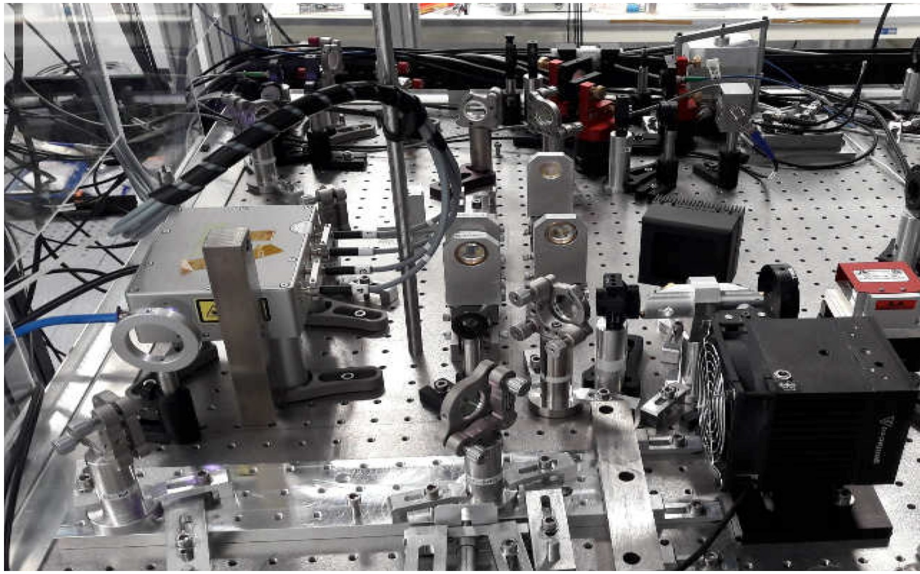




Experimental highlights: optics

Squeezing bench provided by AEI – MAX Planck
14 – 15 dB squeezed vacuum
(then when we match to the main interferometer significant loss in the gain are added)

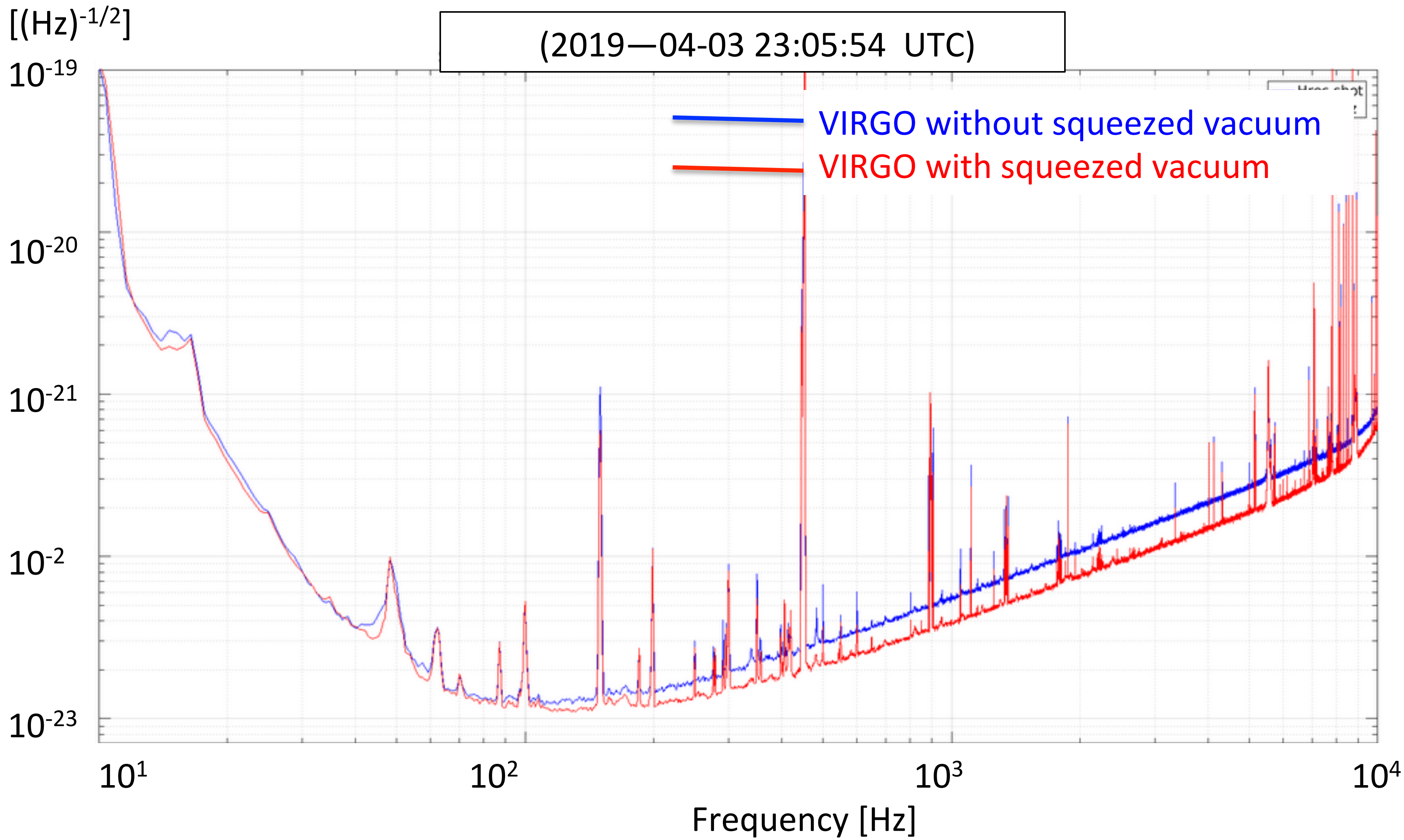
Stray light hunting restarted adding extra baffles



New laser amplifier 70 W ➔ 100 W
New pre-mode cleaner

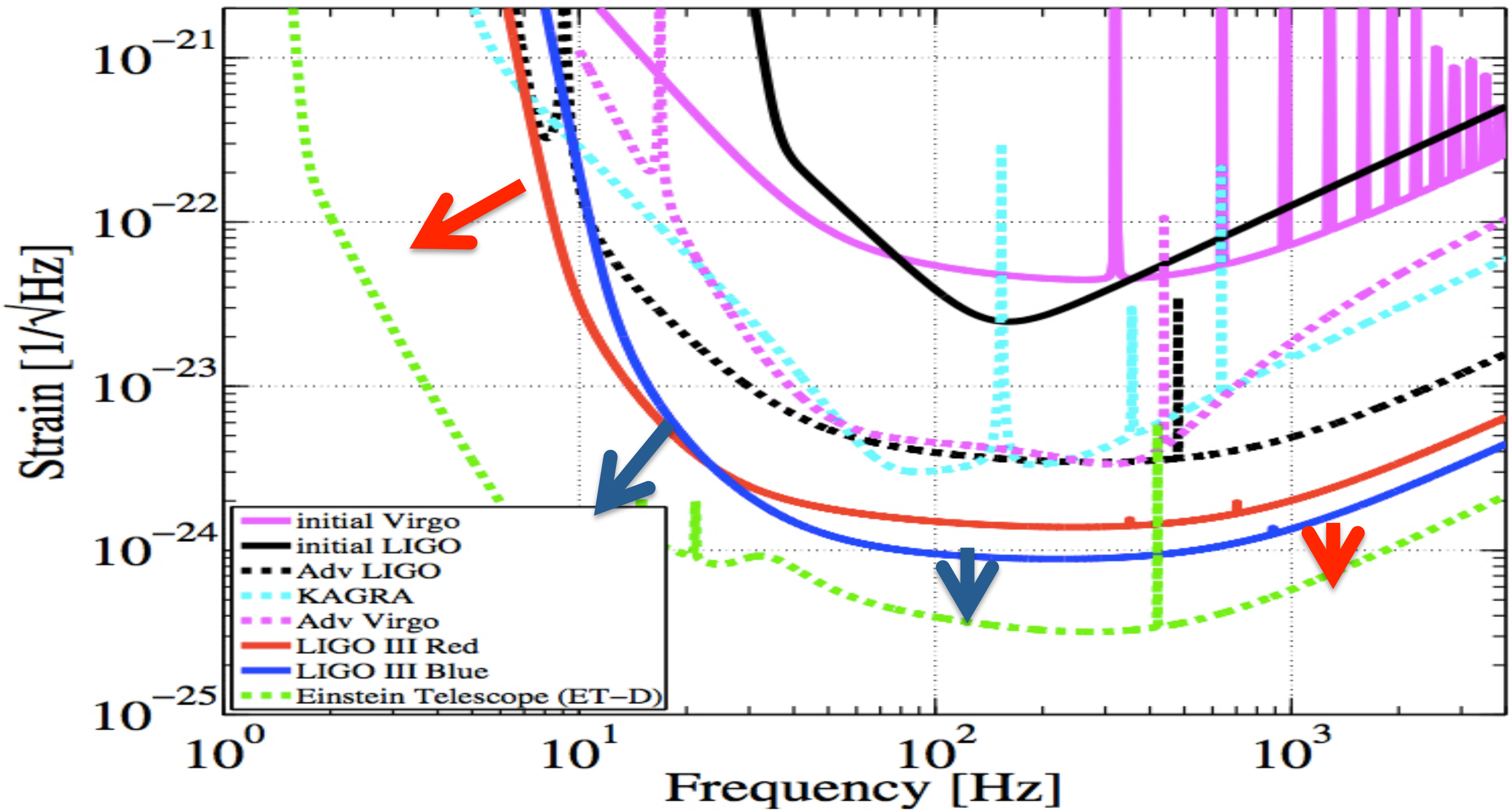
We can inject in the ITF up to 50 W

Running a Quantum Optics Interferometer



How to increase the sensitivity: as first increase the signal by ***increasing the arm length***

..and implement new solutions to reduce noise : Low NN, seismic noise (***underground detectors***) low radiation pressure noises (frequency dependent squeezing)
Low thermal noise using ***cryogenics and large test masses*** , Low optical noise with high power and squeezed vacuum



The limits of the present detectors

- Obsolescence (Virgo infrastructure completed in 2003)
- Length of the arms
- Impossibility to install cryogenic apparatuses
- Limit to the beam size
- Limit to the filter cavities length
- Seismic and Newtonian noise

The Global Scenario

• The GW detection and the beginning of the multimessenger astronomy stimulated a world wide acceleration toward 3G GW observatories

• In Europe we launched the formation of Einstein Telescope (ET) collaboration. A crucial task is to define the parameters on the base of which we candidate sites to host the infrastructure and submit the ET project proposal to the ESFRI roadmap

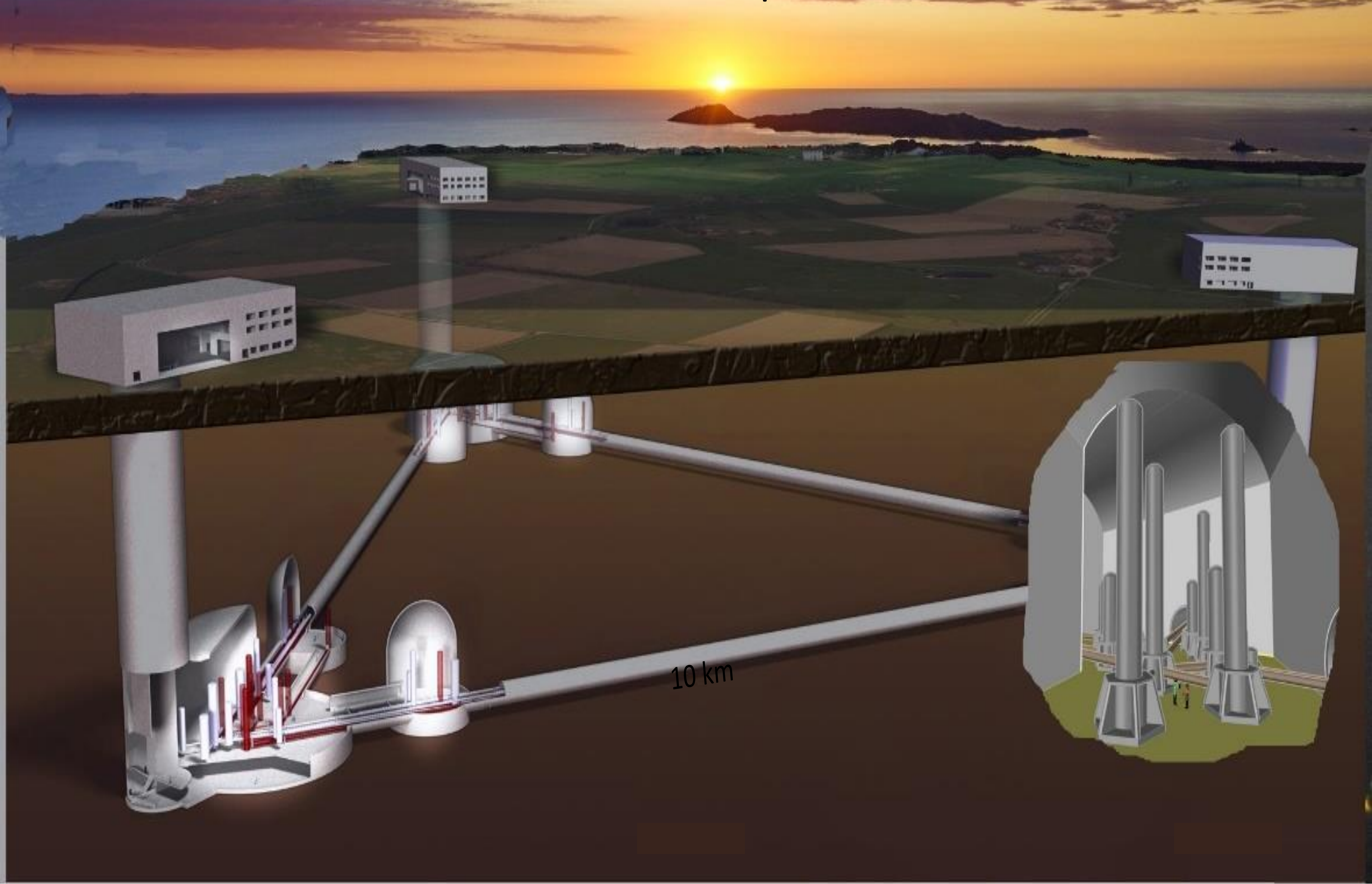
• In USA the idea of a giant 40km detector, named Cosmic Explorer, is now born and supported, as Conceptual Design Study, by NSF

• We set up a global coordination committee (GWIC-3G) that is attempting to harmonise the efforts and to find synergies

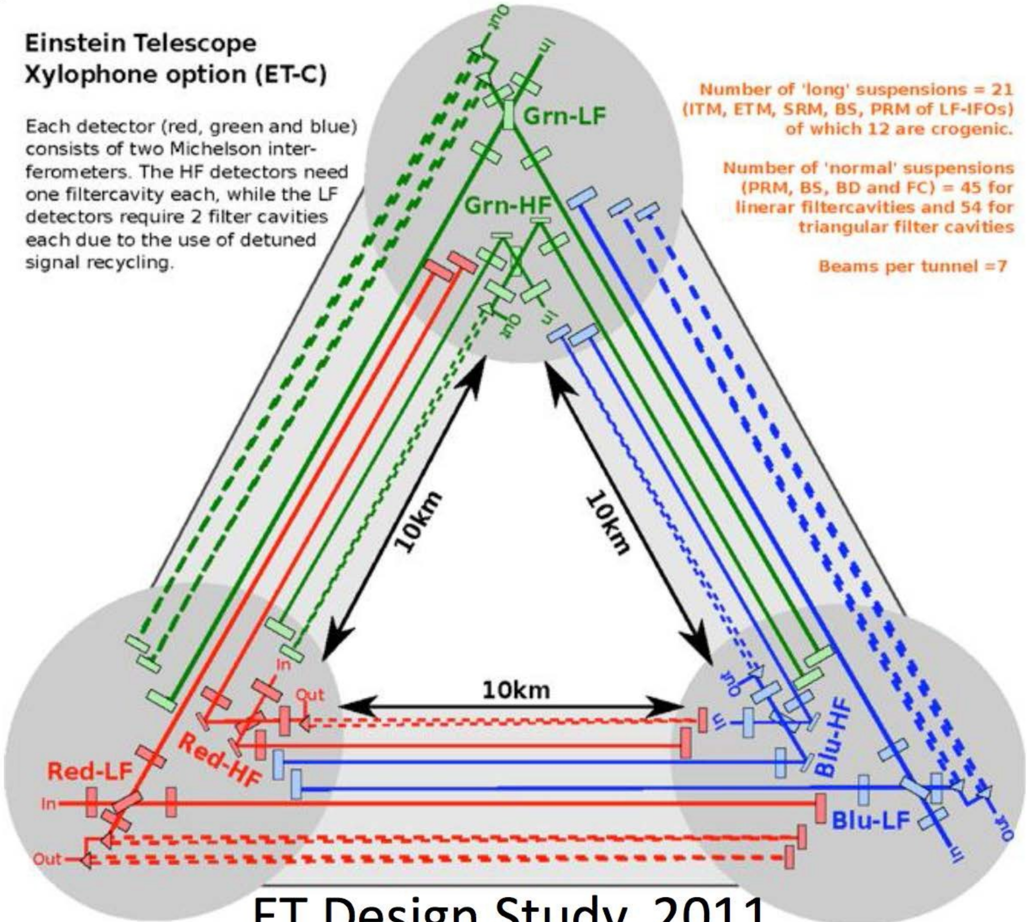
https://gwic.ligo.org/3Gsubcomm/

The Einstein Telescope

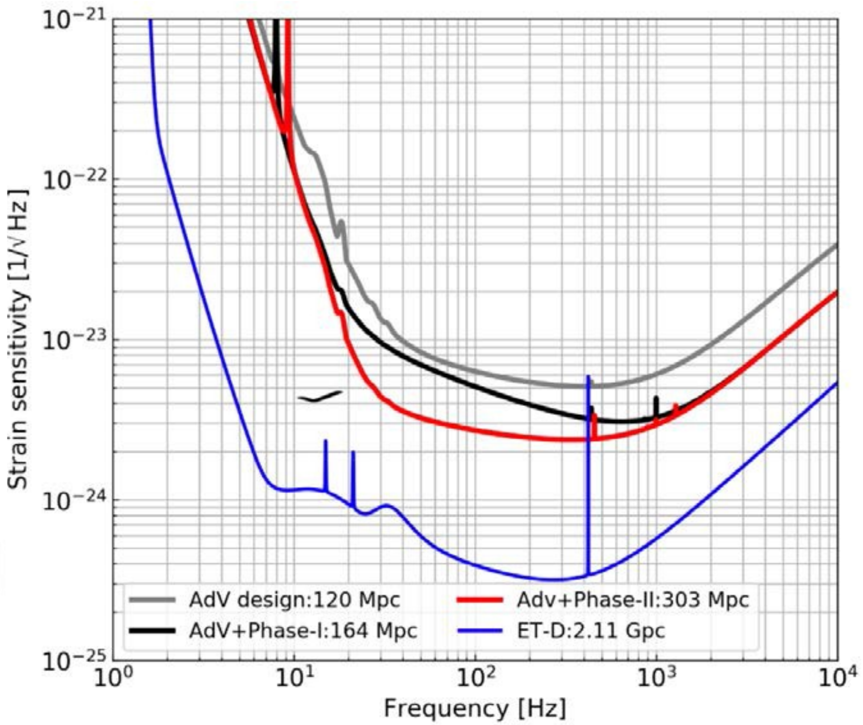
ET EINSTEIN TELESCOPE



The detectors of the EINSTEIN TELESCOPE

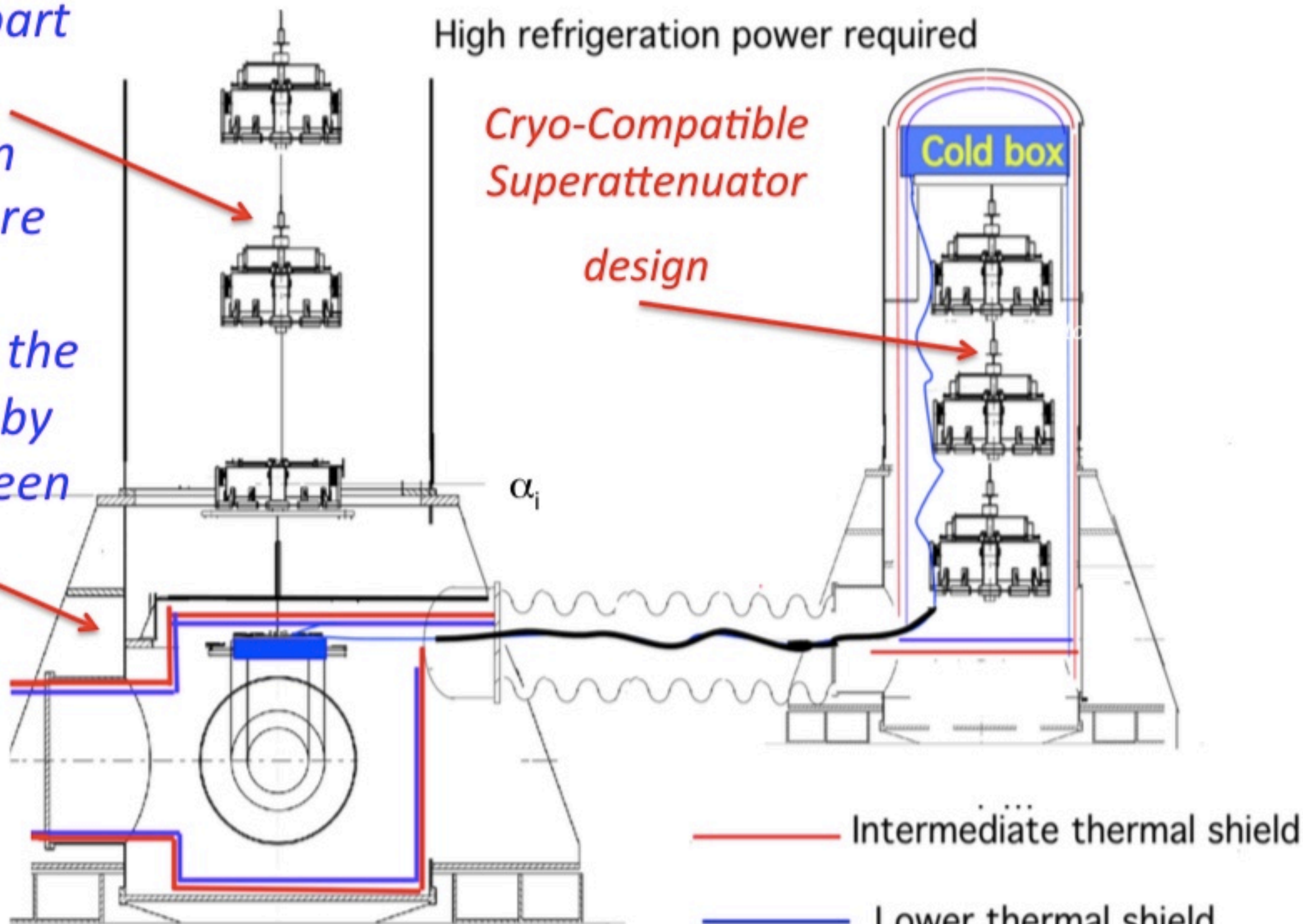


ET Design Study, 2011



ET CRYOGENIC SYSTEM

The upper part (~15 m) is at room temperature and insulated to the lower part by thermal screen



Crucial requirements:

1) negligible mechanical noise due to cooling system, 2) Reduced cooling time

Alternative cooling strategies - I

KAGRA approach ➔ Pulse Tube refrigerators

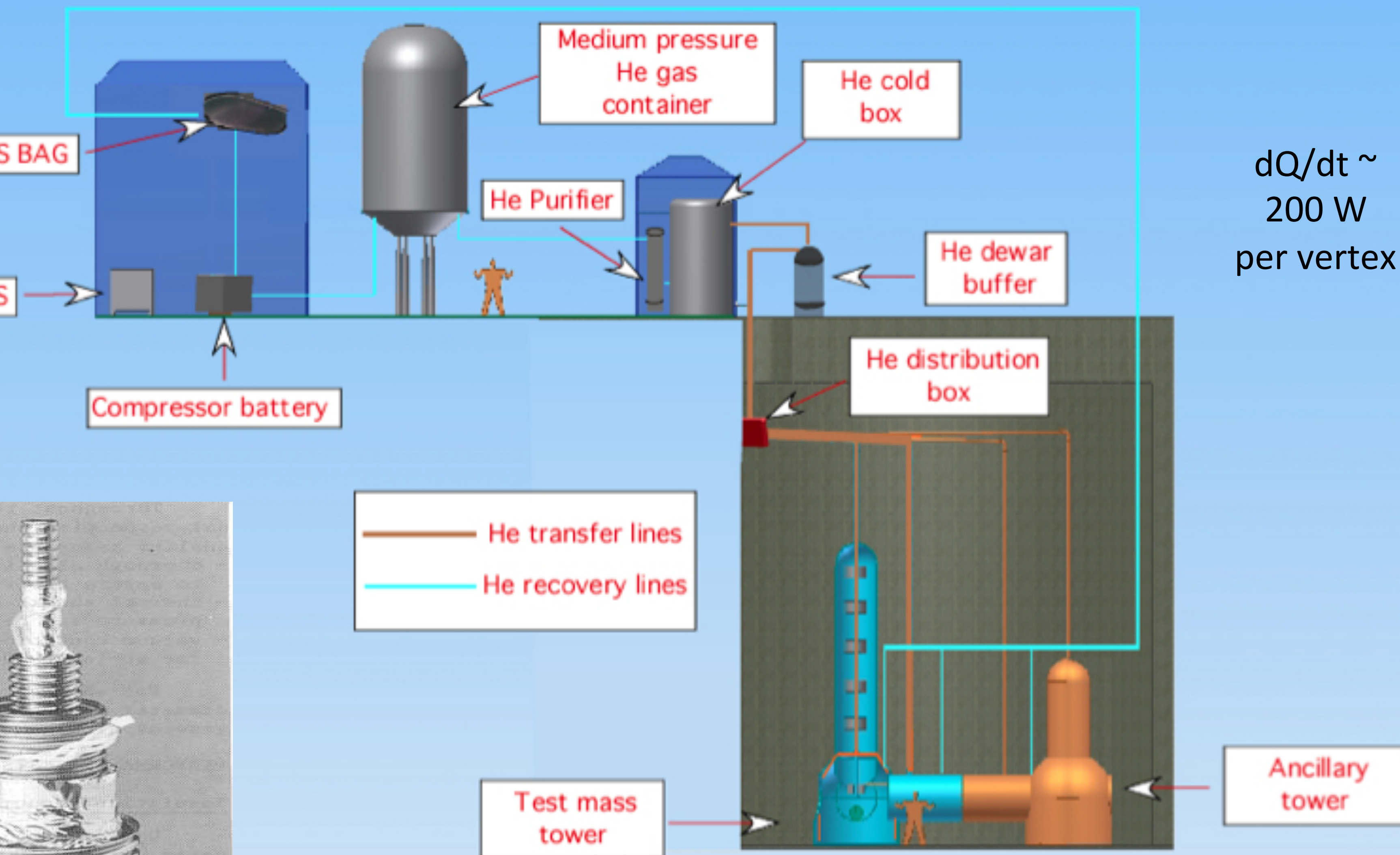
PRO

- Independency of cryogenic liquids,
- Flexibility (only electrical power and cooling water),
- Independent from orientation comparing to normal cryostats,
- Low-maintenance (12,000 h).

Contra

- Mechanical vibrations,
- Temperature oscillations,
- Electromagnetic noise.

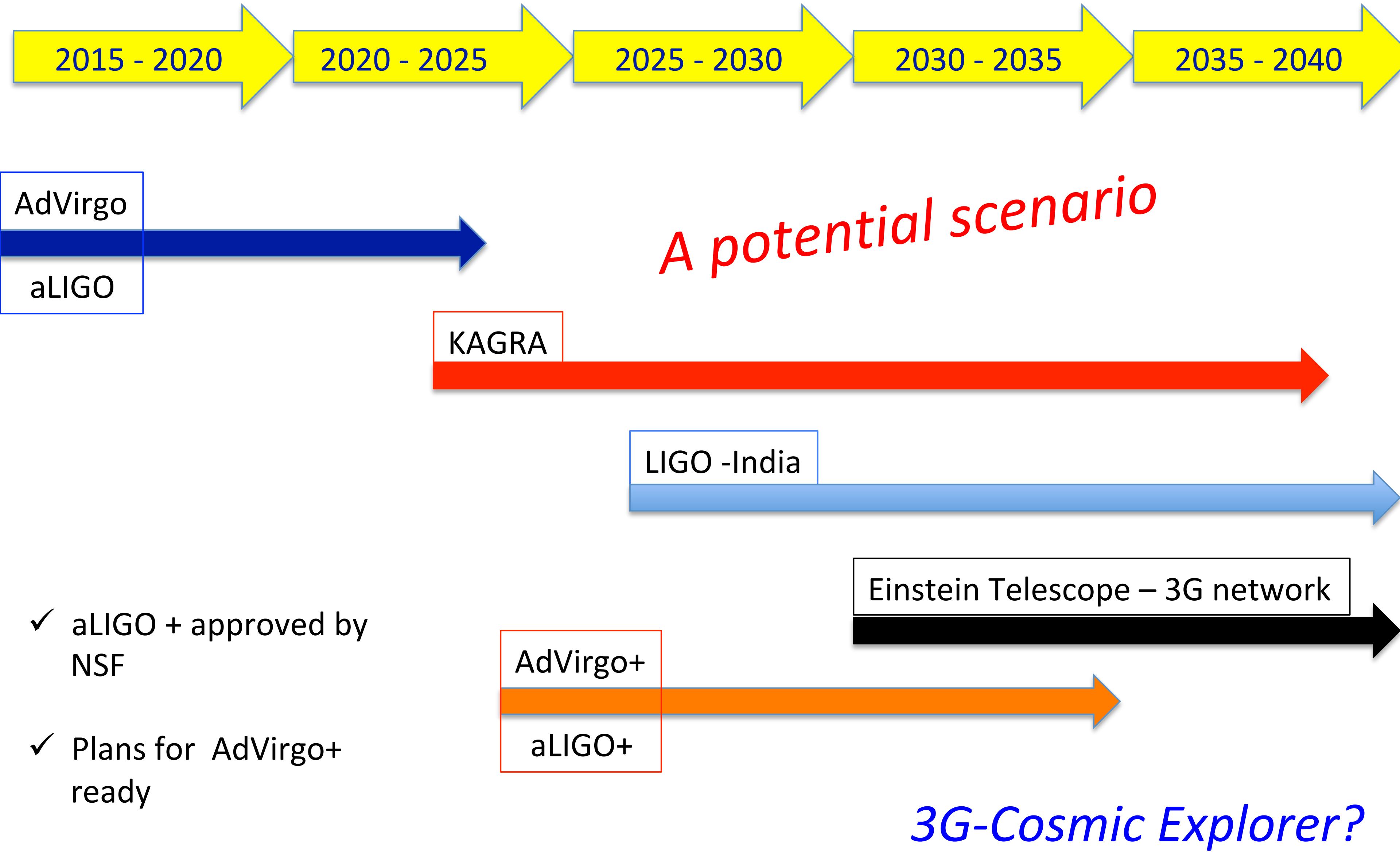
Cryofluid solution: a He plant in each vertex



dQ/dt ~ 200 W per vertex

- Low loss He transfer line (~30 mW/m): lenght ~ 200 m
- Payload and ancillary tower cryostats
- He Cryotraps

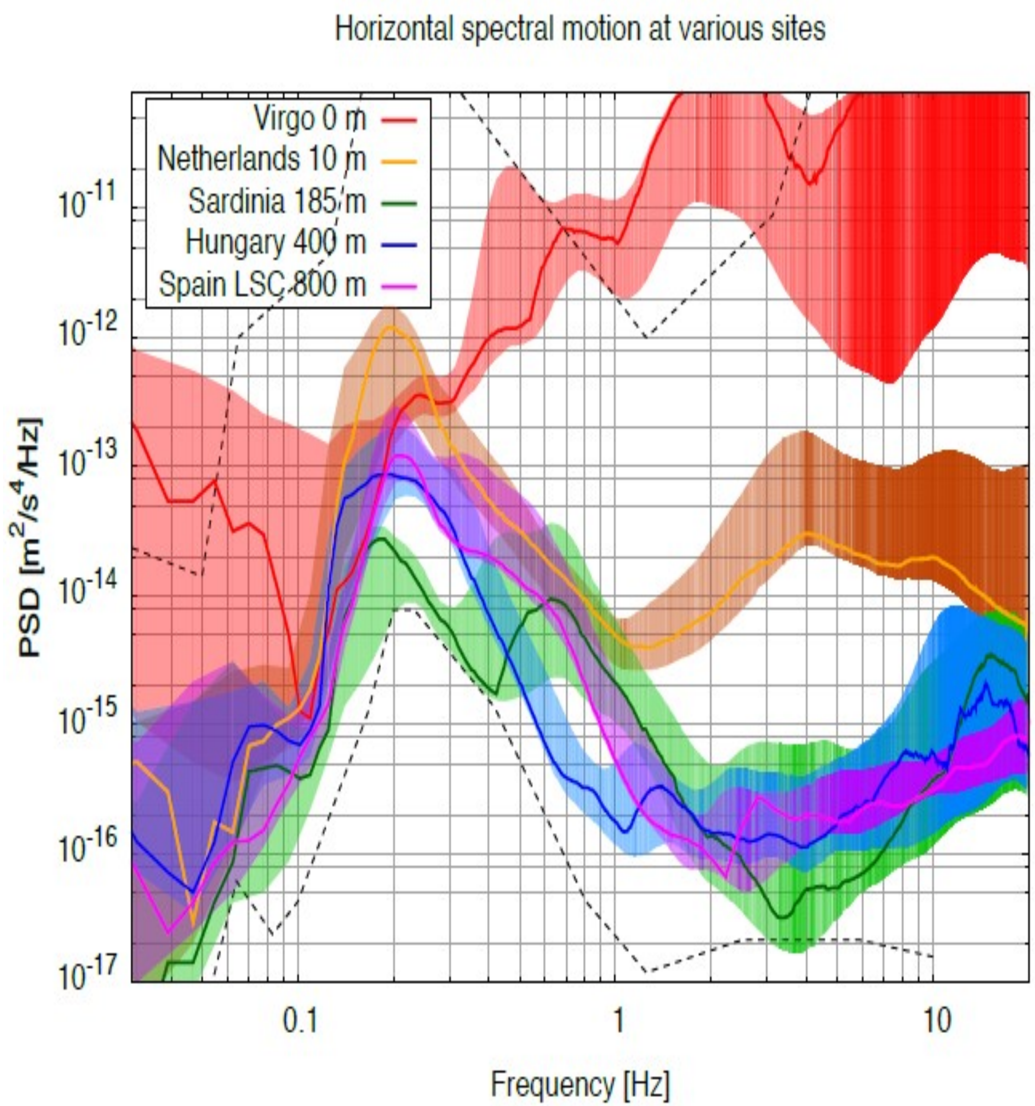
Middle and Long Roadmap



- ✓ aLIGO + approved by NSF
- ✓ Plans for AdVirgo+ ready

Preliminary Investigation on site selection

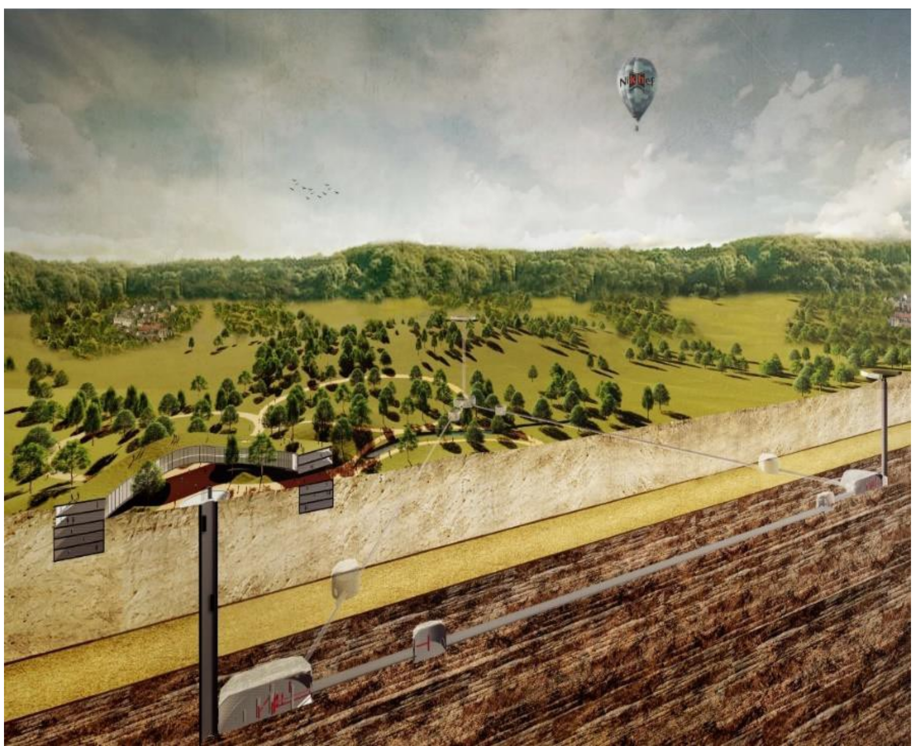
EU: 2 (+1) sites survived



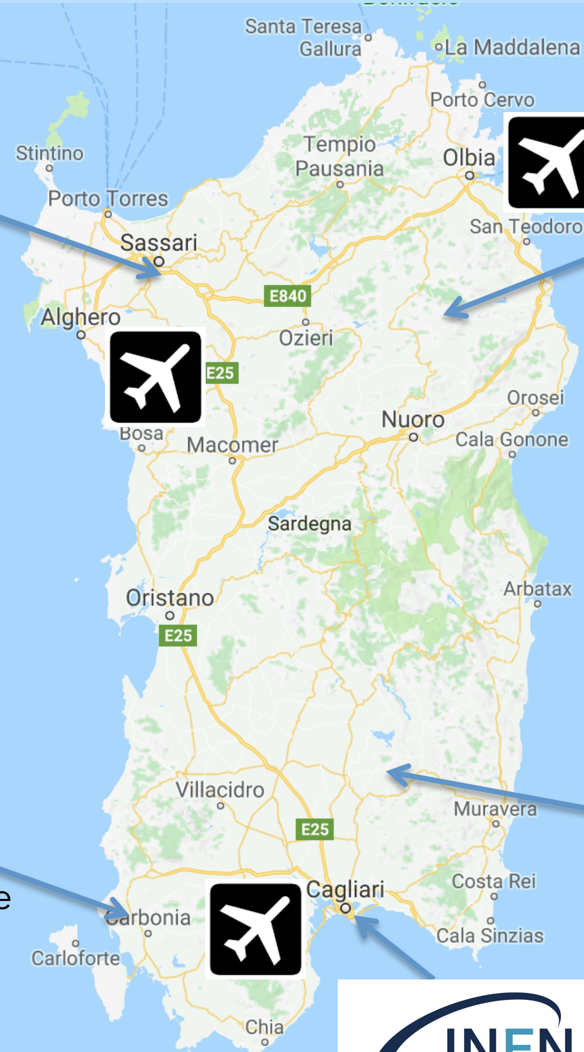
- Belgium-Germany-Netherlands
- Hungary (Matra Mountain)
- Italy (Sardinia-Sos Enattos)

EUREGIO MEUSE - RHINE

- A proposal to realize ET in the Limburg area
- A detector hosted by 3 countries (B-D-NL)
- Site qualification still in progress



Our Proposal is to have ET inSARDINIA



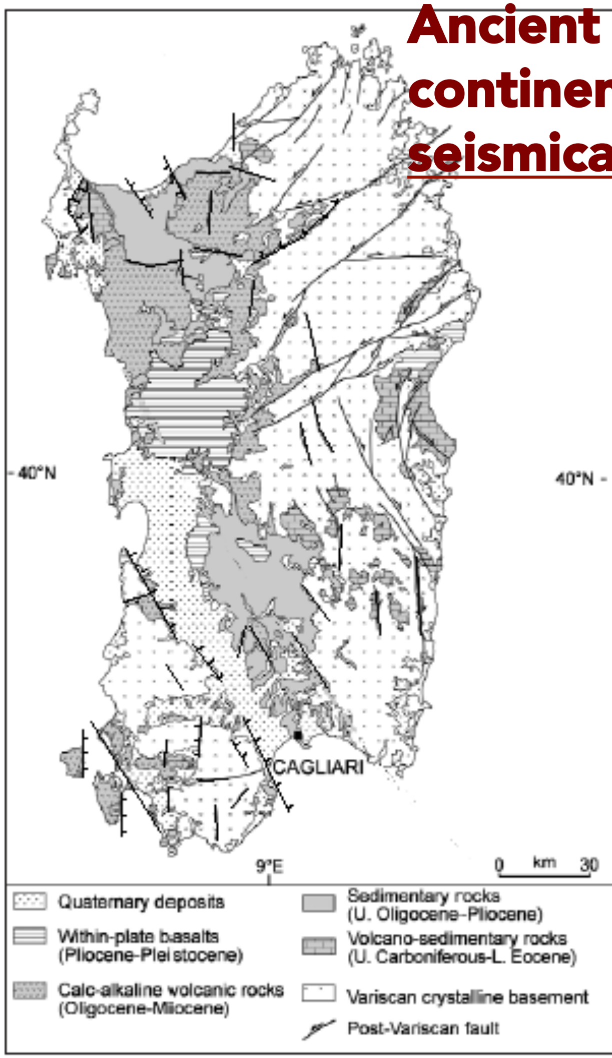
50′ drive from Olbia airport to the Sos Enattos mine (85 km)

"ARIA" PROJECT
(for the Gran Sasso Dark Side DM detector)

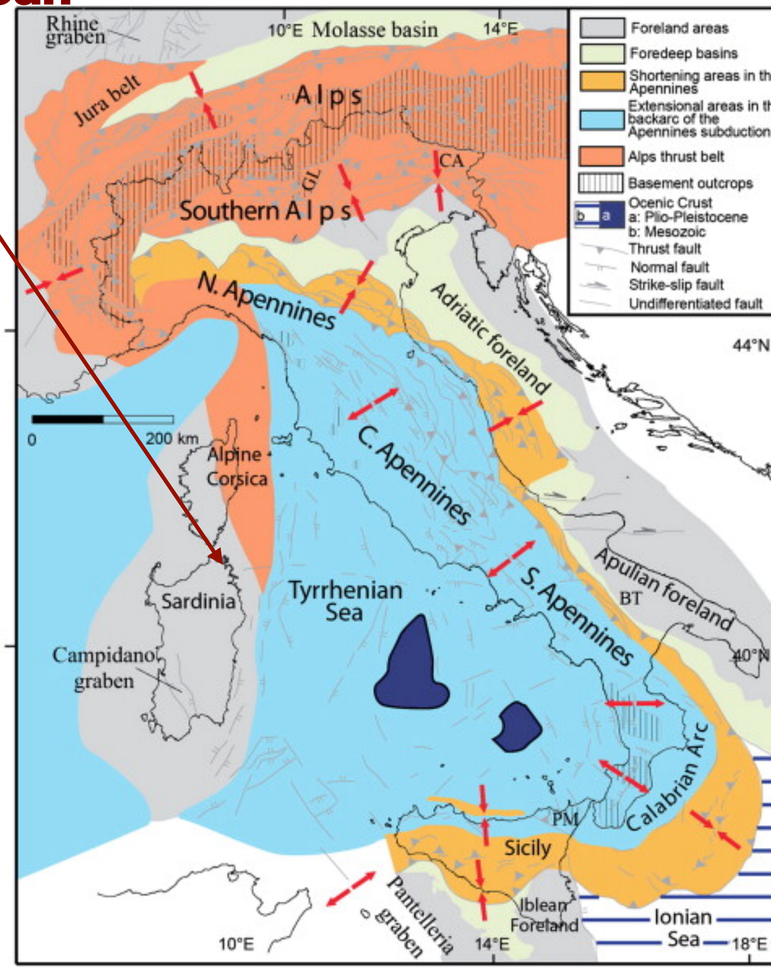
Sardinia Radio Telescope

ET Symposium, April 20th, 2018

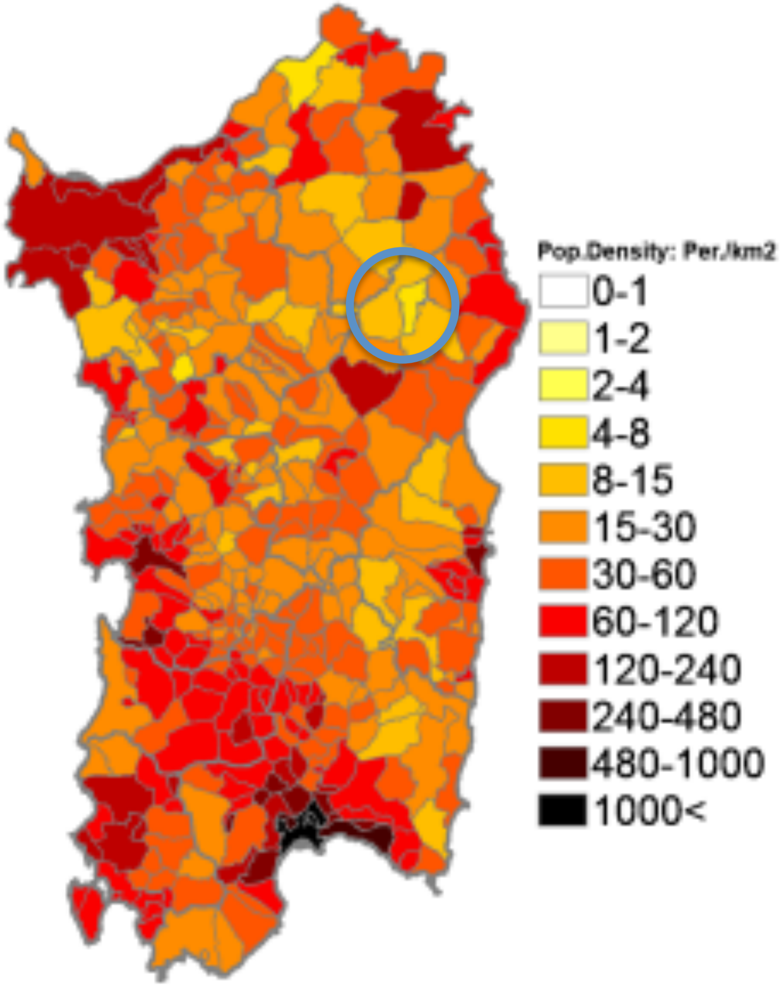
SARDINIA GEOPHYSICS

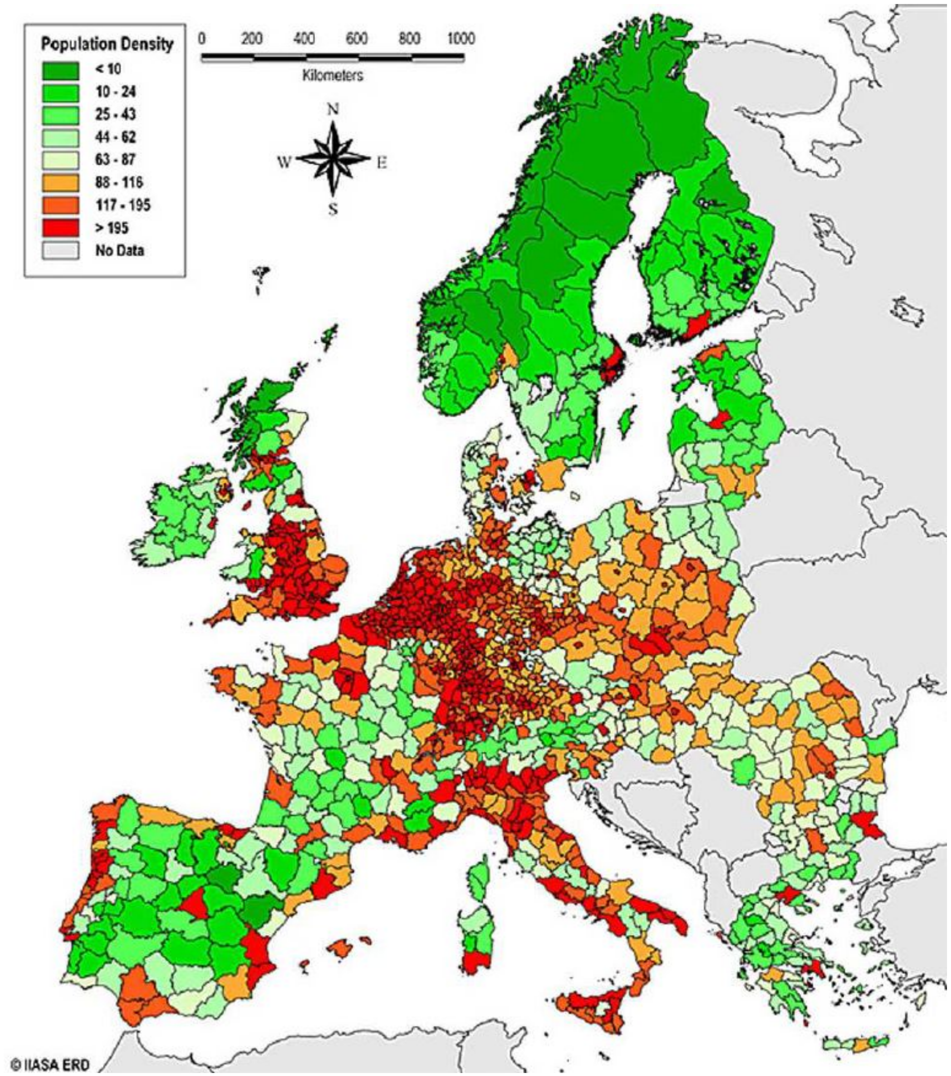


Ancient rocks, European continental landmass: <u>seismically quiet</u>

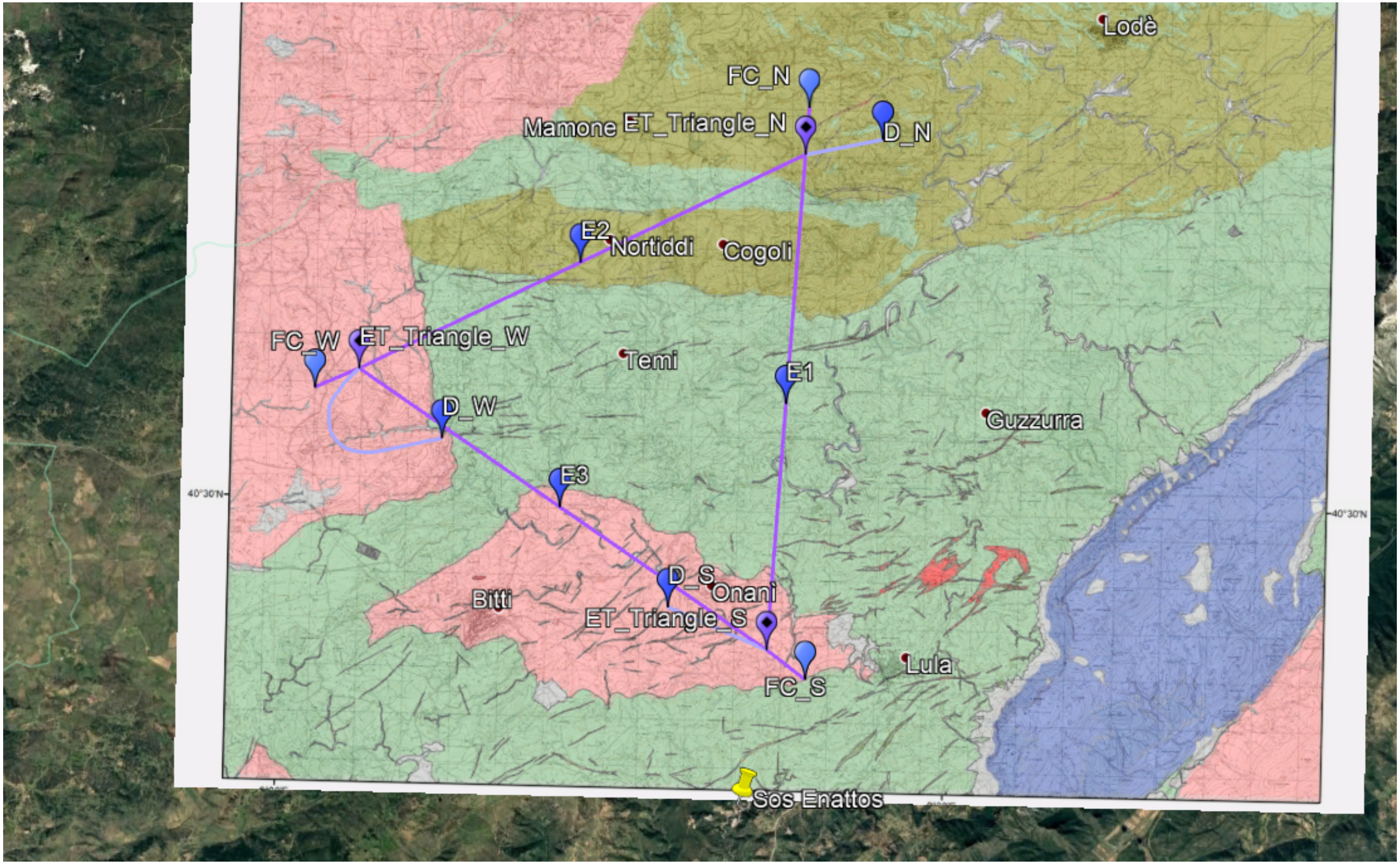


POPULATION DENSITY





LOCATION - TRIANGLE



GEOLOGICAL SECTIONS

Legend

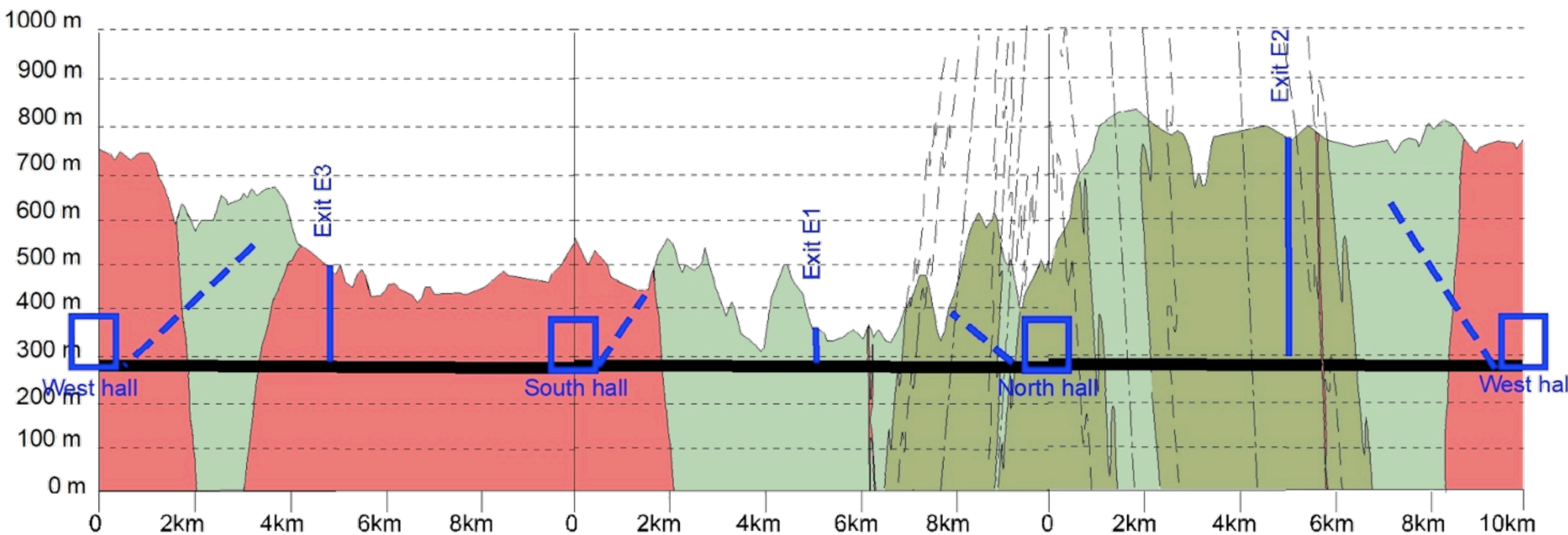
Intrusive complex

Granodiorites and monzogranites

Metamorphic basement

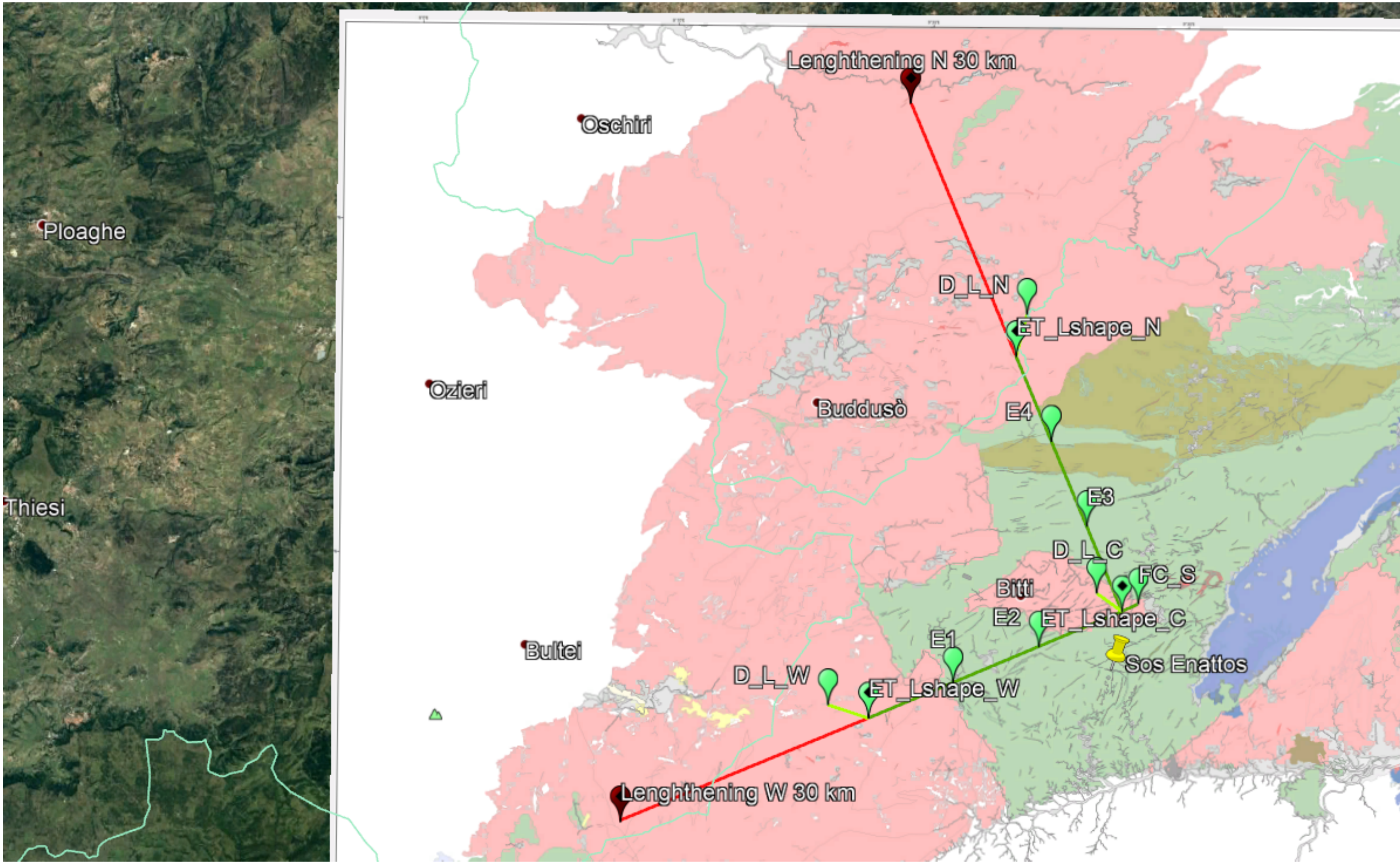
Orthogneiss

Phyllites, micaschist and paragneiss



vertical exaggeration 10x

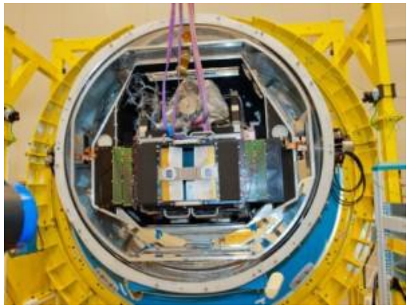
LOCATION - L



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

ET socio-economical impact

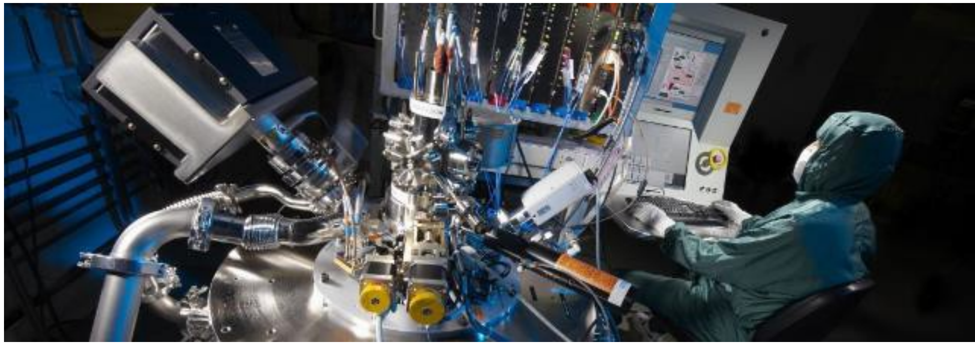
ET will stimulate regional innovation power, activity, employment and attractively for top scientists. The facility poses extreme technical demands to equipment, that must be development specially for this application.



Measuring and attenuating vibrations: nano-technology, medical, defense

Optics, coatings, special materials, laser technology, semiconductor technology

Cryogenic technology: fusion and superconductivity



Vacuum technology:
ET will be one of the biggest UHV plants i the world

Credit: Jo van den Brand

R&D for ET

Class. Quantum Grav 28 (2011) 094013

Table 1. Summary of the most important parameters of the ET-D high- and low-frequency interferometers as shown in figure 5. SA = superattenuator, freq. dep. squeez. = squeezing with frequency-dependent angle.

Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	Fused silica	Silicon
Mirror diameter/thickness	62 cm/30 cm	min 45 cm/TBD
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	detuned (0.6)
SR transmittance	10%	20%
Quantum-noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×10 km	2×10 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	9 cm
Scatter loss per surface	37.5 ppm	37.5 ppm
Partial pressurefor H_2O, H_2, N_2	$10^{-8}, 5 \times 10^{-8}, 10^{-9}$ Pa	$10^{-8}, 5 \times 10^{-8}, 10^{-9}$ Pa
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \times 10^{-10}\ \mathrm{m}/f^2$	$5 \times 10^{-10}\ \mathrm{m}/f^2$
Gravity-gradient subtraction	none	none

ITALY GOVERNMENT SUPPORT

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

Hunting new GW Signals with new GW detectors on the Earth

Gravitational Wave amplitude

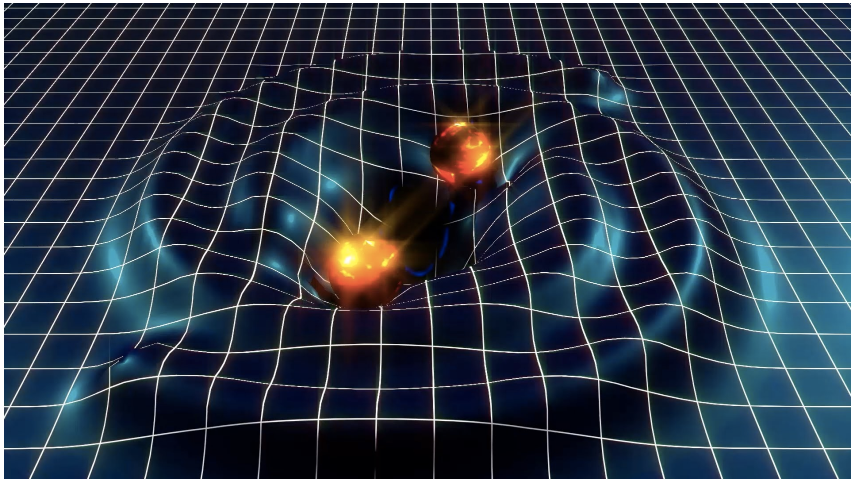
The amplitude of the space-time deformation is:

$$h_{\mu\nu} = \frac{2G}{c^4}\frac{1}{r}\dddot{Q}_{\mu\nu}$$

Where $Q_{\mu\nu}$ is the quadrupolar moment of the GW source

and r is the distance between the detector and the GW source

Let suppose to have a system of 2 coalescing neutron stars, located in the Virgo cluster (r~10Mpc):



$$h \approx 10^{-21} - 10^{-22}$$

$$\left.\begin{array}{l} \Delta L \approx h\,L \\ L \approx 10^3 m \end{array}\right\} \Rightarrow \Delta L \approx 10^{-18} - 10^{-19} m$$

Target GW amplitude

Luminosity

$$P = \frac{G}{5c^5} < \dddot{Q}^{ij} \dddot{Q}_{ij} > \approx \varepsilon \cdot \frac{c^5}{G} \left(\frac{R_S}{R} \right)^2 \left(\frac{v}{c} \right)^6$$

10^{59} erg/s

Compactness C

1 for BH

0.3 for NS

10^{-4} for WD

An efficient source of GW must be "compact" and "fast"

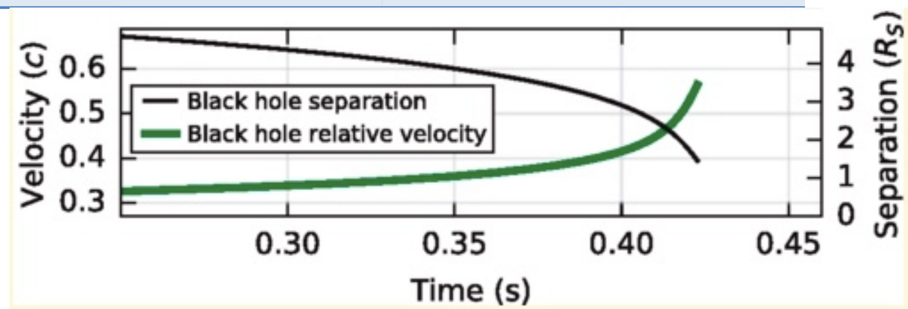
Mean compactness	Mass [kg]	Radius [km]	Density [kg/lt]
Water	1	sphere of 6.2 cm ~ 1 lt	1
Earth	6×10^{24}	6400	5.5
Sun	2×10^{30}	750000	1.4
Neutron Star	**3×10^{30}**	**12**	**4×10^{14}**
Proton	1.7×10^{-27}	1×10^{-18}	4×10^{14}

Velocity *v* of two BHs during the merging phase (*c units*)

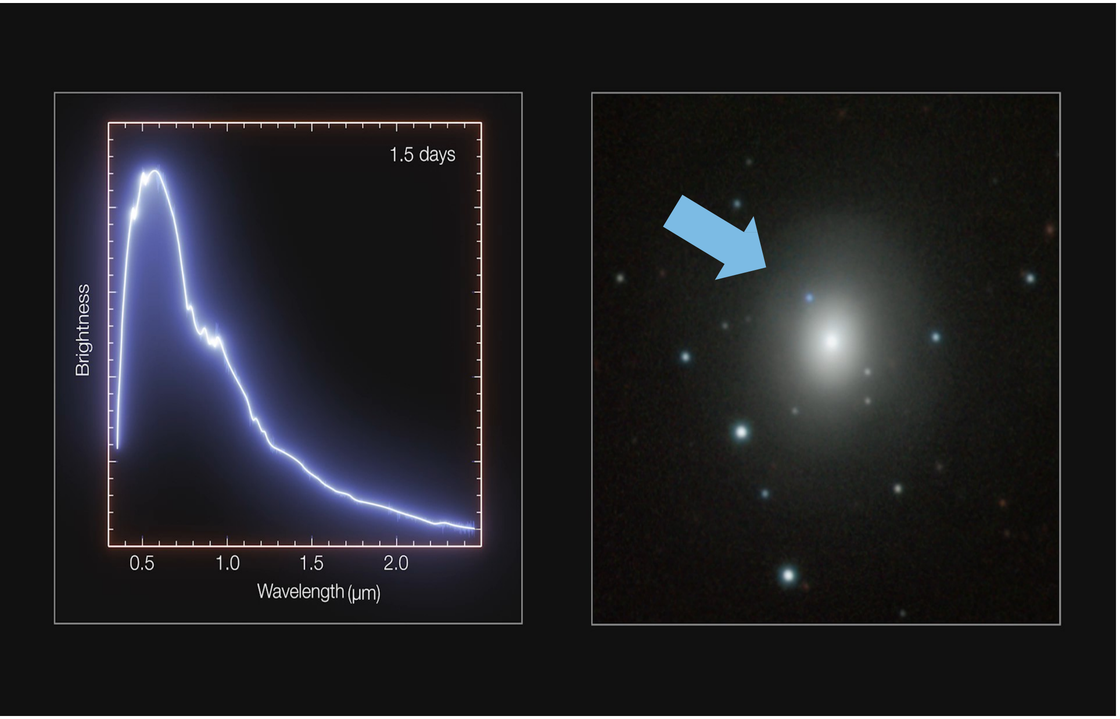
$v/c = (G M \pi f / c^3)^{1/3}$

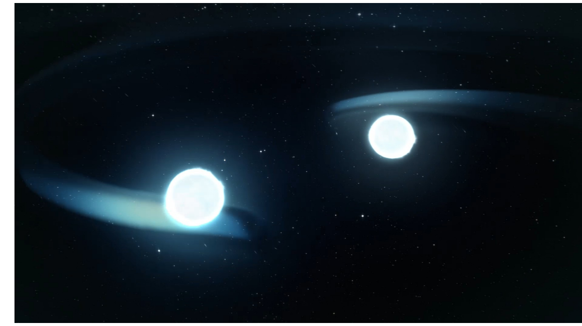
Separation R in units of Schwarzschild radius

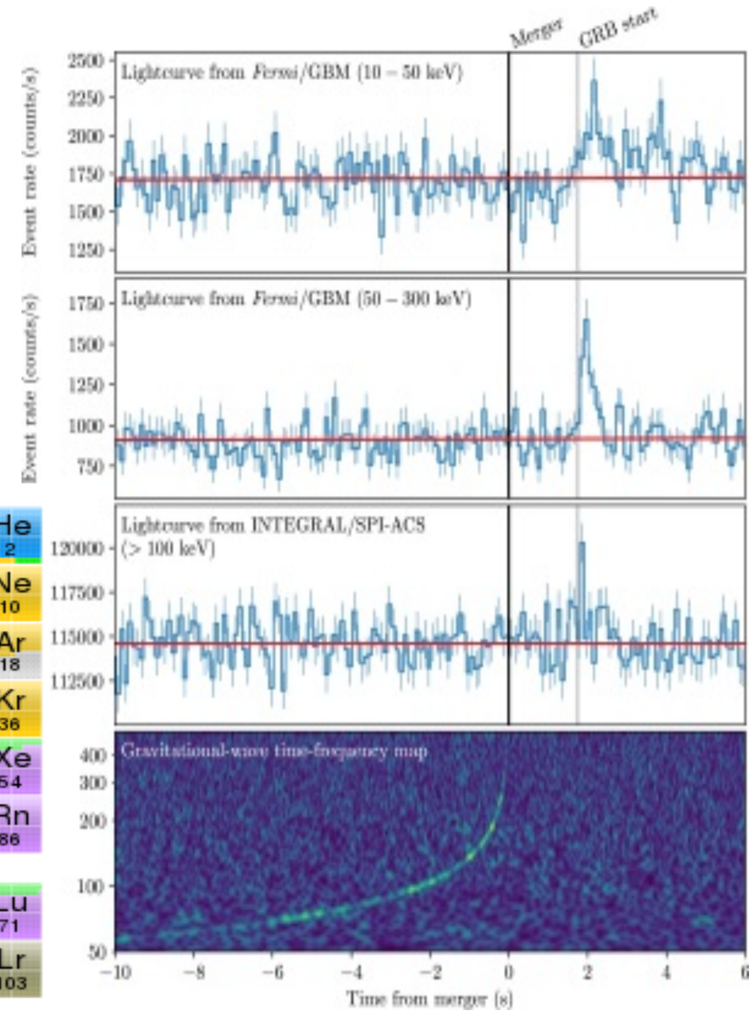
$R_s = 2GM / c^2$

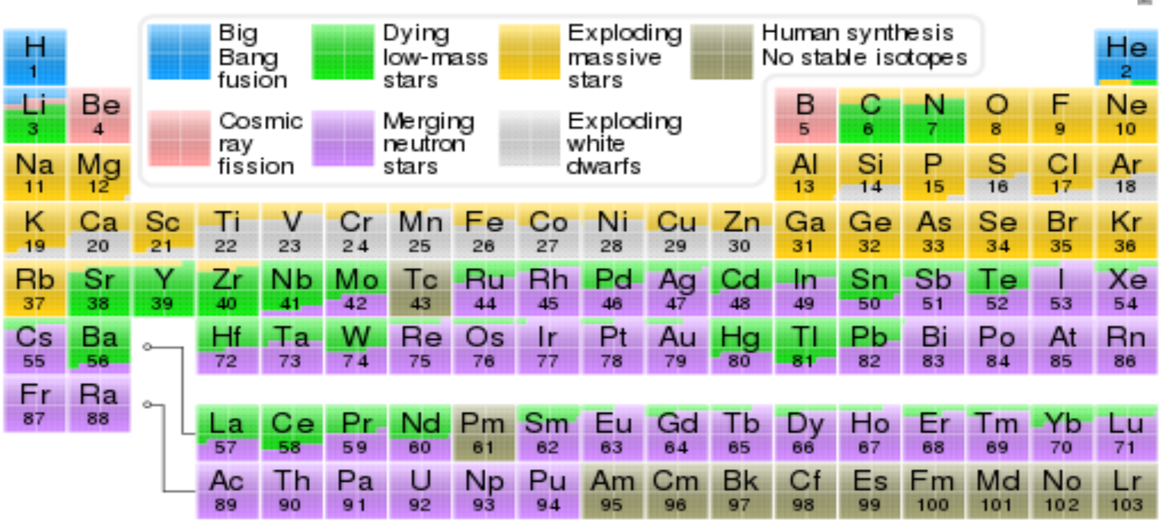


Binary Neutron Stars









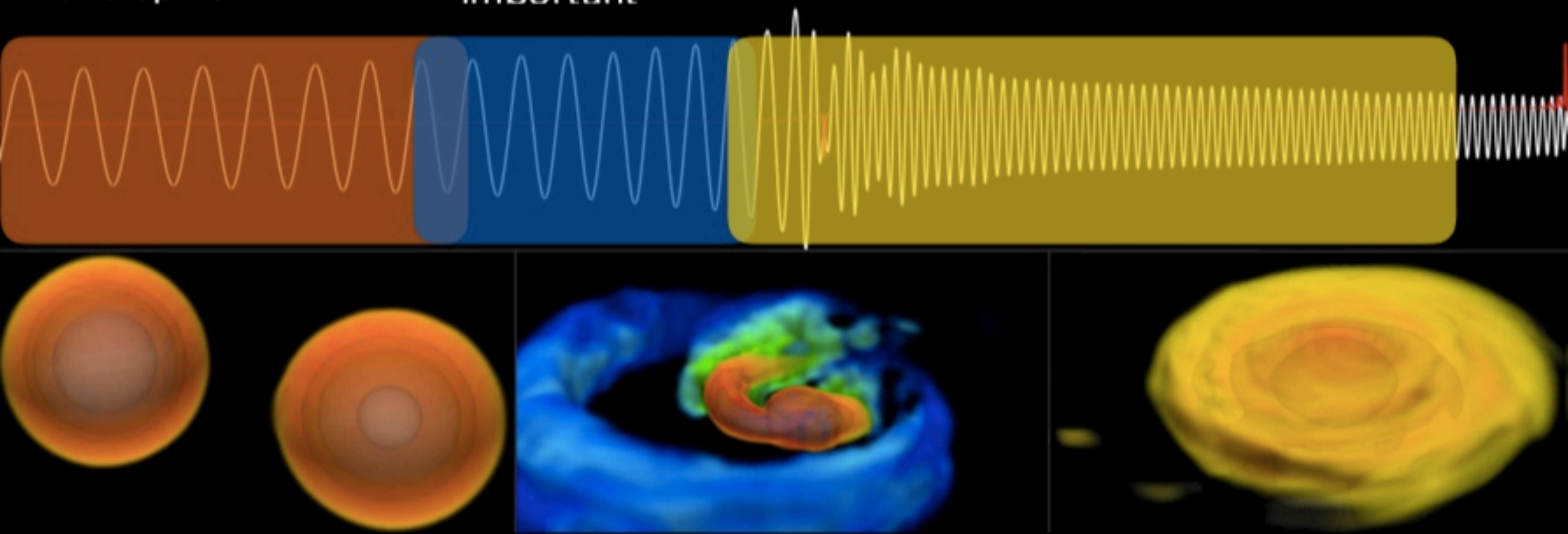
PHYSICAL EFFECTS IN BINARY NEUTRON STAR COALESCENCE WAVEFORMS

Credits: Sebastiano Bernuzzi

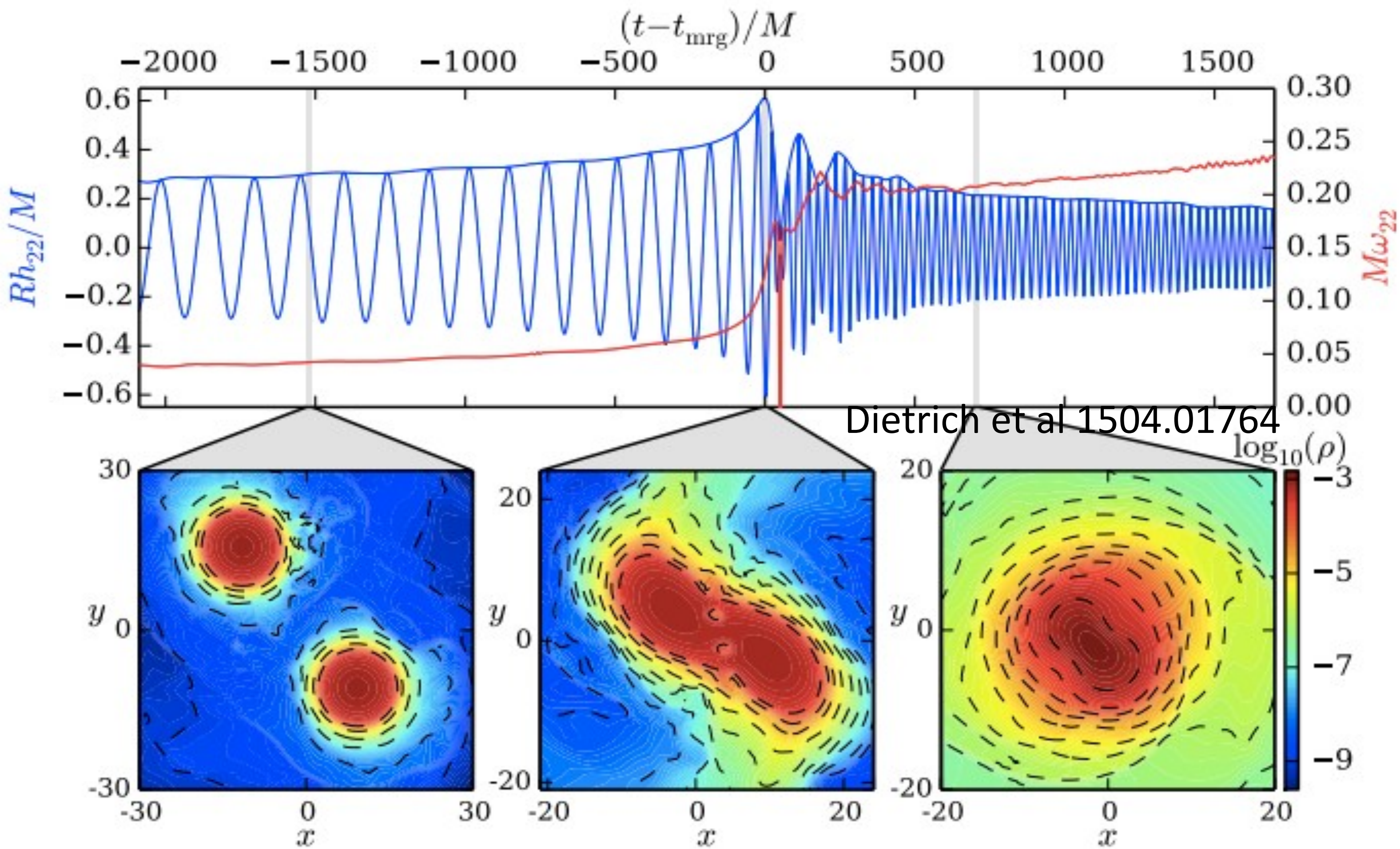
dominated by gravitational radiation back reaction - masses and spins

tidal effects appear at high PN order, dynamical tides might be important

complex physics of the merger remnant, multi-messenger source, signature of neutron star EoS



The waveform

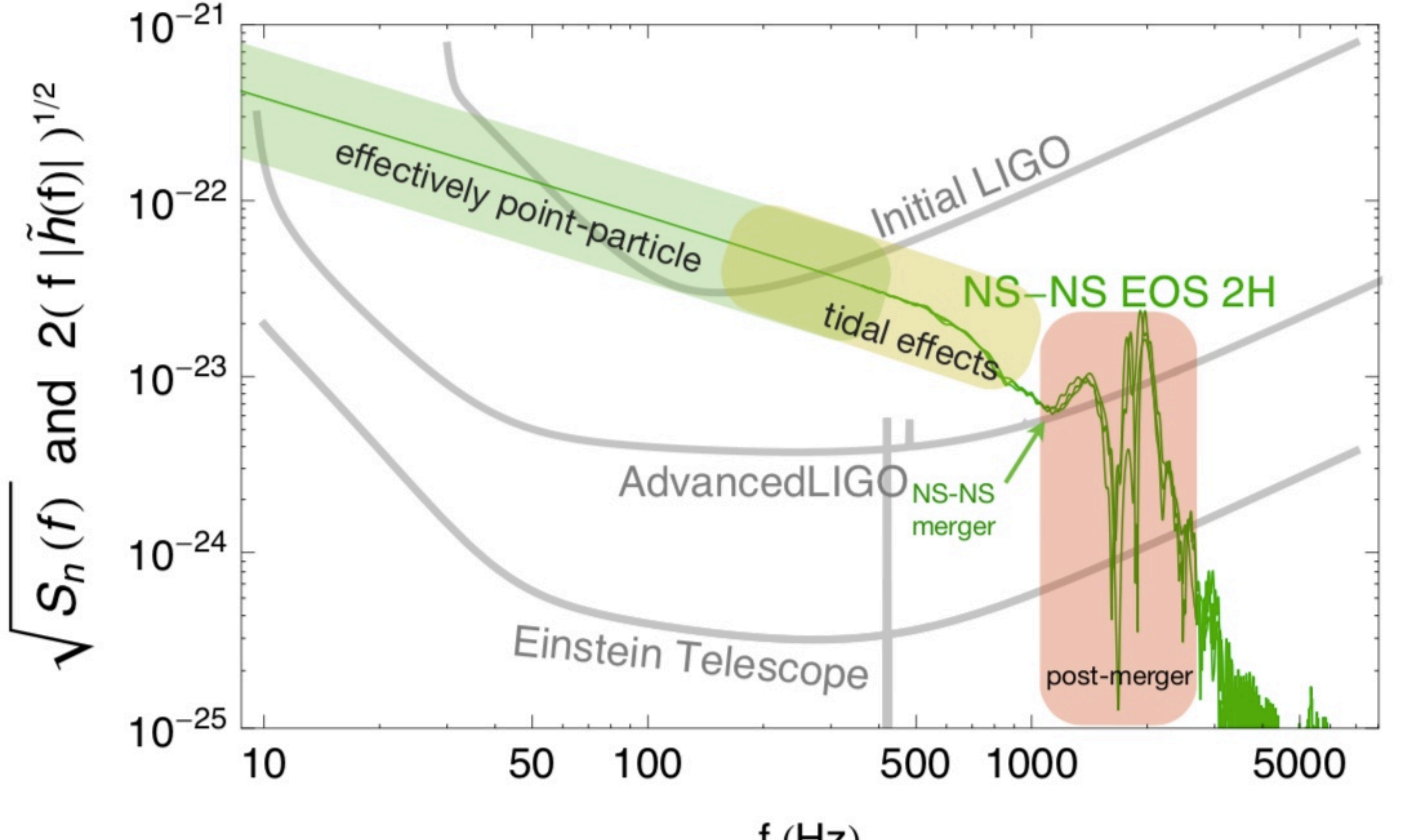


Dietrich et al 1504.01764

- Tidal field ε of one companion induces a quadrupole moment Q in the other
- In the adiabatic approximation $Q_{ij} = -\lambda(m)\,\varepsilon_{ij}$ $\lambda(m) = 2/3\, k(m)\, R^5(m)$

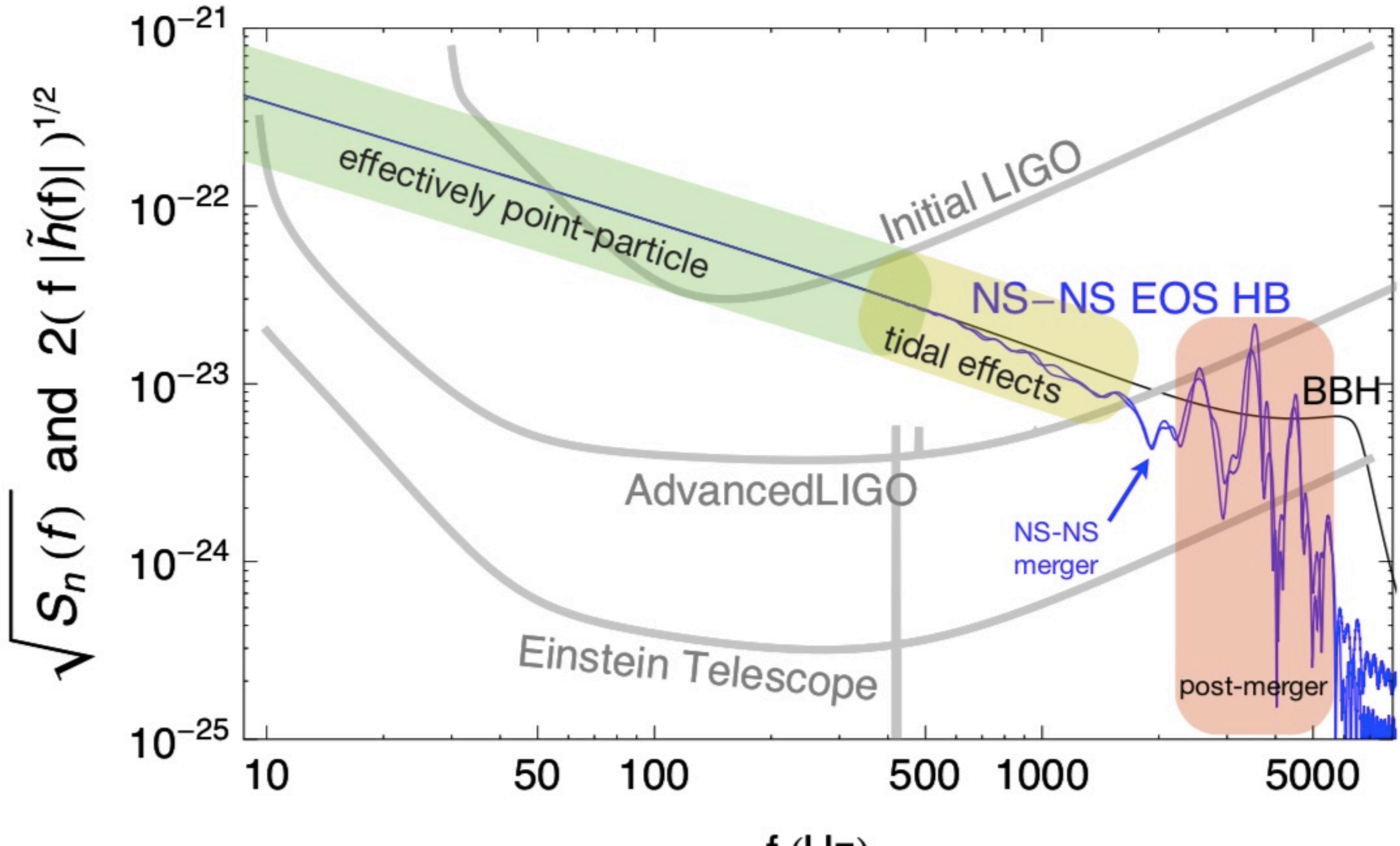
λ(m) ➔ tidal deformability, (size of the quadrupole deformation/strength of external field),
$k_2(m)$ ➔ Love number, R ➔ NS radius

Hard NS EOS



10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
$\sqrt{S_n(f)}$ and $2(f\,|\tilde{h}(f)|)^{1/2}$
effectively point-particle
Initial LIGO
tidal effects
NS–NS EOS 2H
AdvancedLIGO
NS-NS merger
Einstein Telescope
post-merger
10
50
100
500
1000
5000
f (Hz)

Soft NS EOS



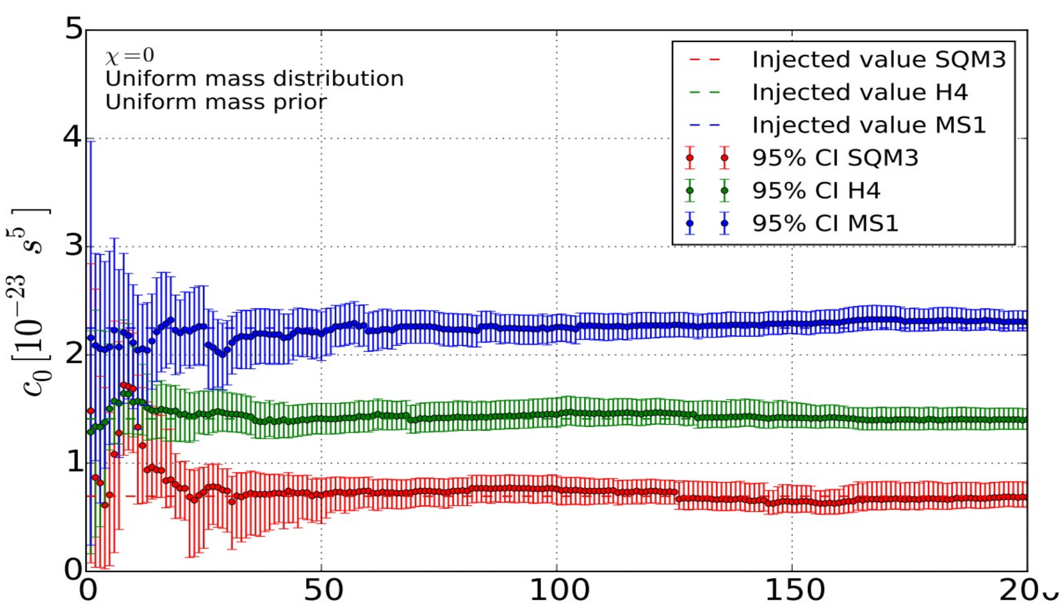
effectively point-particle
Initial LIGO
NS−NS EOS HB
tidal effects
BBH
AdvancedLIGO
NS-NS
merger
Einstein Telescope
post-merger
10
50
100
500
1000
5000

Constraining the NS EOS

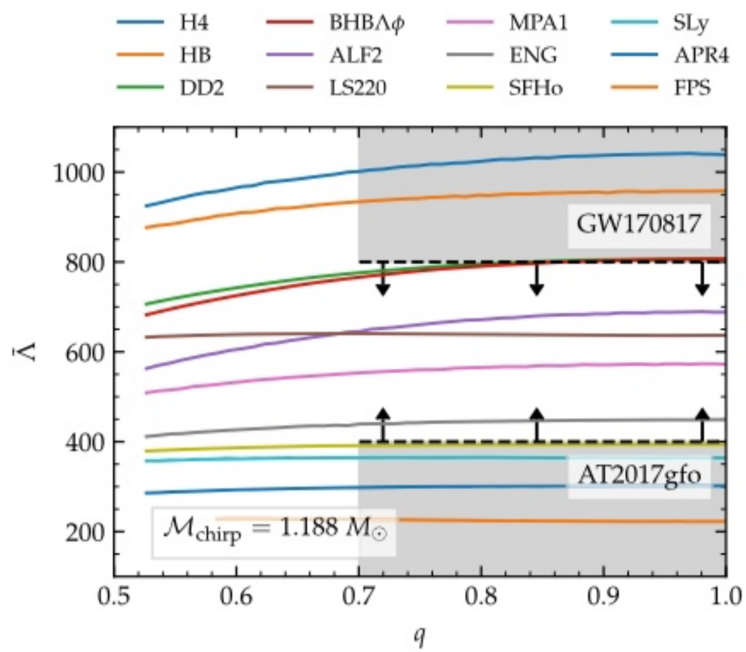
Measuring the tidal deformation through the ephasing in the GW signal is possible to constrain the EOS of the NS

Adding the em information helps to impose ore stringent constrain

- Knowing the EOS it is possible to describe the status of the matter in the over-critical pressure condition in the NS

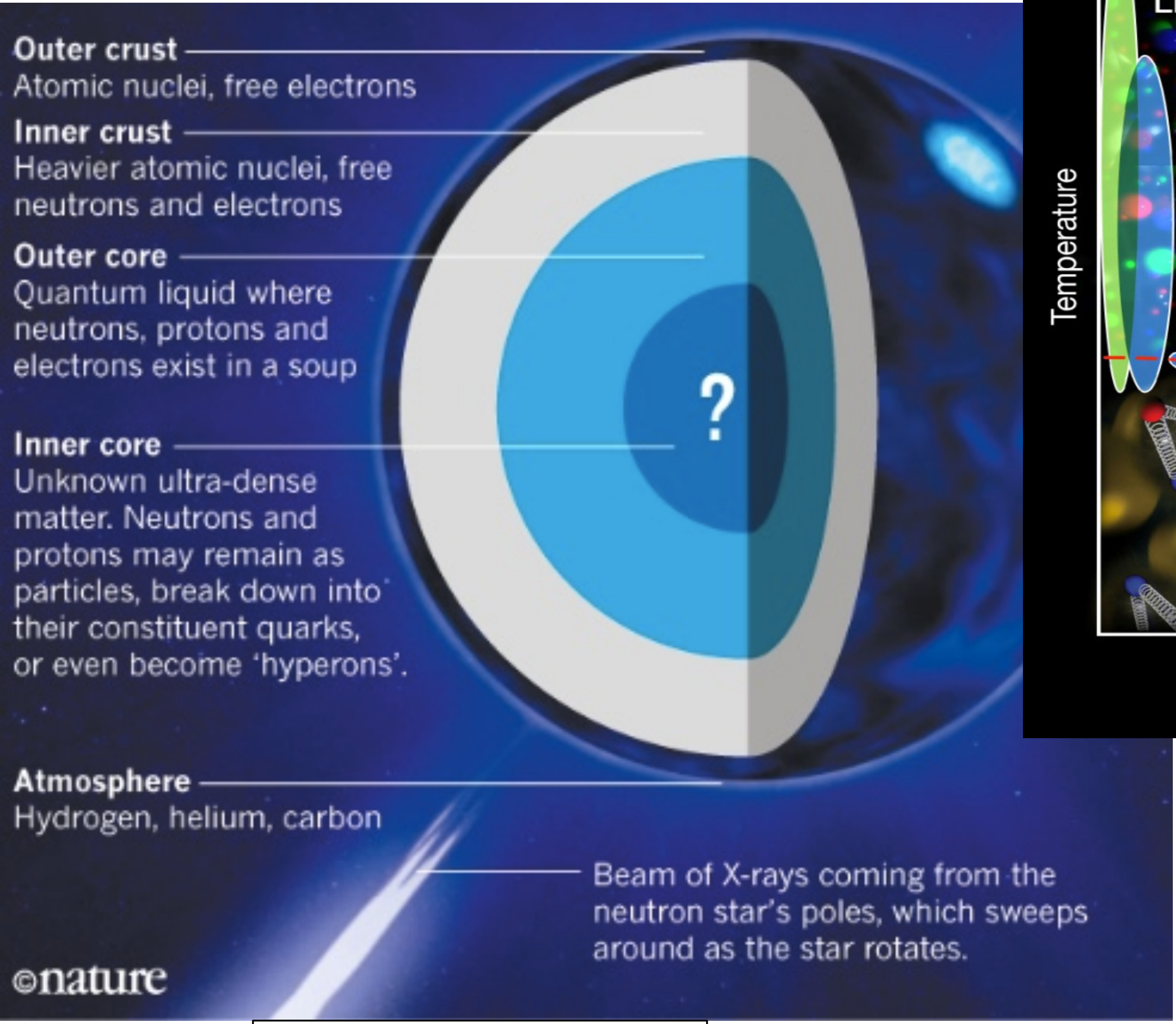


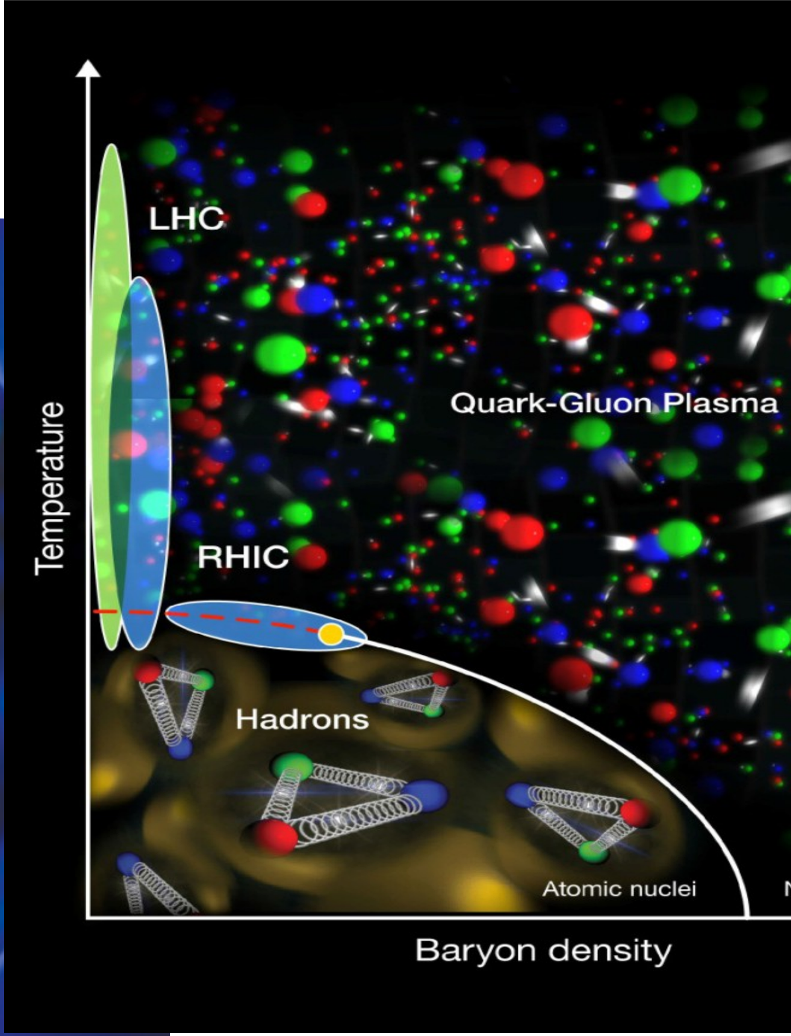
M. Agathos et al, Phys. Rev. D 92, 023012 (2015)



D. Radice et al. APJ Letters, 852, 2, 20

Neutron Star as nuclear physics lab



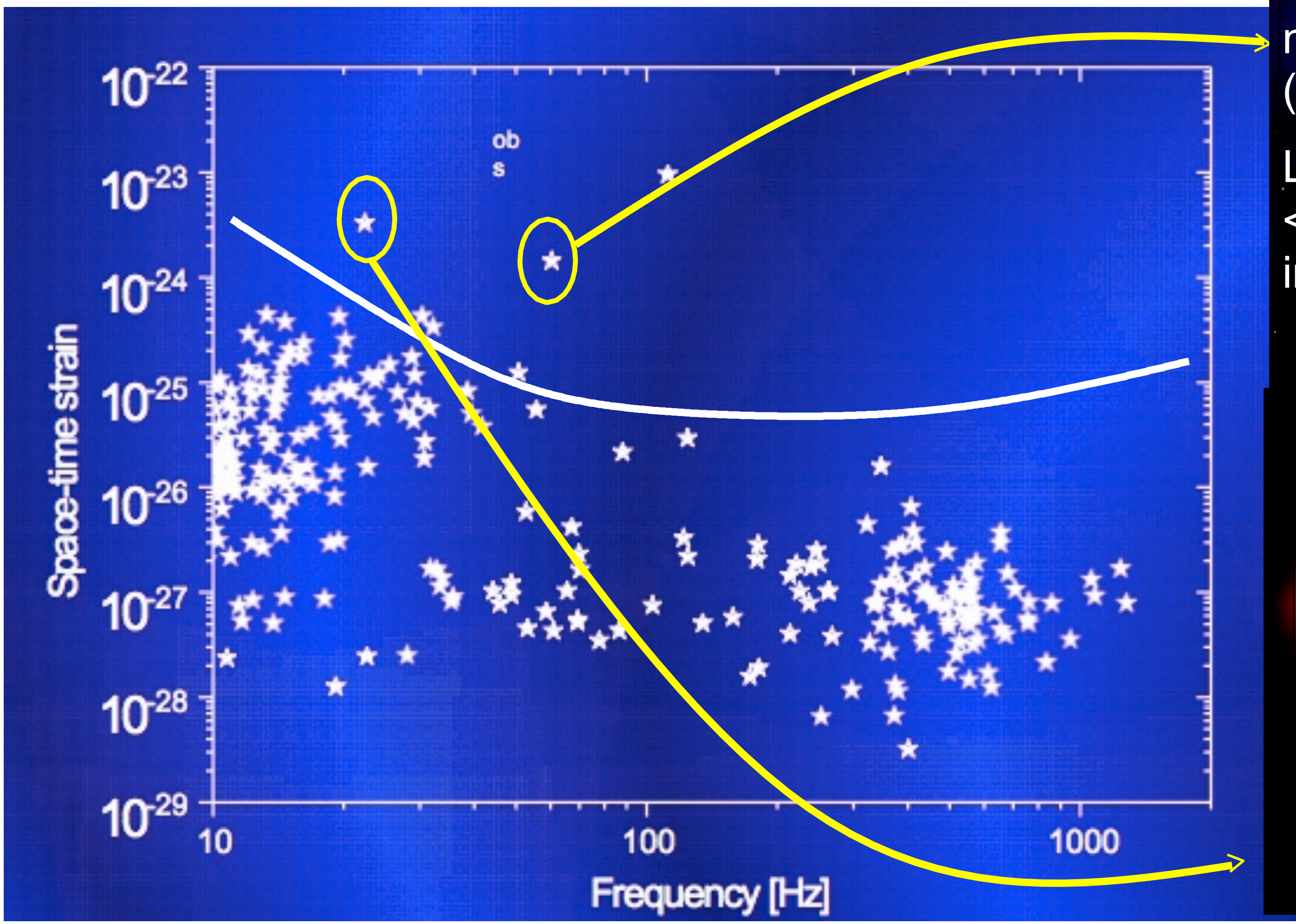


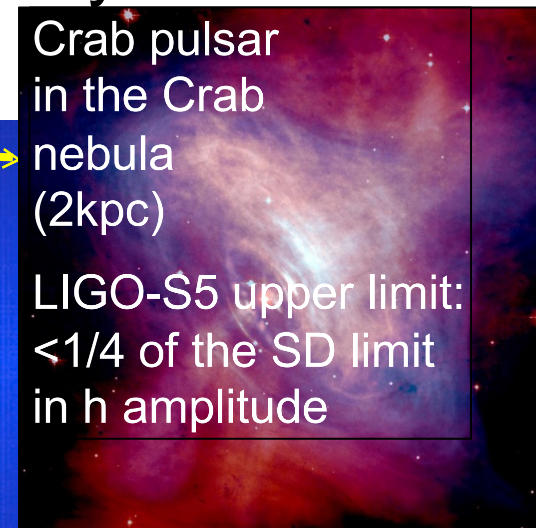
The core is a Fermi liquid of uniform neutron-rich matter ("Exotic phases"? Quark-Gluon plasma)

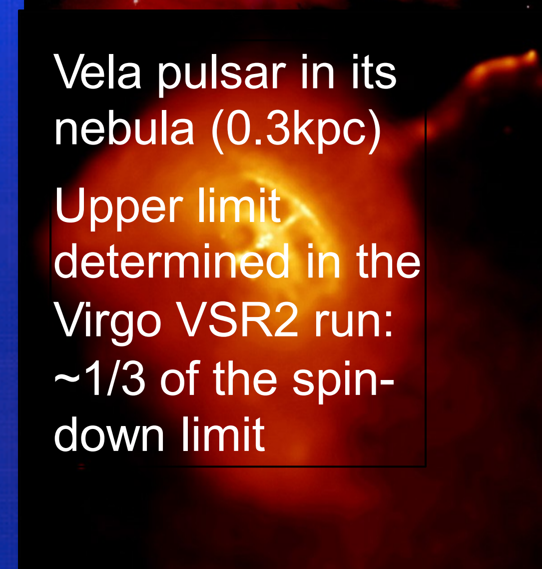
$\rho \sim 4 \times 10^{17}\ kg/m^3$

NS as GW source of continous GW signals

Isolated NS are a possible source of GW if they have a non-null quadrupolar moment (ellipticity)

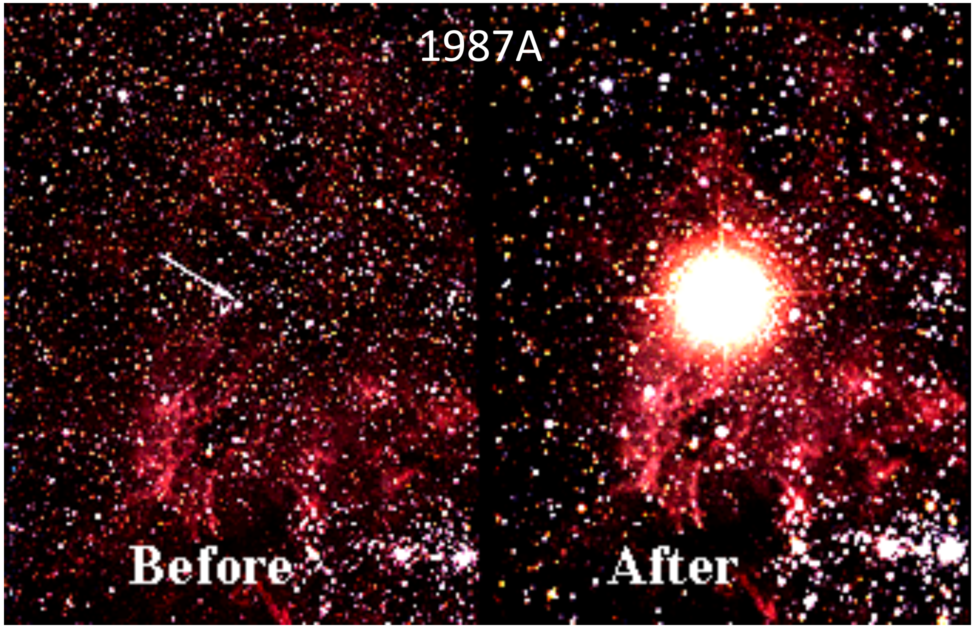






The supernova puzzle

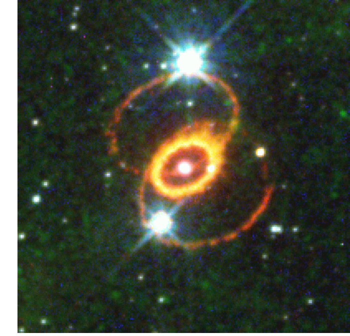
<u>Type II Supernovae unsolved problem:</u> how the neutrino burst transfers its energy to the rest of the star producing the shock wave which causes the star to explode?



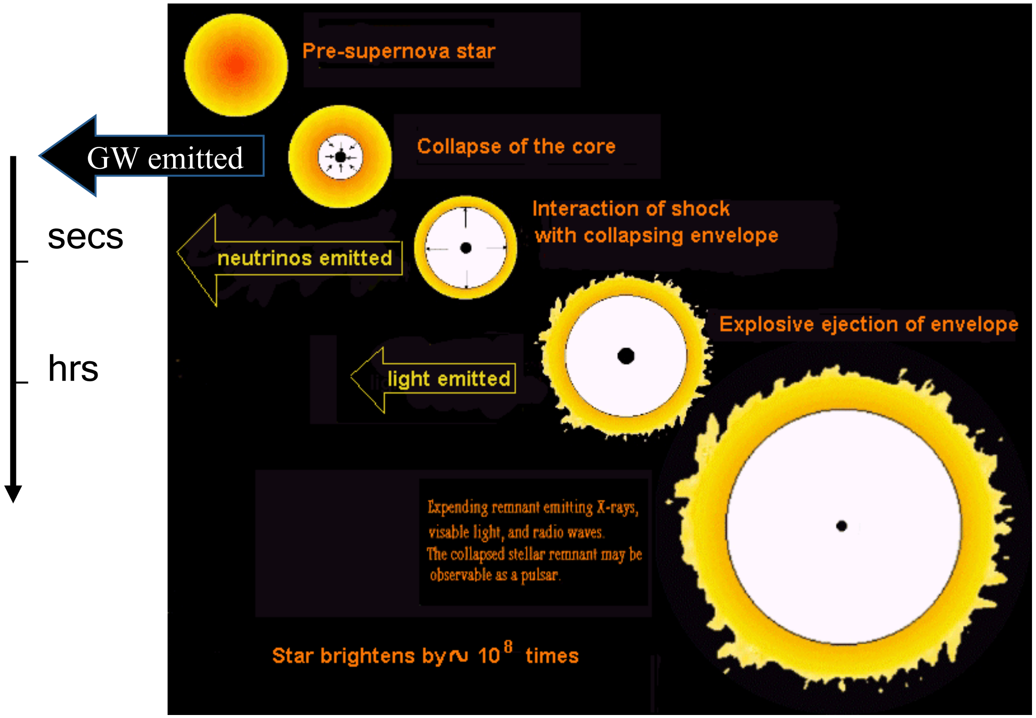
- For Type II supernovae, the collapse should be halted by short-range repulsive neutron-neutron interactions, mediated by the strong force, as well as by the degeneracy pressure of neutrons, at a density comparable to that of an atomic nucleus.
- <u>Through a process that is not clearly understood</u>, about 1%, of 10^{44} J of the energy released in the form of neutrinos is reabsorbed by the stalled shock, producing the supernova explosion. How does it occur this 1% energy transfer?
- Theoretical models has to include a hydrodynamical instability for re-energizing the stalled shock: ***<u>Standing Accretion Shock Instability (SASI)</u>*** are <u>consequence of non-spherical oscillating perturbations, exciting the protoneutron star formed with the collapse</u>

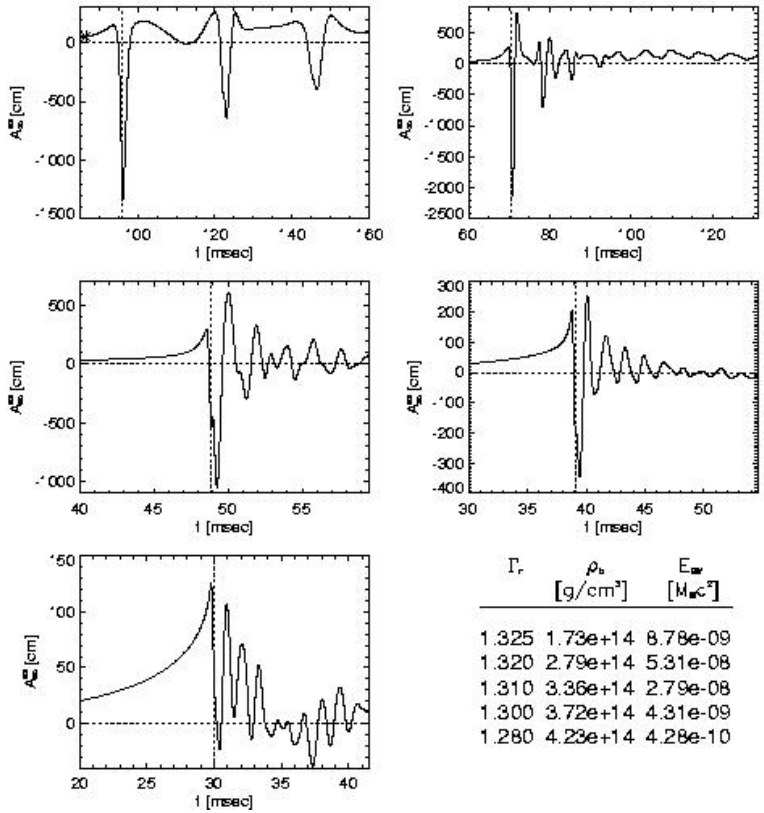
- *This implies that we should find characteristic features in the GW signals*

Hunting GWs: from Supernovae



- Collapse dynamics and waveform badly predictable (giant numerical effort)
- Estimated rate: several /yr in the VIRGO cluster, but the efficiency of GW emission is strongly model dependent
- Simulations suggest $E_{GW} \sim 10^{-6} - 10^{-9}\ M_{\odot}c^2$, but NS kick velocities suggest possible strong asymmetries



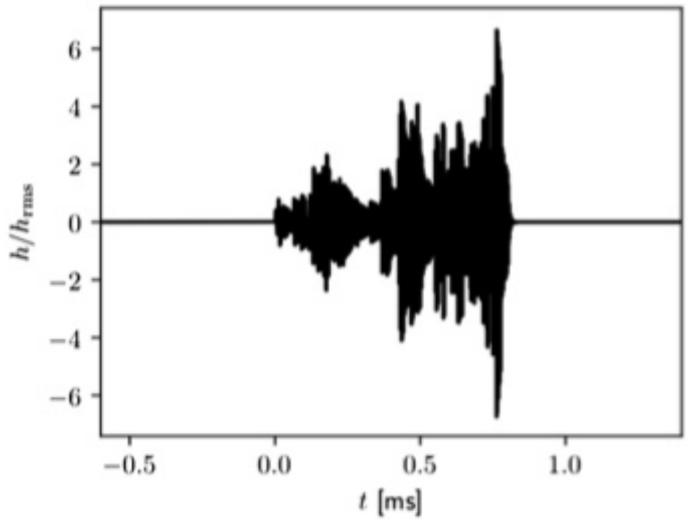


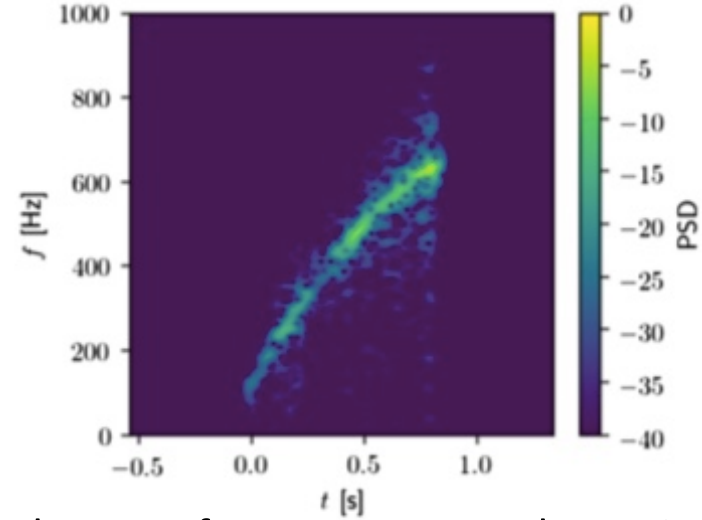
Γ_r	ρ_b [g/cm³]	E_{gw} [$M_\odot c^2$]
1.325	1.73e+14	8.78e-09
1.320	2.79e+14	5.31e-08
1.310	3.36e+14	2.79e-08
1.300	3.72e+14	4.31e-09
1.280	4.23e+14	4.28e-10

[Zwerger, Muller]

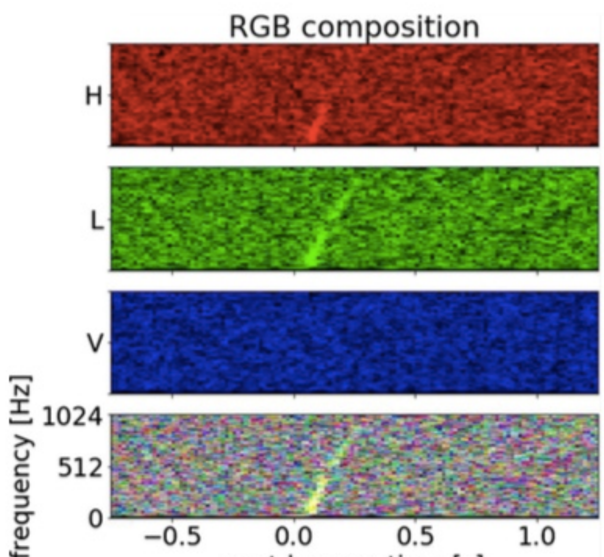
New methods to catch signal peculiarities

P. Astone, Cerdá-Durán, Di Palma, M. Drago, F. Muciaccia, C. Palomba and F. Ricci , Phys. Rev. D 98, 122002 (2018)





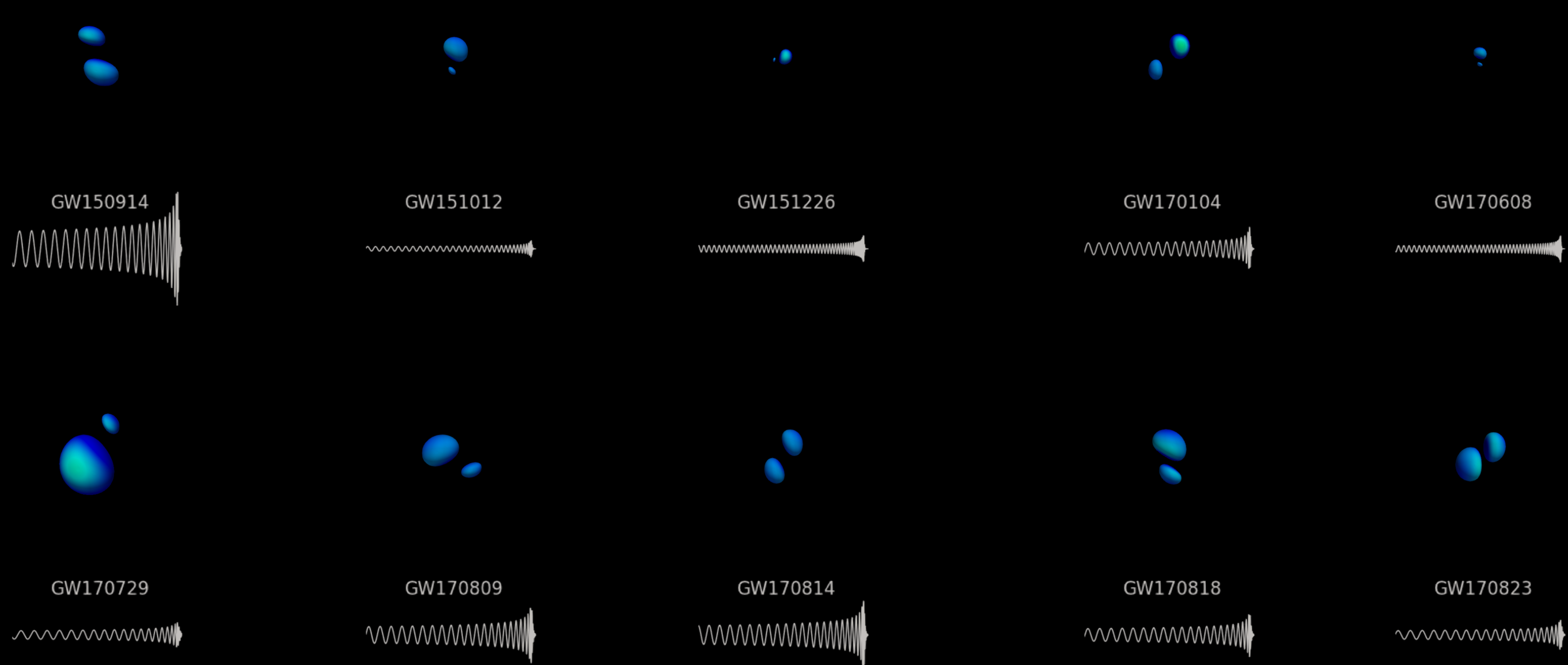
The driving idea is to identify a set of N features in the data chunks, which are the outcomes of the CCSNe 3D simulations.



The waveforms represent the typical features observed in numerical simulations of neutrino- driven CCSNe. Their origin is well understood (g-modes in the proto-neutron star).

These features are not expected to disappear in more detailed, numerical simulations, although the parameter space of possible values for the waveform may change in the future.

Black Holes Studies



BBH population study

The detected signals confirmed the existence of black holes with masses larger than 20 $M_\odot$

- ❖ How many black holes? Which size? How are they formed?
- ❖ How metallicity environment influence the formation ? (stellar wind depends on metallicity)

Two models for the binary black hole formation:

- ✓ Two object formed and exploded at the same time from two stars➔ similar spins with the same orientation
- ✓ Black holes in a stellar cluster sink to the center of the cluster and pair up ➔ spin randomly oriented

- ➢ Do it exist miniature black holes ?

  They may have formed immediately after the Big Bang. Rapidly expanding space may have squeezed some regions into tiny, dense black holes less massive than the sun.

BBH population study: from 2G to 3G

Under a simplified hypothesis of a uniform distribution of BBH creation on the universe history

With a 3G detector we expect

- 10^5 y^{-1} BBH
- SNR ~ 10^4 for rare events

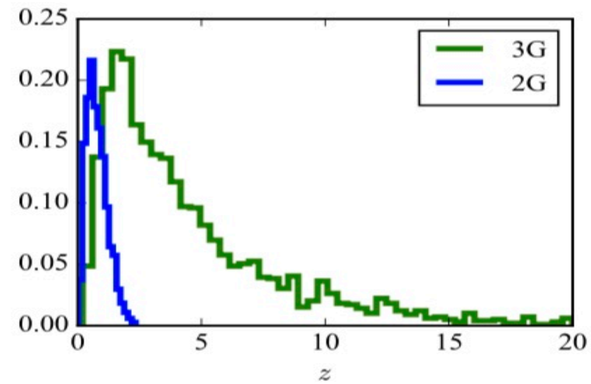


FIG. 2. The redshift distribution of detectable events with a 2-detector network of advanced detectors at design (2G) or CE-like (3G). Note that the two curves use different y scales to improve clarity.

- ➢ Population study biased in function of the achievable SNR

GW signal amplitude depends on $\mathcal{M}^{5/2}$

$\mathcal{M}$ = *chirp mass* = $(m_1 m_2)^{3/5} / (m_1 + m_2)^{1/5}$

Higher $\mathcal{M}$ ➔ easier detection

GW signal duration decreases ***with*** $M_{tot} = m_1 + m_2$

Too massive systems ➔GW signals at frequency out of the detector bandwidth

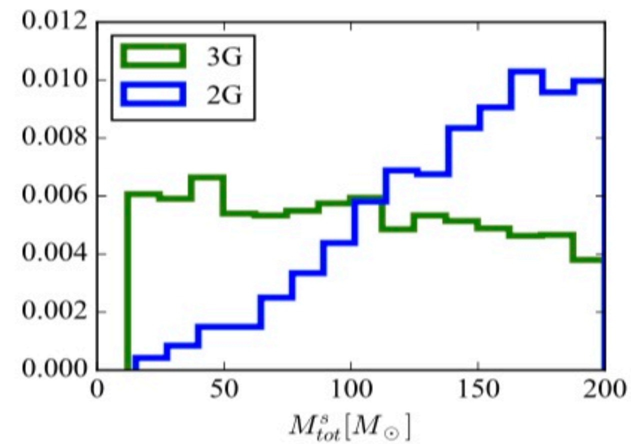
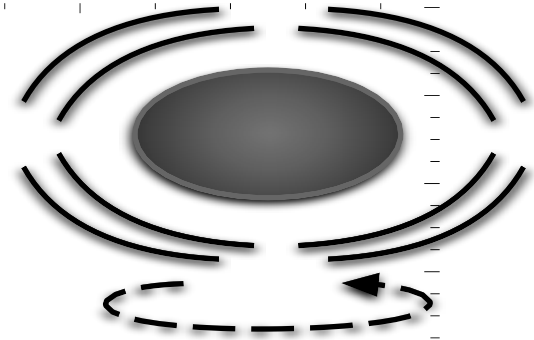


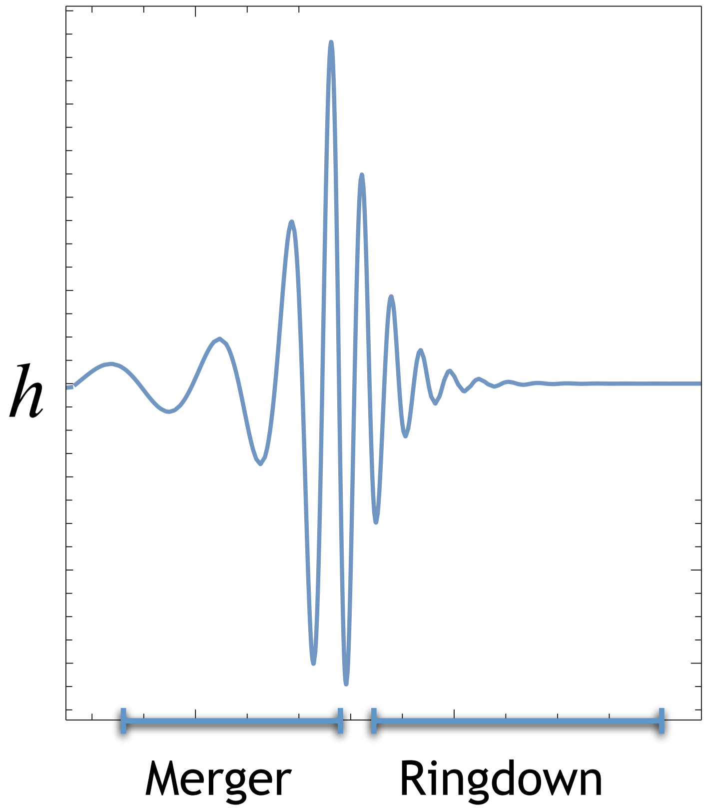
FIG. 3. The source-frame total mass distribution of detectable events with a 2 interferometers network of advanced detectors at design (2G) or CE-like (3G).

In addition the signals detected depend on the redshifted masses M (1+z)

Salvatore Vitale, Phys. Rev. D 94, 121501 (2016)

Ringdown of a Kerr Black hole





Scheel et al. PRD (2009)

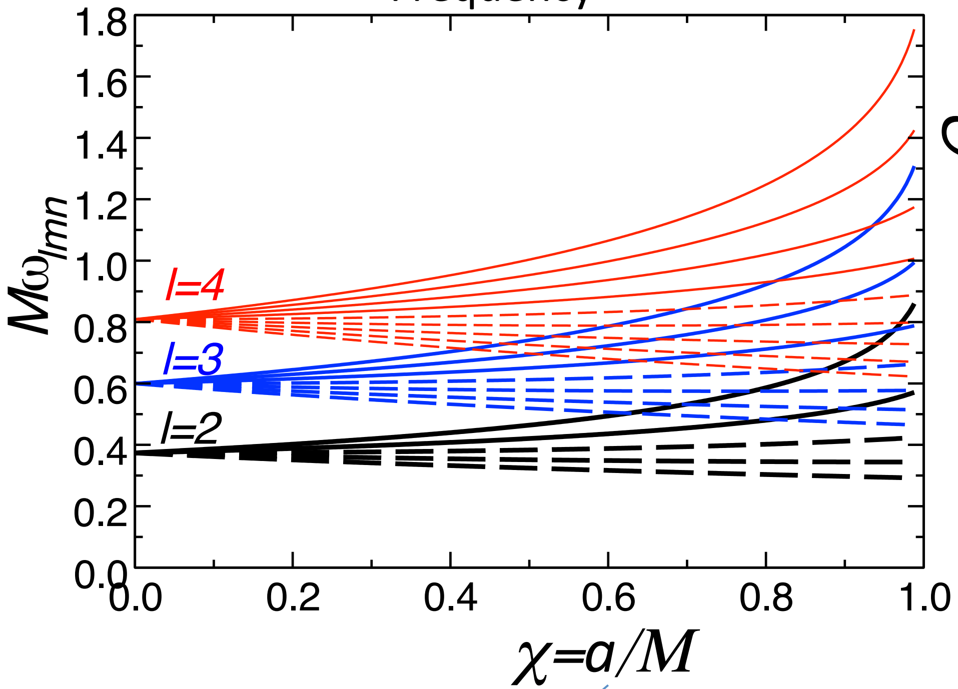
The spectrum of Quasi Normal Modes (QNM) is characterized only by the BH mass and angular momentum.

The detection of a few modes from the ringdown signal can allow for precision measurements of the BH mass and spin

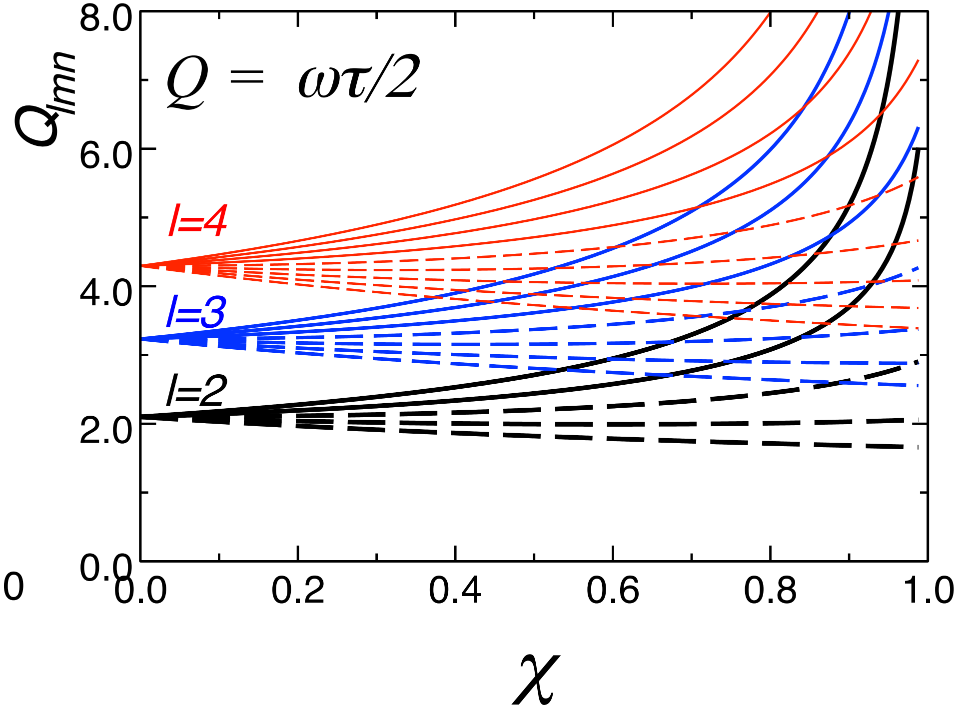
In addition the detection of higher multipole moments can be used to perform null- hypothesis tests of the no-hair theorems of general relativity

Black hole spectroscopy

Frequency



Quality Factor



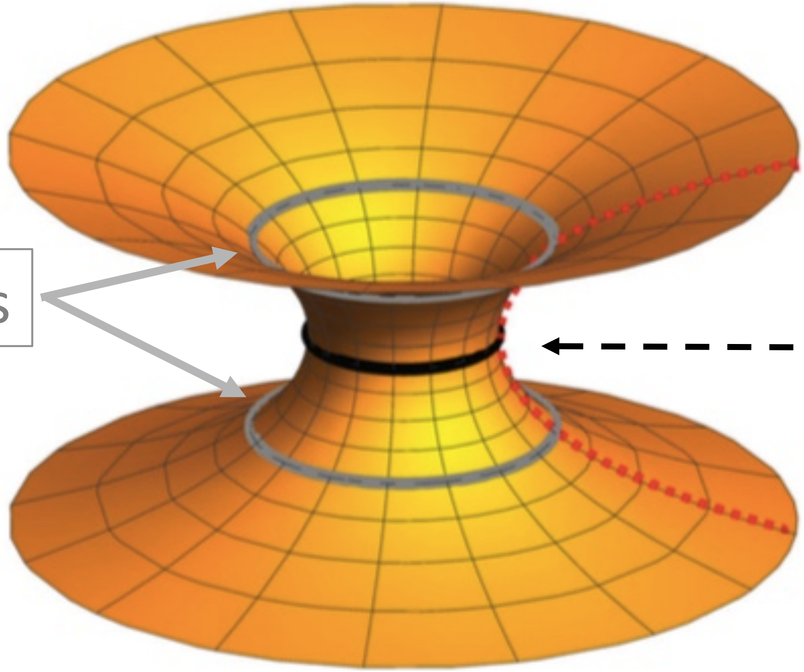
a =*J*/*M* ➔ Kerr rotation parameter

(ω,τ) ➔ (M, χ)

Berti,Cardoso, Starinets (2009)

QNM to Probe Wormhole Spacetime

Cardoso, Franzin, Pani PRL 116, 171101 (2016)

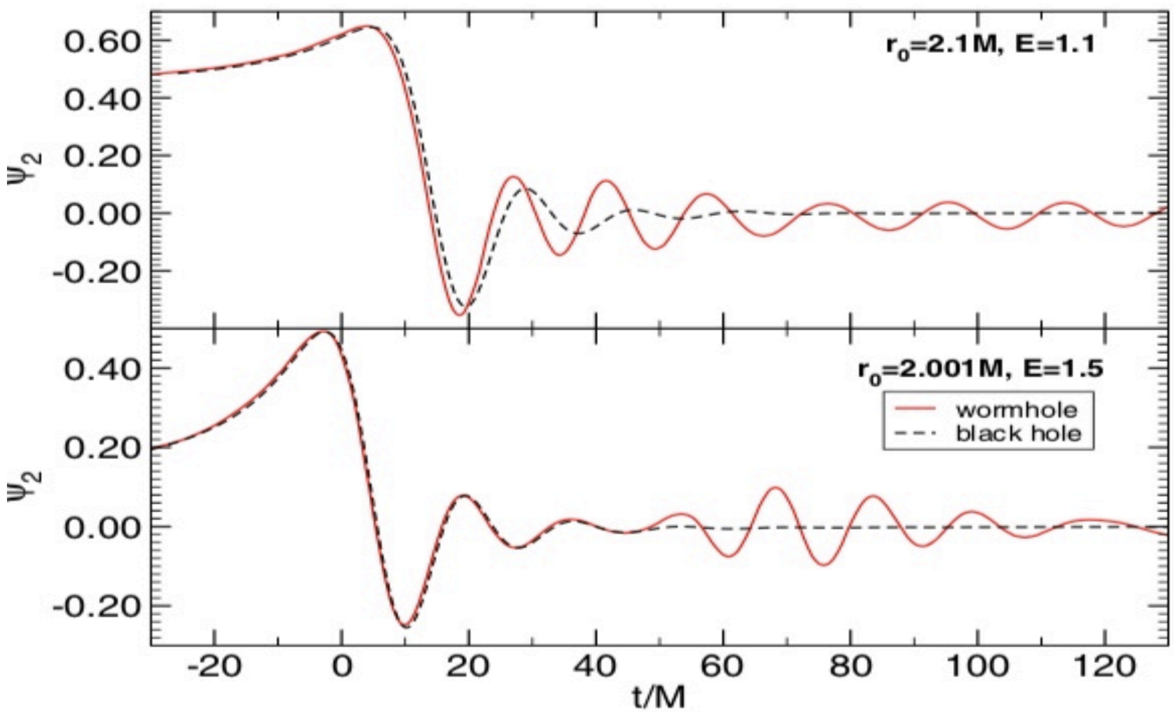


Assumption: Specific solution obtained by identifying two Schwarzschild metrics with the same mass M at the throat $r = r_0 > 2M$ ($G=c=1$)

A point particle plunges radially and emerges in another "universe". When the particle crosses each of the light rings curves, <u>it excites QNM characteristic modes</u> trapped between the light-ring potential wells

Comparison of the GW waveform between the BH and wormhole case

- Particle plunging into a Schwarzschild BH with the energy E compared to the particle crossing a traversable wormhole



GW waveforms comparison for different values of E.

The BH waveform was shifted in time to account for the dephasing due to the light travel time from the throat to the light ring

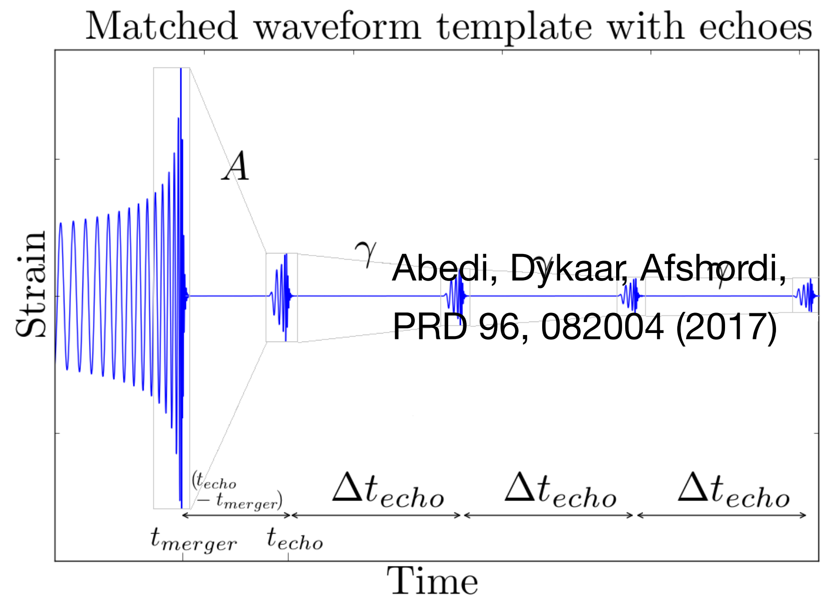
Echos Searches

- Exotic compact objects (ECOs): resemble BHs
- But are not perfectly absorbing
- Parametrize by reflecting barrier
- Initially ringdown normally
- Waves going into the horizon become "echoes"

Abedi, Dykaar, Afshordi 1701.03475

Conklin, Holdom, Ren 1712.06517

Abedi, Afshordi 1803.10454



Event	[19]	original 16s (32s)	widened priors 16s (32s)
GW150914	0.11	0.199 (0.238)	0.705 (0.365)
LVT151012	-	0.056 (0.063)	0.124
GW151226	-	0.414 (0.476)	0.837
(1,3)	-	0.159	0.801
(1,2,3)	0.011	0.020 (0.032)	0.18 (0.144)

Westerwick et al.1712.09966

Ashton et al. 1612.05625

Tsang et al. 1804.04877

Time delay between the echoes is related to the ECO compactness while the decay and shape of each pulse encodes the reflective properties of the ECO

Black Hole and Dark Matter

***Dark matter is made of black holes formed during the first second of our universe's existence*?**

During radiation era an initially large (at horizon entry) density perturbation can collapse to form **Primordial Black Holes** (PBH) with mass of order the horizon mass. After formation PBH evolve generating today a broad mass-spectrum of black holes with masses ranging from 0.01 to 10^5 $M_\odot$
[*PBHs evaporate (Hawking radiation) with a lifetime longer than the age of the of the Universe for M > 10^{12} kg.*]

To form an interesting number of PBHs, the primordial perturbations must be significantly larger on small scales than on cosmological scales.

BH mass depends on size of fluctuation

$$M = k\, M_H\, (\delta - \delta_c)^\gamma$$

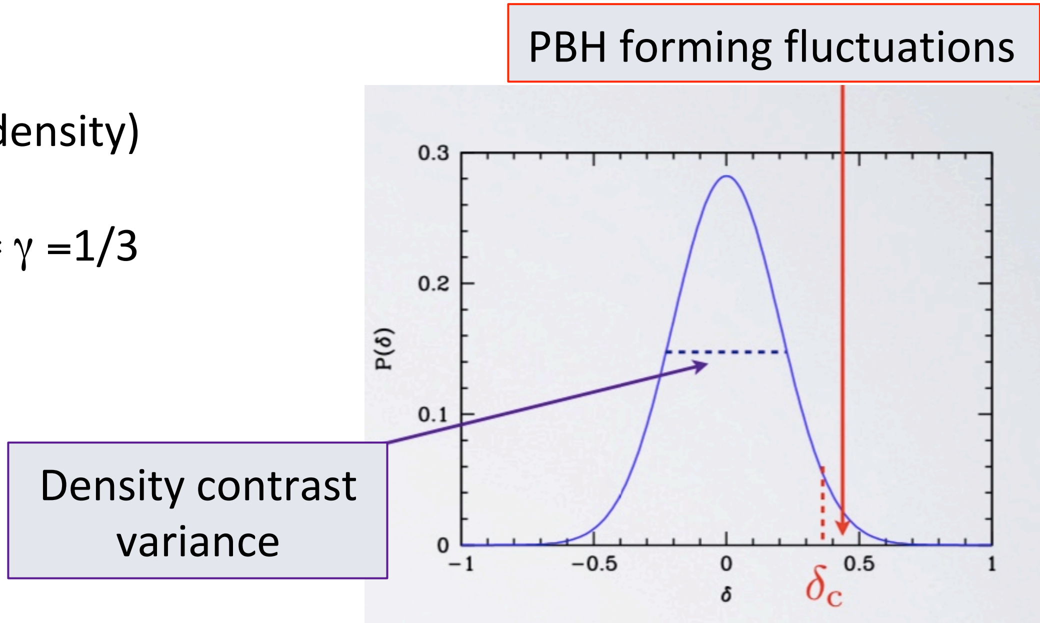
M_H ➔ mass within the horizon

Equation of state factor $\gamma = p/\rho$ (pressure/density)

$\delta = (\rho - \rho_m)/\rho_m$ ➔ ***density contrast***

δ_c critical contrast for the BH formation $\delta_c \approx \gamma = 1/3$

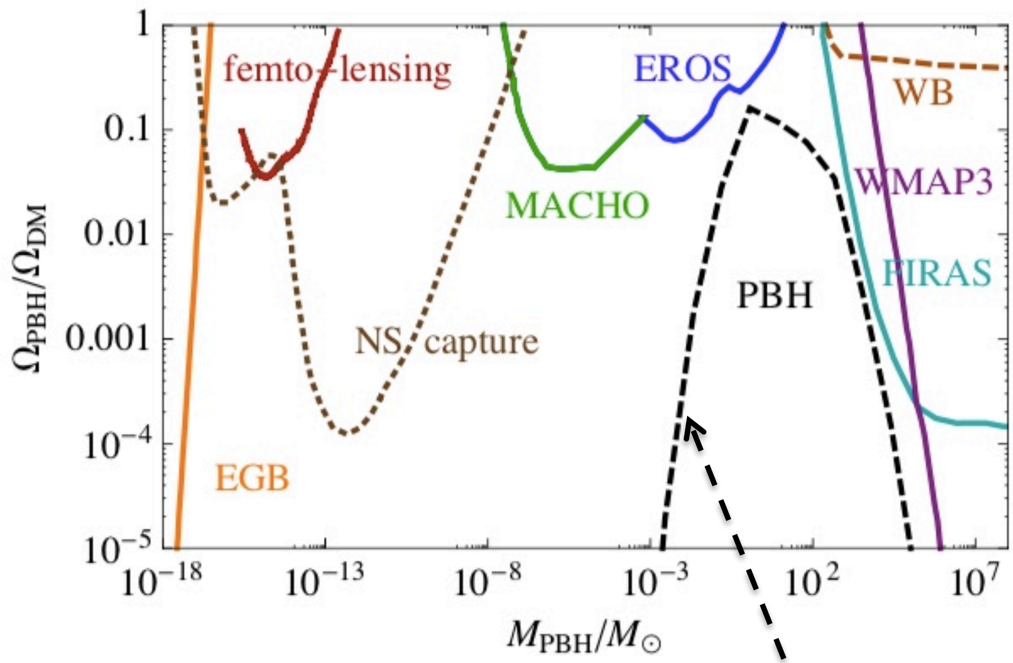
Various inflation models can produce large density perturbations on small scales



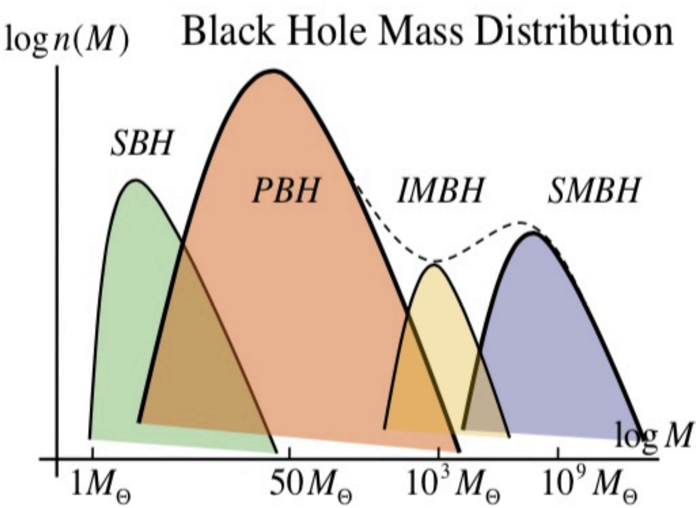
Limits on the abundance of PBH

Juan García-Bellido 2017 *J. Phys.: Conf. Ser.* **840** 012032

PBH could be directly detected by the gravitational waves emitted when they merge to form more massive black holes,

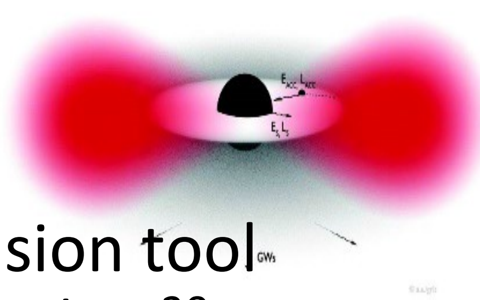


The black dashed line corresponds to a particular scenario of PBH formation



Continuous merging of PBH since recombination could have generated a stochastic background of gravitational waves that could be detected by LISA and PTA

BH and particle physics



- With a stellar mass BH we have a new precision tool that may diagnose the presence of new light (10^{-20} 10^{-10} eV) and weakly interacting bosonic particles

- When such a particle's Compton wavelength is comparable to the horizon size of a rotating BH,

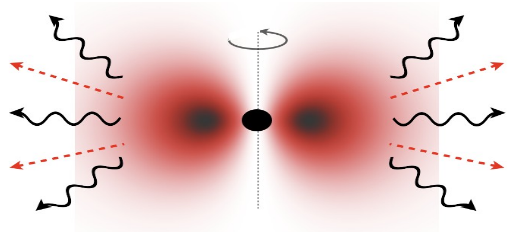
$$\lambda_C \geq R_s$$

the super radiance effect spins down the BH, populating bound orbits around the BH with an exponentially large number of particles

- The BH already detected by LIGO/Virgo can act as attractors of QCD axions

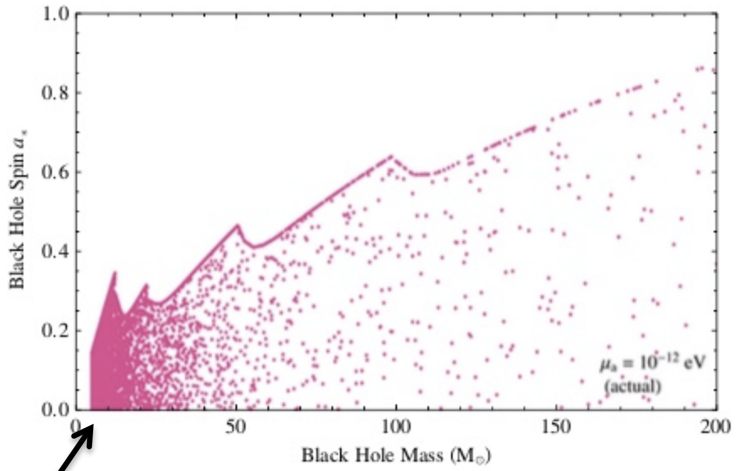
ET as particle detector

Masha Baryakhtar, Robert Lasenby, and Mae Teo   Phys.Rev. D96 035019 (2017)



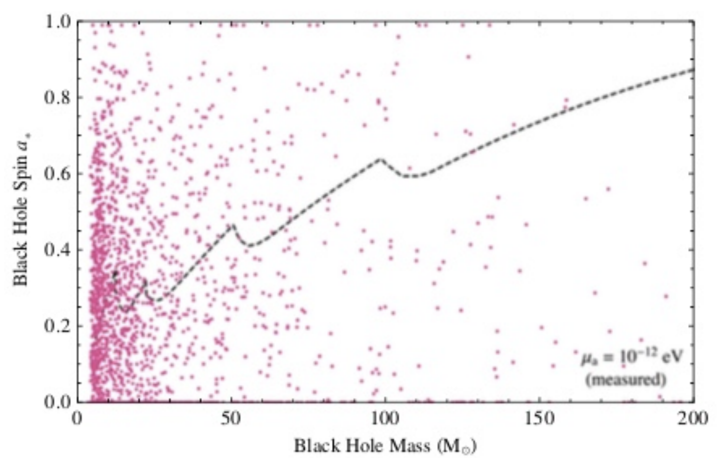
The bosonic field trapped around the BH can produce emission of a quasi-monochromatic GW by extracting energy from the angular momentum of the BH. The emitted wave can be either detected directly or as stochastic background, but the main interesting approach is in the statistical analyses of masses and spins of merging BHs

$m_a = 10^{-10} - 10^{-14}$ eV $\lambda_C = 10 - 10^5$ km



Arvanitaki et al., Phys. Rev. D 95, 043001 (2017)

Expected distribution of spins and masses of merging BHs in the presence of a gravitationally coupled vector of mass 10^{-12} eV



Simulation showing how it would be observed by Advanced LIGO/Virgo

Cosmology

To measure the cosmology one needs luminosity distance *and* redshift of the source

$$D_L(z) = \begin{cases} \frac{(1+z)}{\sqrt{\Omega_k}} \sinh[\sqrt{\Omega_k} \int_0^z \frac{dz'}{H(z')}] & \text{for} \quad \Omega_k > 0 \\ (1+z) \int_0^z \frac{dz'}{H(z')} & \text{for} \quad \Omega_k = 0 \\ \frac{(1+z)}{\sqrt{|\Omega_k|}} \sin[\sqrt{|\Omega_k|} \int_0^z \frac{dz'}{H(z')}] & \text{for} \quad \Omega_k < 0 \end{cases}$$

$$H(z) = H_0 \sqrt{\Omega_m (1+z)^3 + \Omega_k (1+z)^2 + \Omega_\Lambda E(z, w(z))}$$

$$E(z, w(z)) = (1+z)^{3(1+w_0+w_1)} e^{-3w_1 z/(1+z)}$$

Usually, GWs provide the distance

How do we get the redshift?

How to get the redshift information

- If the CBC produces an EM counterpart (e.g. GRB) (Sathyaprakash+ CQG 27 215006, Nissanke+ 1307.2638)
- If one knows the neutron star (NS) equation of state (Read & Messenger PRL 108 091101; Del Pozzo+ 1506.06590)
  GW phase encodes the equation of state of neutron stars and it depends on the source-frame masses. If the EOS is known through other means (EM) one can measure both source-frame and redshifted masses, hence get the redshift
- If the post-merger signal is observed (Messenger+ PRX 4, 041004)
  Compare the measured redshifted frequency of the post merger phase with expected frequency gives redshift.
- If the shape of NS mass distribution is known (Taylor+ PRD 85 023535; Taylor & Gair PRD 86, 023502)
- Even if no EM is found, but there is a reliable galaxy catalog (Schutz, Nature 1986, Del Pozzo PRD 86 043011)

Conclusion – I

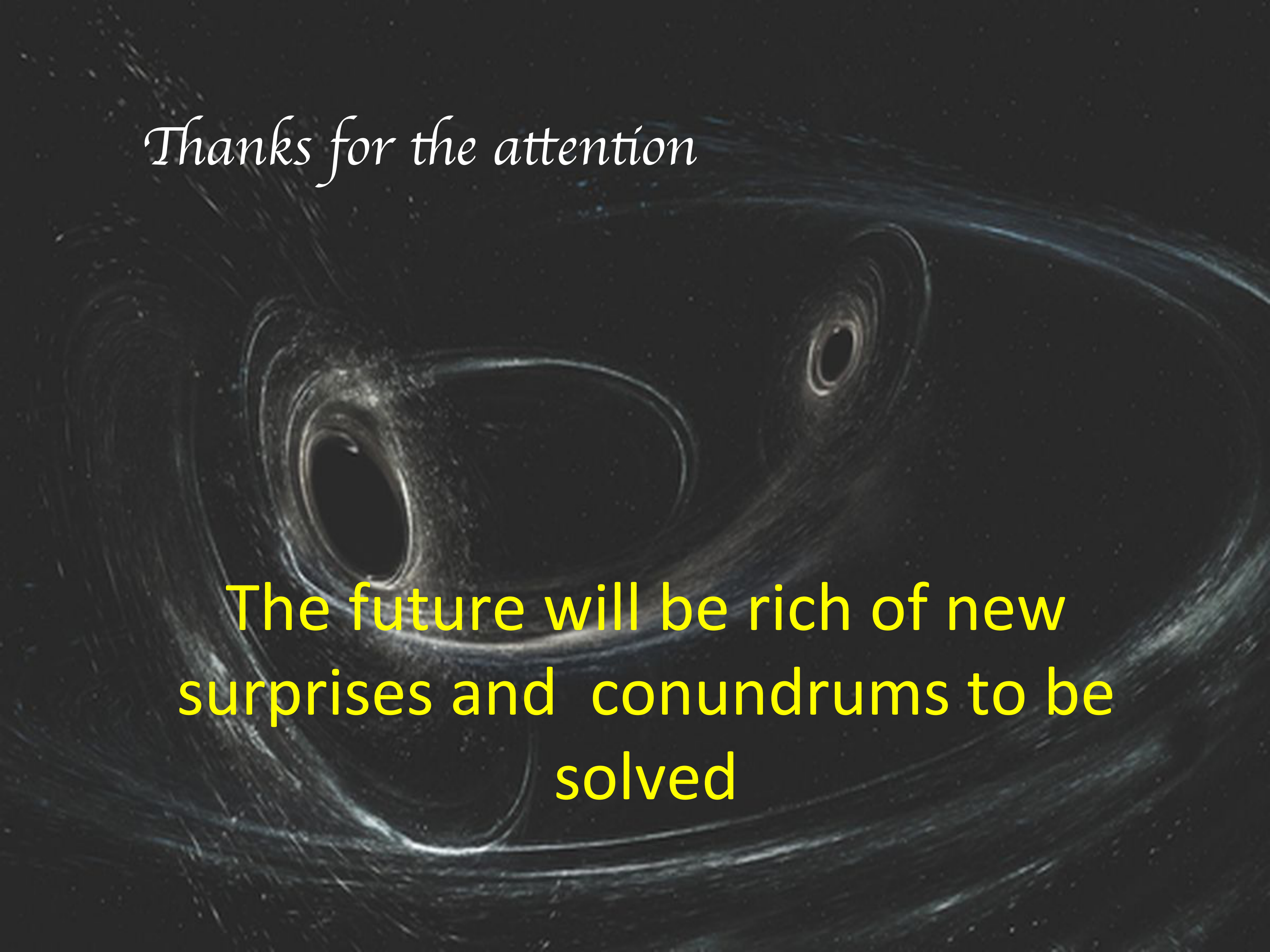
A robust R&D program for ET must start

The R&D program, focused on some crucial technologies, will pave the way for the realization of the next generation of instruments:

– the improvement of the seismic attenuation system, to increase the low frequency sensitivity and permit the suspension of heavier mirrors
– the design, construction and test of a cryogenic payload
– the development of innovative frequency dependent squeezing techniques, to reduce quantum noise;
– the improvement of the (optical and mechanical) losses of the mirrors' coatings, to reduce thermal noise

Conclusion - II

- While the 2G detectors are in action again detecting new signals, we are paving the way for the construction of the new 3 G detectors
- My wish is to see the first new 3 G detector, as the Einstein Telescope, installed in Sardinia with perspectives to write new chapters on physics and cosmology textbooks



Thanks for the attention

The future will be rich of new surprises and conundrums to be solved