Future Large Facilities for the study of Gravitational Waves

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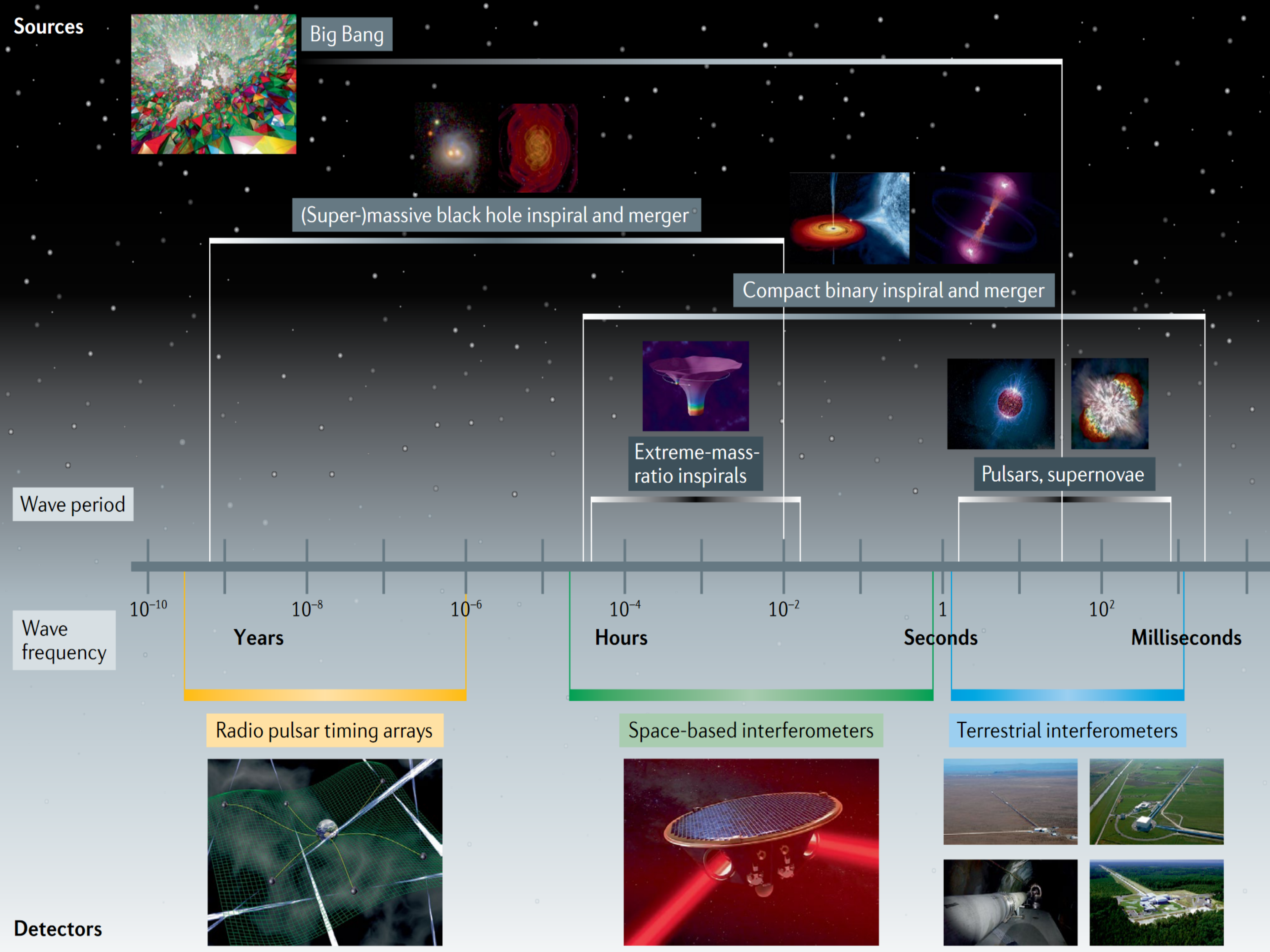
Outline

- Fast Review of the present*
- Beyond LVK O5
- The 3G worldwide scenario
- The Einstein Telescope
  - Conceptual design
  - Physics potential
  - Time Scales and costs
  - R&D for its realization
  - Organization
- ET as an ESFRI new reality
- The Spanish involvement
- Final notes

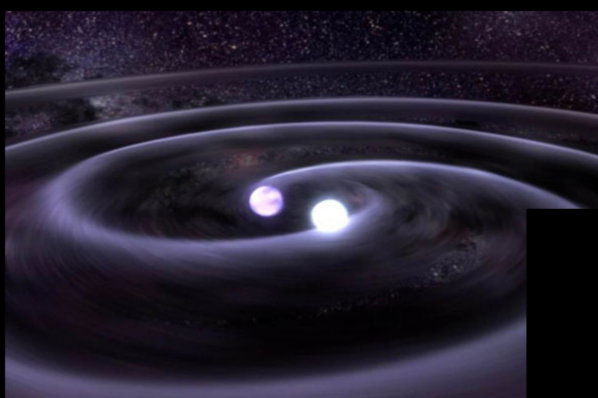
Mostly focused on ground-based GW experiments

***For a comprehensive review of all the LIGO/Virgo results see the very nice talks by Jo van den Brand**

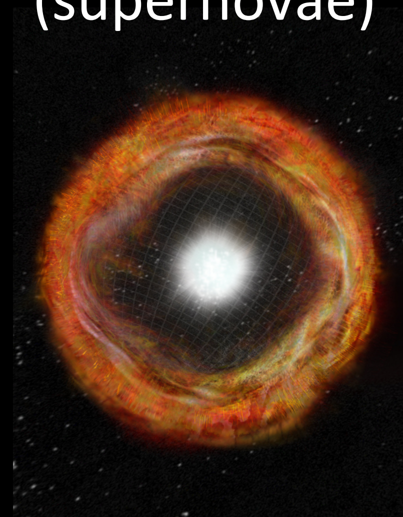

Sources
Big Bang
(Super-)massive black hole inspiral and merger
Compact binary inspiral and merger
Extreme-mass-ratio inspirals
Pulsars, supernovae
Wave period
Wave frequency
10^−10
10^−8
10^−6
10^−4
10^−2
1
10^2
Years
Hours
Seconds
Milliseconds
Radio pulsar timing arrays
Space-based interferometers
Terrestrial interferometers
Detectors

Sources of GWs

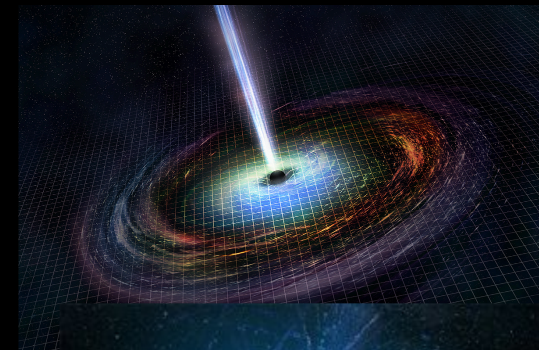
Binary systems
(Black holes, Neutron Stars)

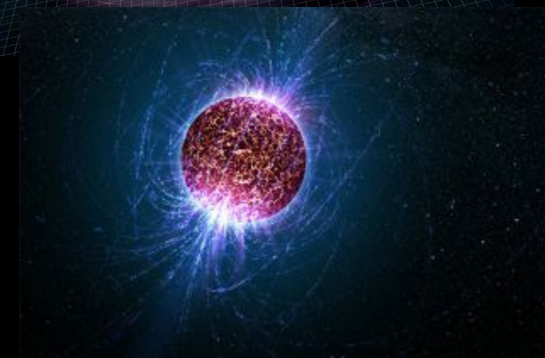


Stellar collapse
(supernovae)

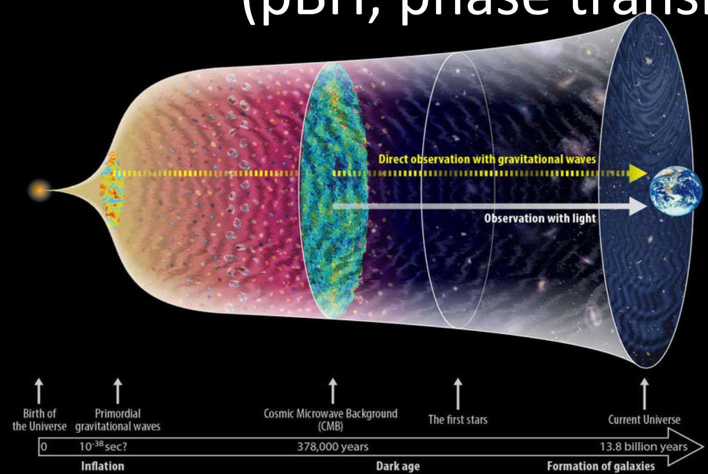


Pulsars

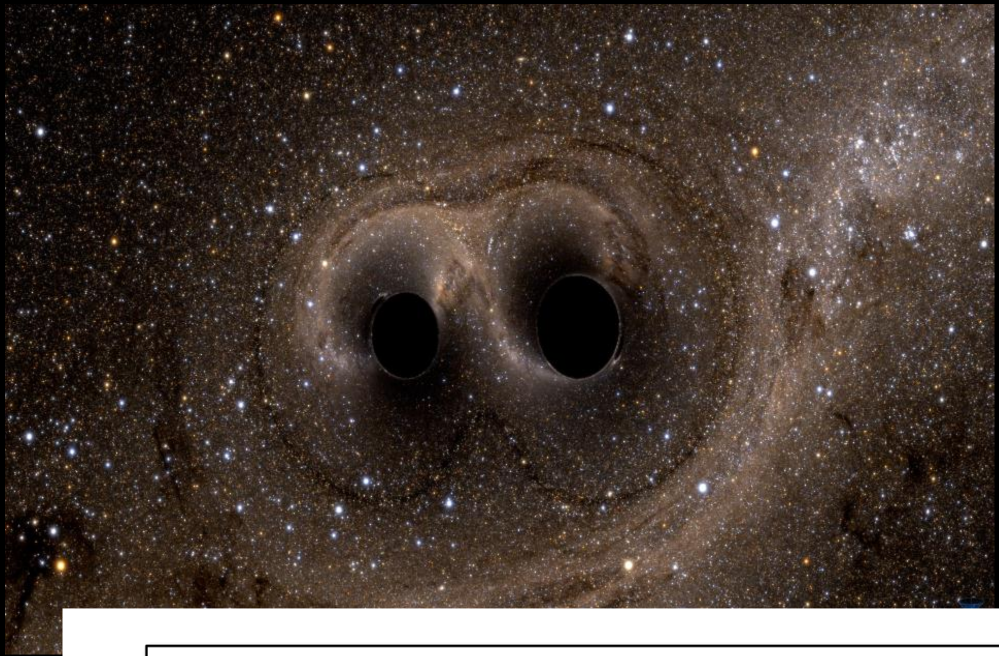




Stochastic Signals
(pBH, phase transitions, astrophysics)



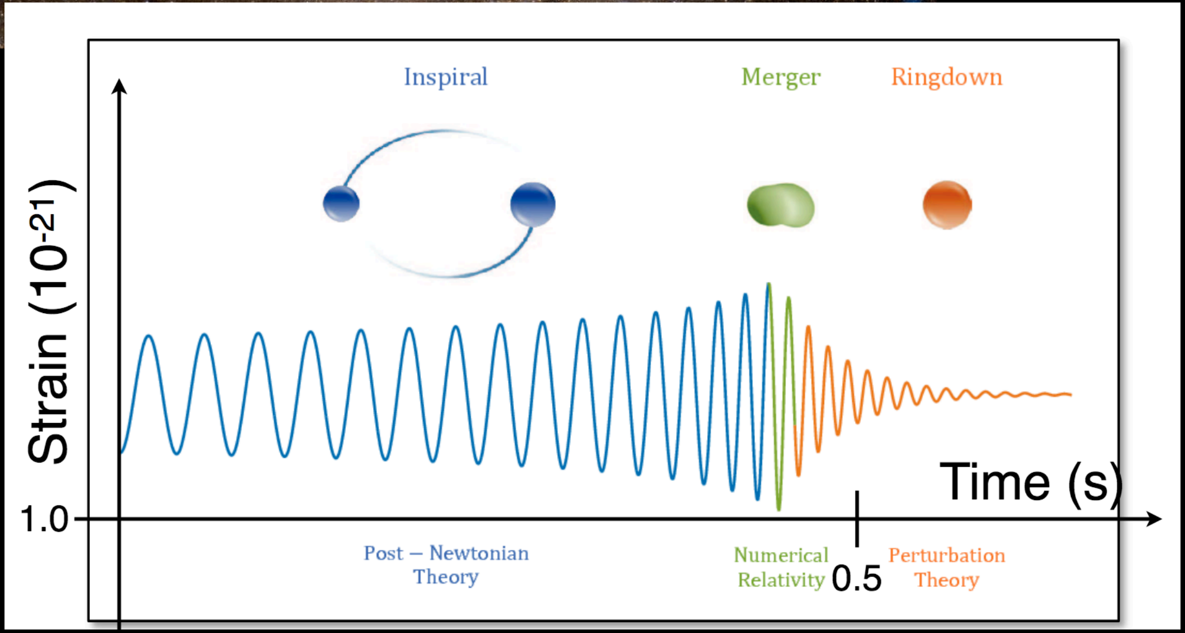
Black hole Binary



$m_1 = m_2 = 30\ M_\odot$
Distance = 100 km
frequency = 100 Hz
$r = 3\ 10^{24}$ m (500 Mpc)

$1\ \text{Mpc} = 31 \times 10^{18}$ km

0.000000000000000000001



$h \sim 10^{-21}$

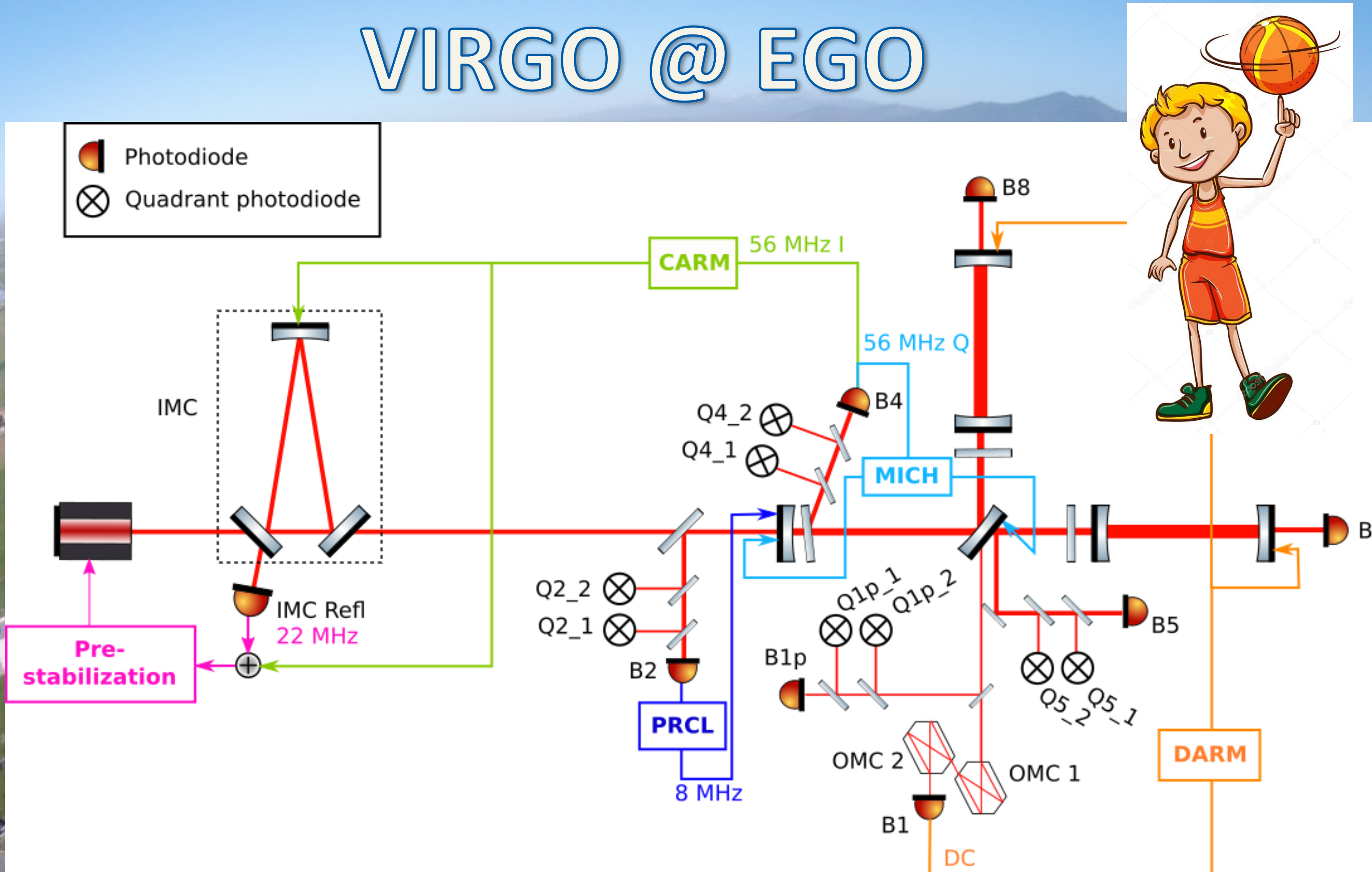
Interferometers

The interferometers act as a network

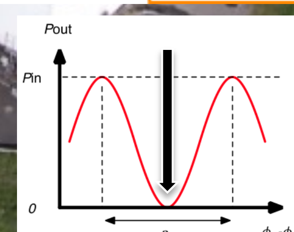
- Allows for a precise positioning in the sky
- Veto against fakes and employs correlations to search for stochastic signals


VIRGO @ EGO
UHV to avoid pressure fluctuations
Filter 0
Suspension wire
Standard filters
Filter 7
IP legs
Complex attenuators
With a power of 1/10^{14}
Almost perfect mirrors
99.9995 % reflection)
Complex network of sensors to
monitor the environment
Powerful lasers

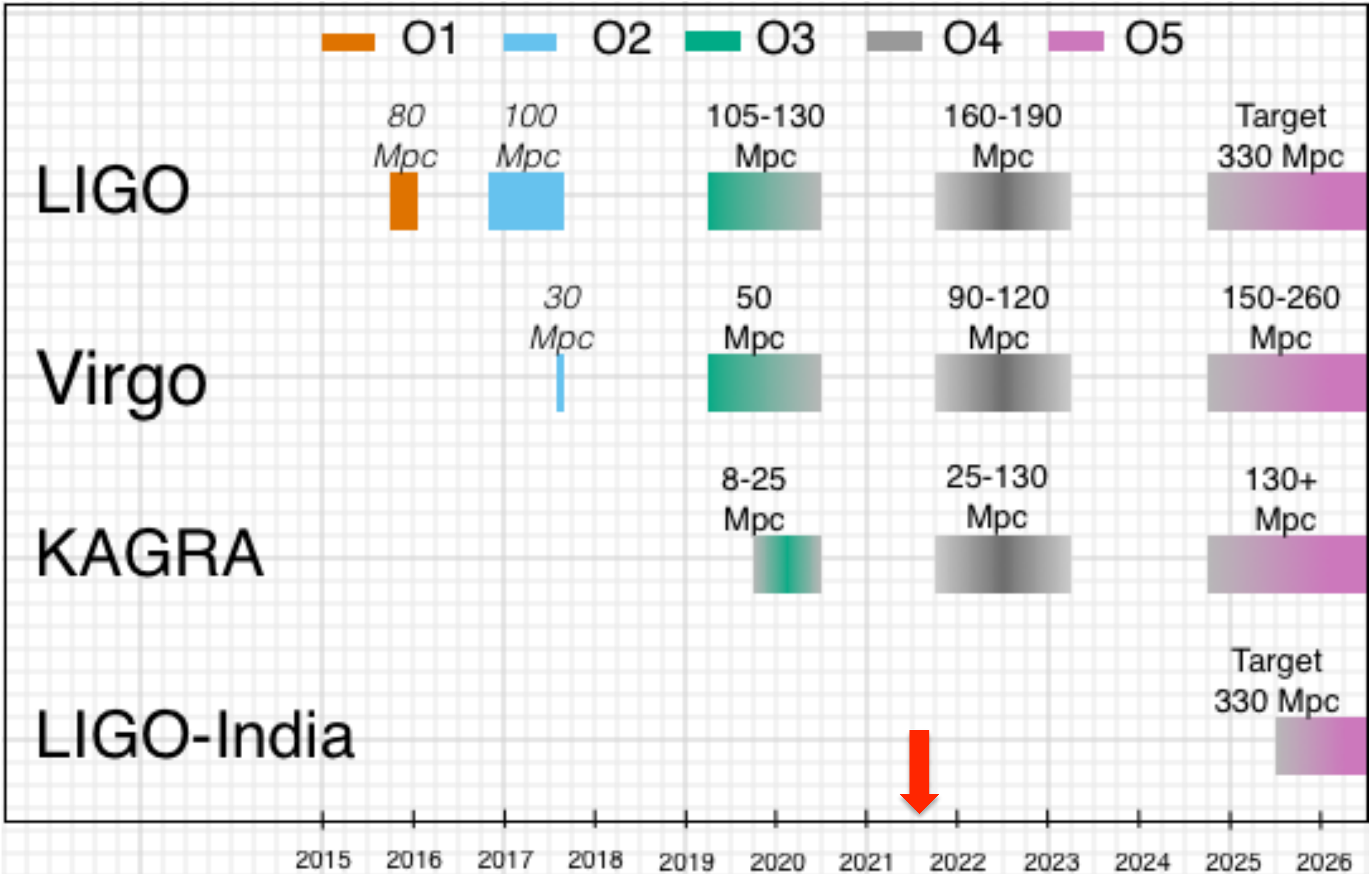
VIRGO @ EGO



Interferometers are huge dynamic feedback systems to maintain the “dark fringe” (maintains the system in destructive interference with null output In the absence of GWs



LIGO/Virgo/KAGRA (approved) Schedule



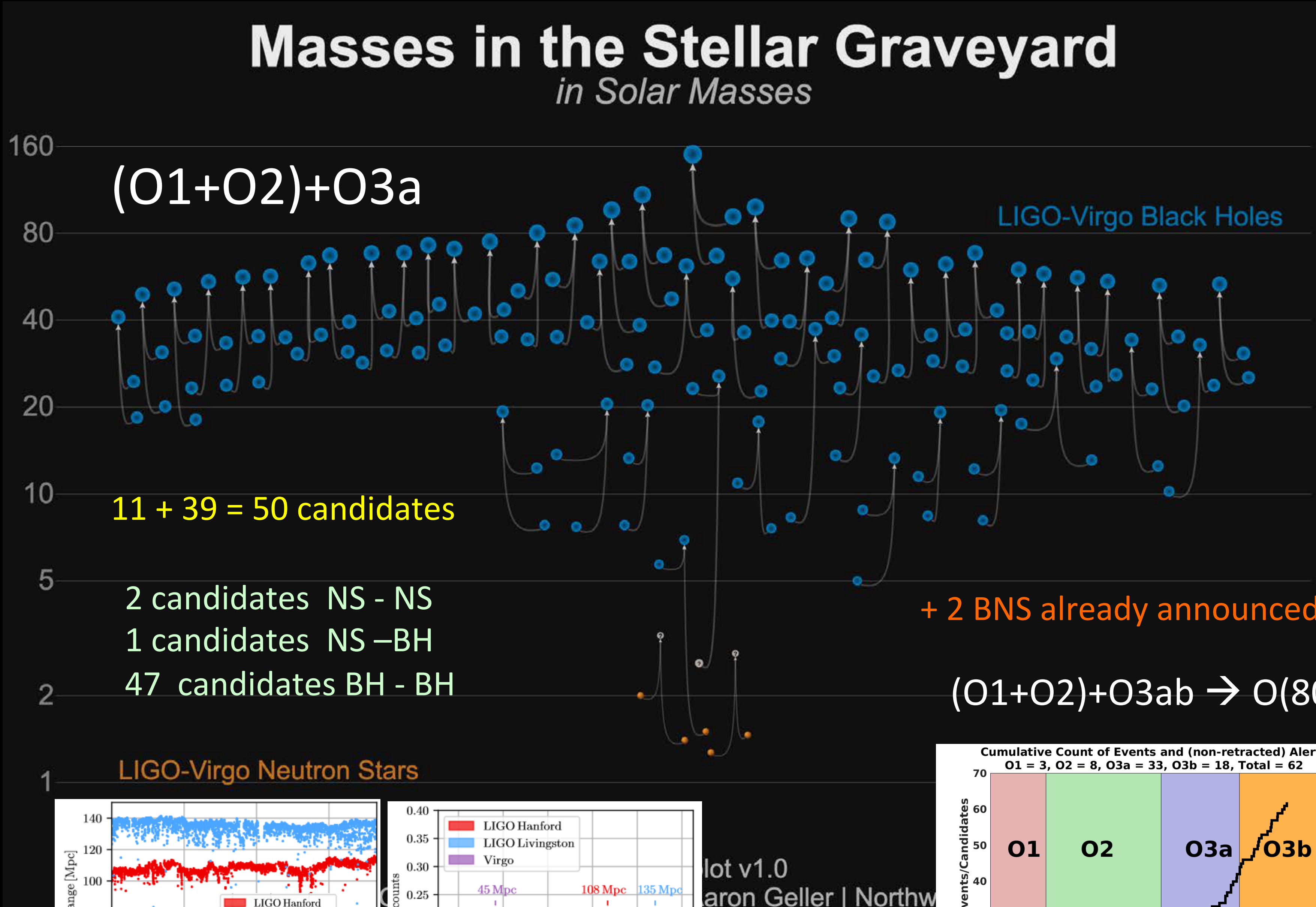
(O1+O2)+O3a

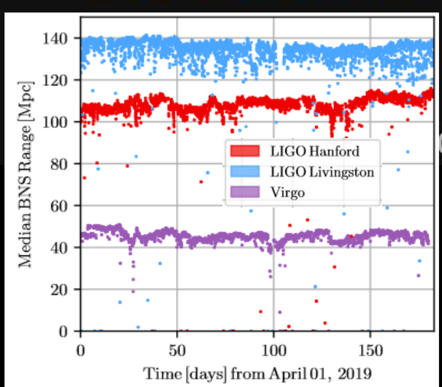
11 + 39 = 50 candidates

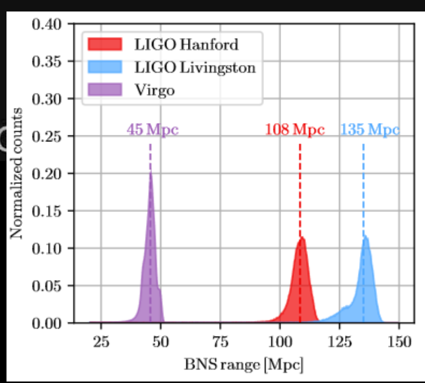
2 candidates NS - NS
1 candidates NS –BH
47 candidates BH - BH

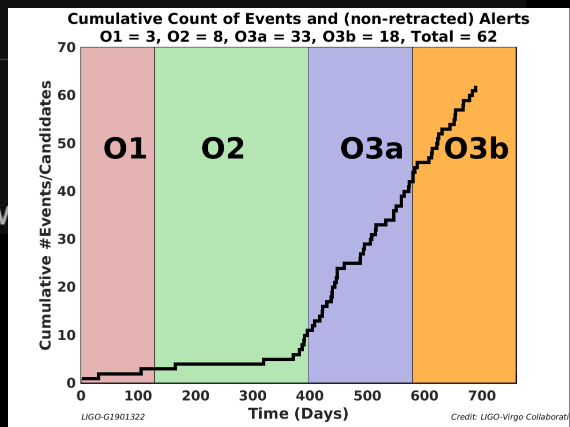
+ 2 BNS already announced

(O1+O2)+O3ab → O(80)



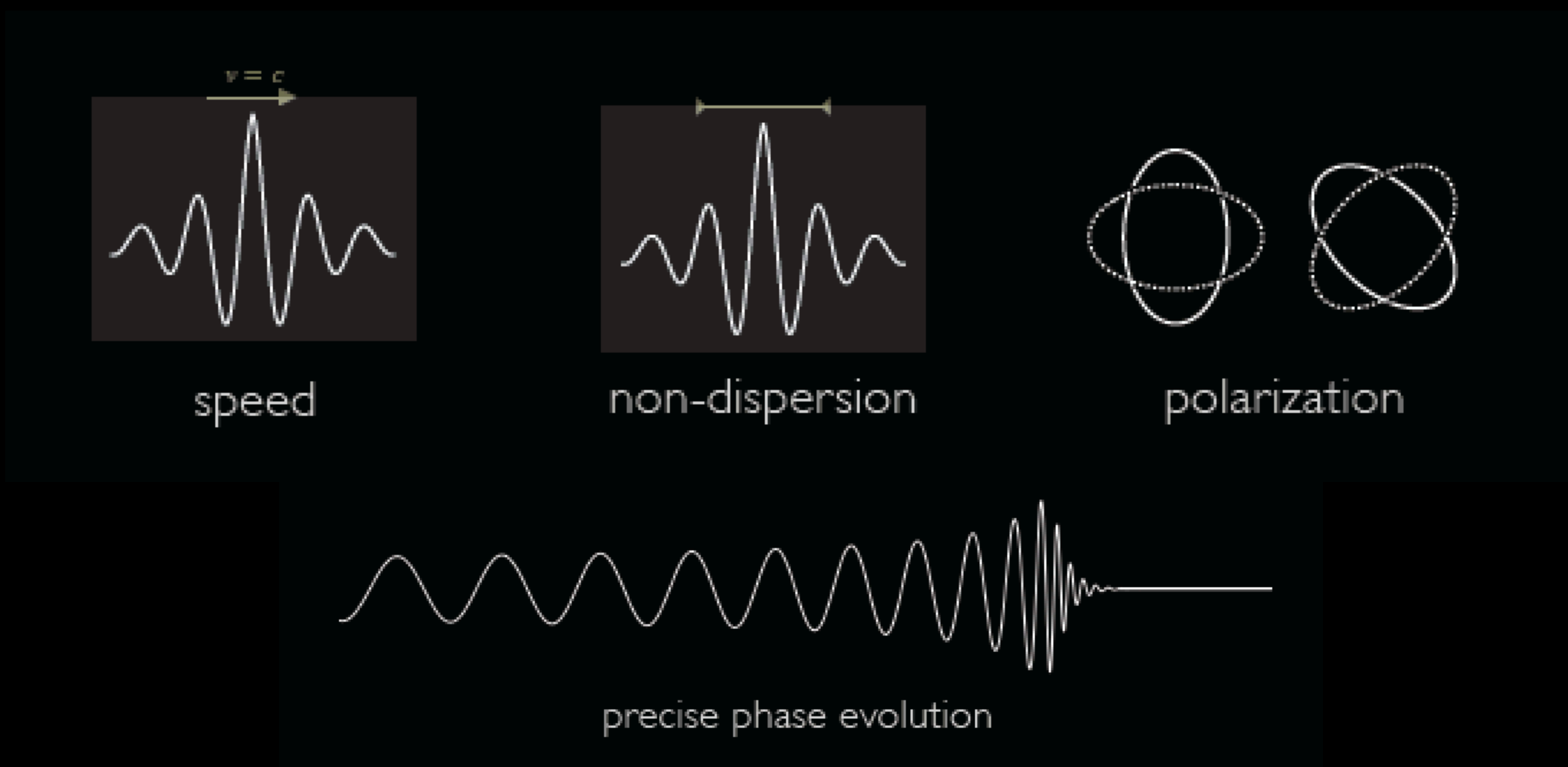




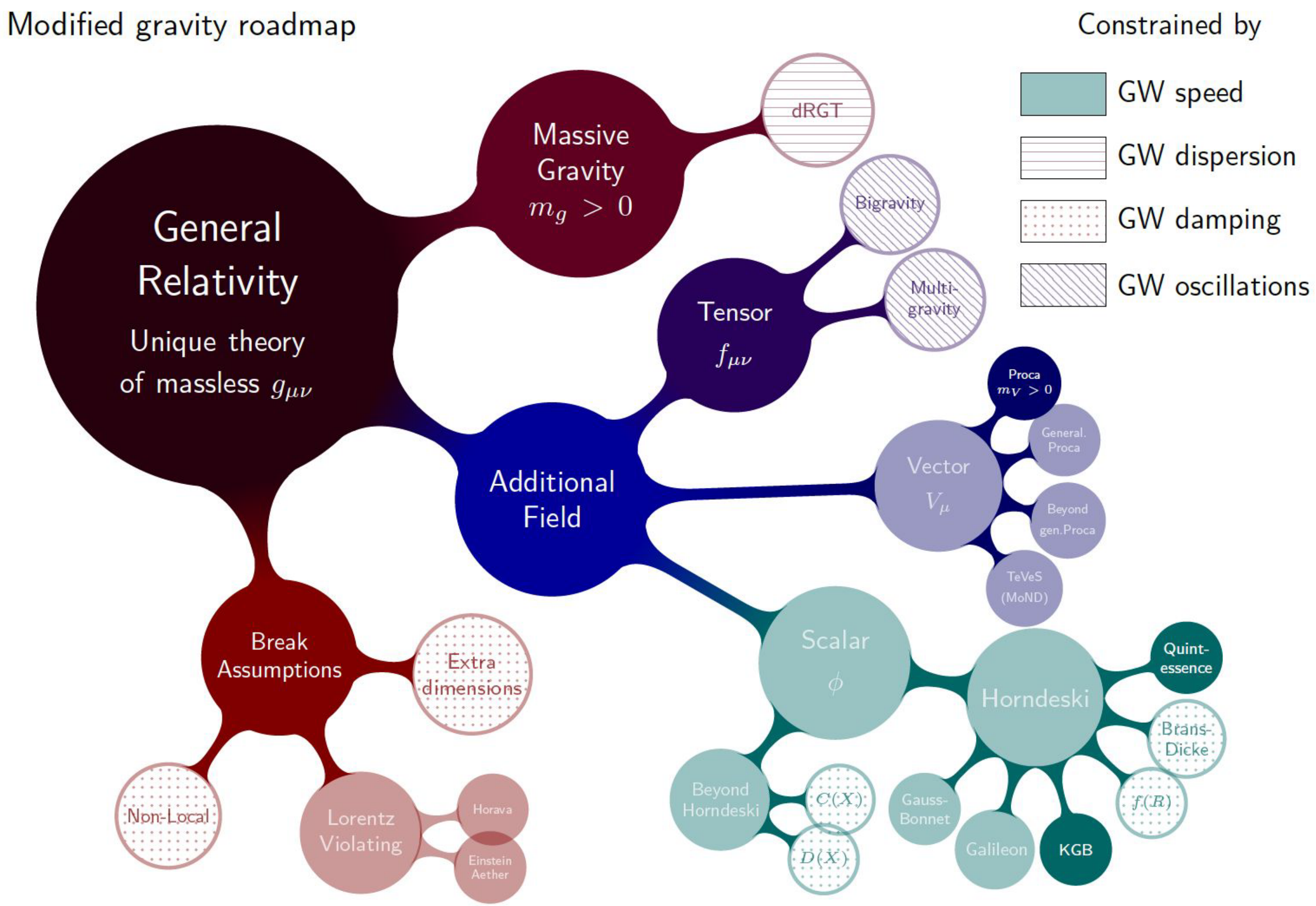


Test of General relativity

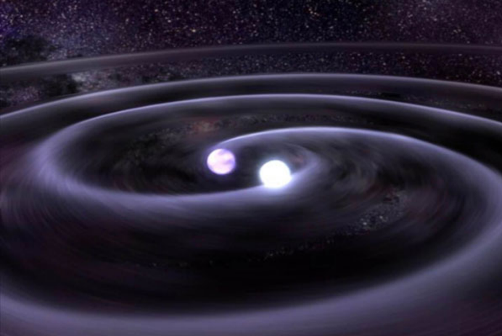
GR provides very precise predictions on wave velocity, non-dispersion, polarizations (+,x) and waveform (phase evolution)

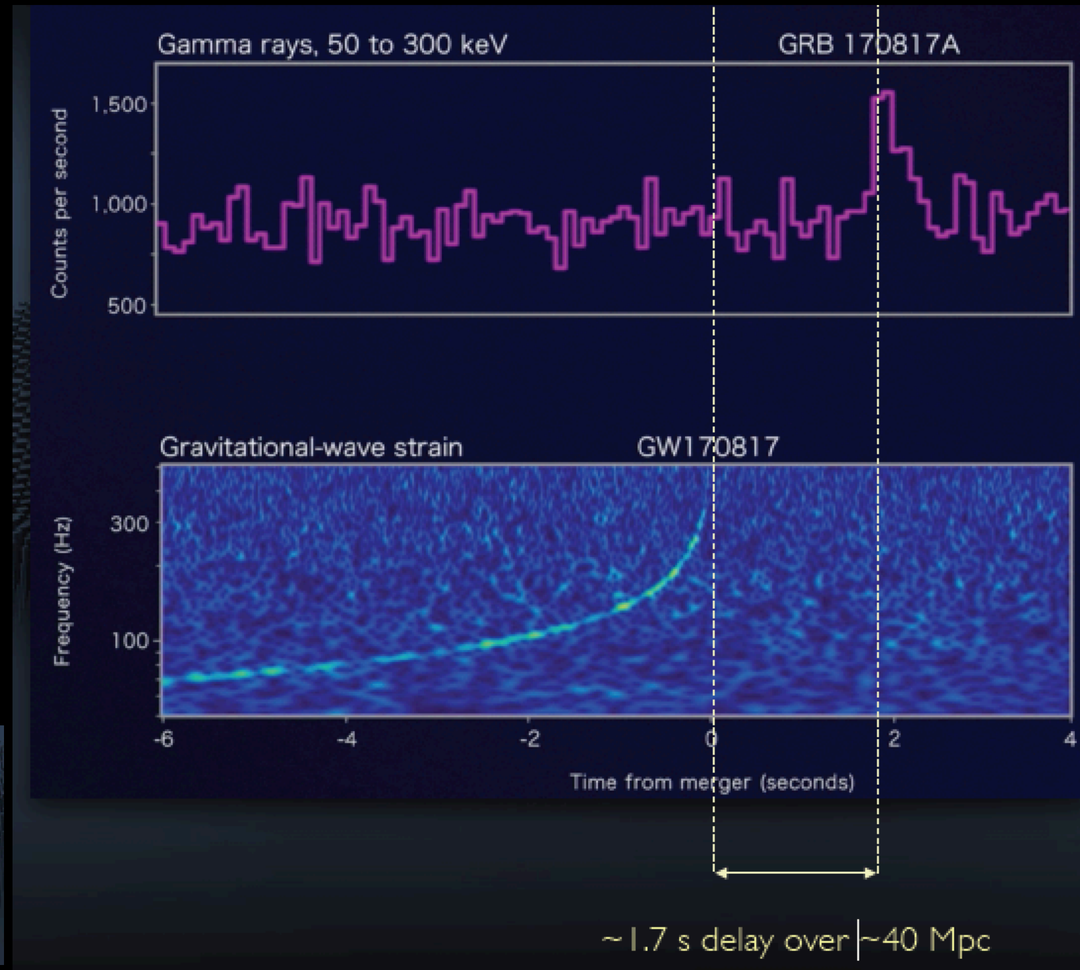


Tests of General Relativity



Speed of Gravity





Time of arrival of GW and EM

GW170817

$$-3 \times 10^{-15} \leq c_{gw}/c - 1 \leq 7 \times 10^{-16}$$

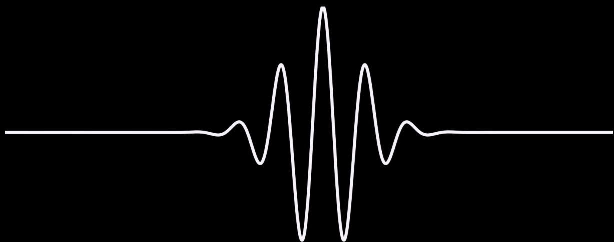
Abbott+2017 [arxiv:1710.05834]

Introduces severe constrains to models with modified GR at cosmological scales

Baker+2017 [arxiv:1710.06394], Creminelli+2017 [arxiv:710.05877], Ezquiaga+2017 [arxiv:1710.05901], Sakstein+2017 [arxiv:1710.05893

Dispersion

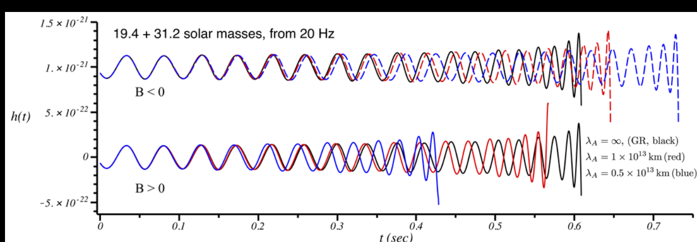
$$m_g = \sqrt{A_0}/c^2$$

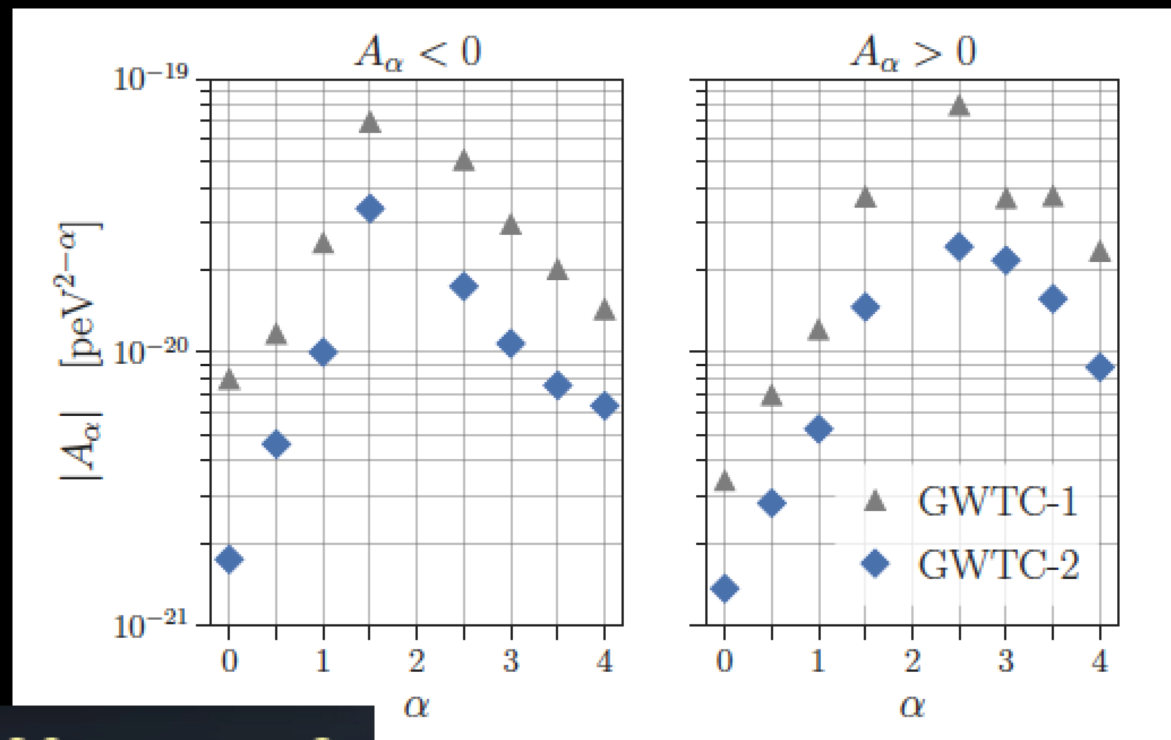


$$E^2 = p^2c^2 + m^2c^4$$

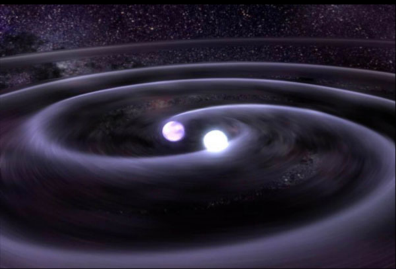
$$E^2 = p^2c^2 + A_\alpha p^\alpha c^\alpha$$

Propagation velocity will depend on the frequency





$$m_g \leq 1.76 \times 10^{-23}\ \mathrm{eV}/c^2$$



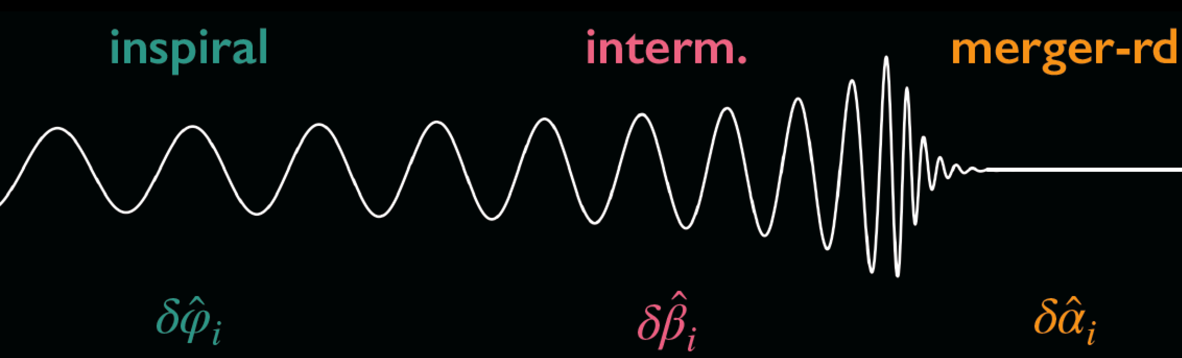
Waveform

Express inspiral phase as a series expansion in the orbital velocity v (f ~ v³/M)

GW tails

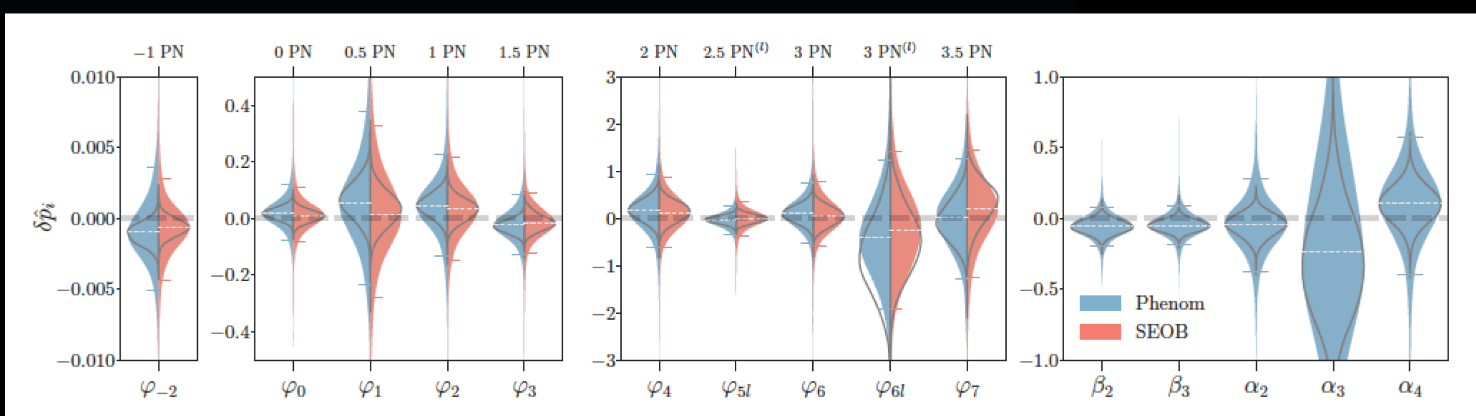
$$\Phi(v) = \left(\frac{v}{c}\right)^{-5}\left[\varphi_0 + \varphi_1\left(\frac{v}{c}\right) + \varphi_2\left(\frac{v}{c}\right)^2 + \ldots + \varphi_{5l}\ln\left(\frac{v}{c}\right)\left(\frac{v}{c}\right)^5 + \ldots + \varphi_7\left(\frac{v}{c}\right)^7\right]$$

0PN + 0.5PN + 1PN + ... + 2.5PN(l) + ... + 3.5PN

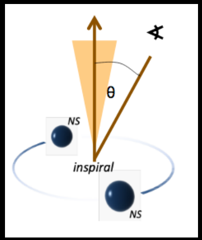


$$p_i \rightarrow \left(1 + \delta\hat{p}_i\right) p_i$$

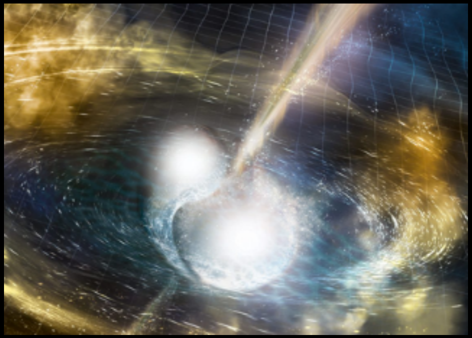
Consistent with GR

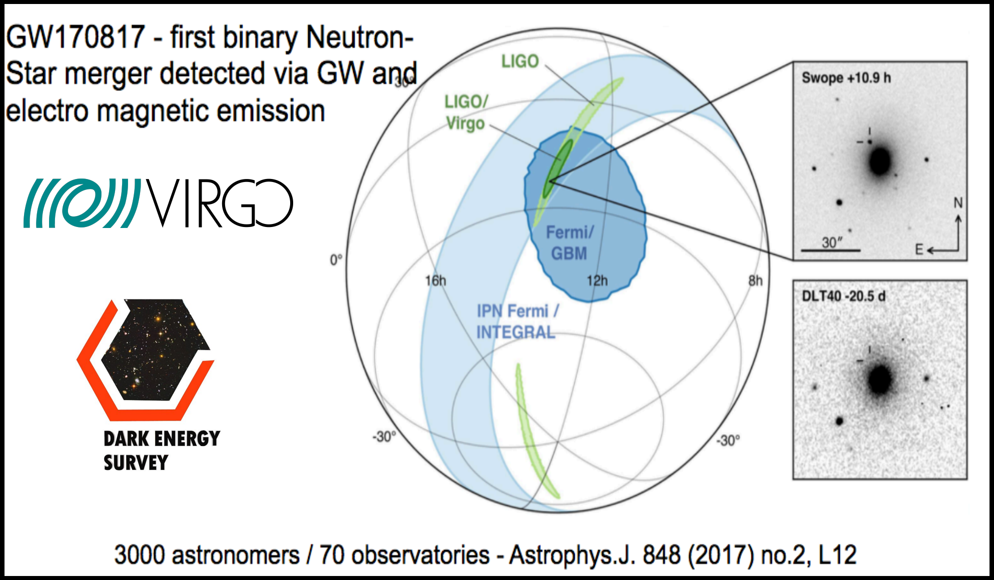


Neutron Star Collisions



Confirmed BNS as origin for some GRBs





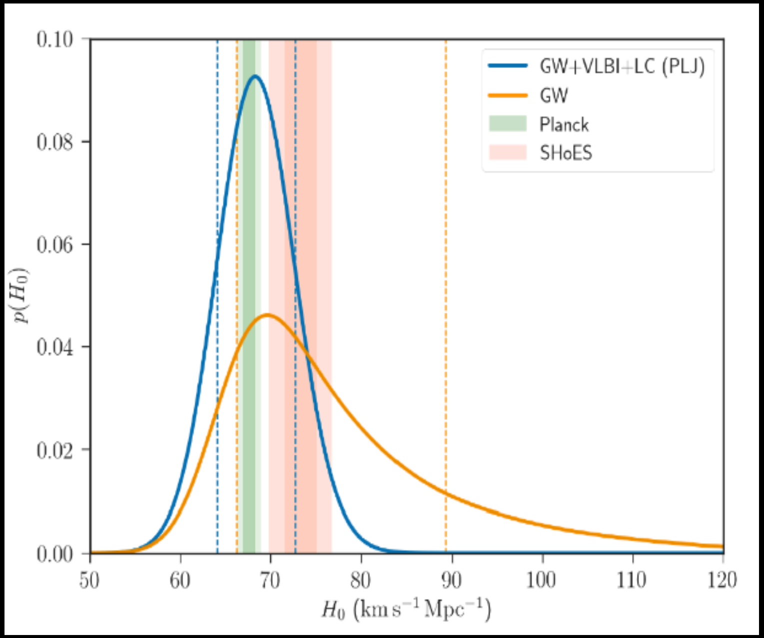
Few events of BNS will allow for few % precision in the determination of H_0

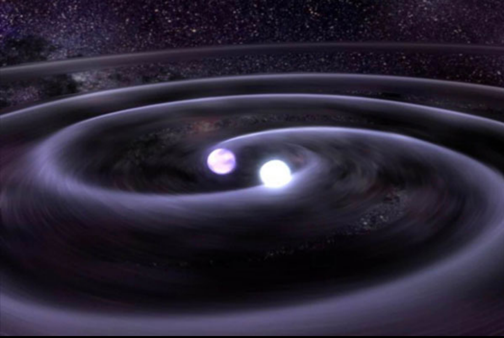
Observation with GWs and EM optics

$$v_H = H_0\, d \quad \text{(GW + EM)}$$

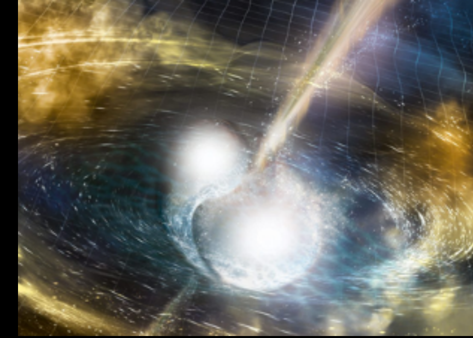
Direct measurement of Hubble parameter H_0

$$H_0 = 69 \pm 5\, \mathrm{km\,s^{-1}\,Mpc^{-1}}$$

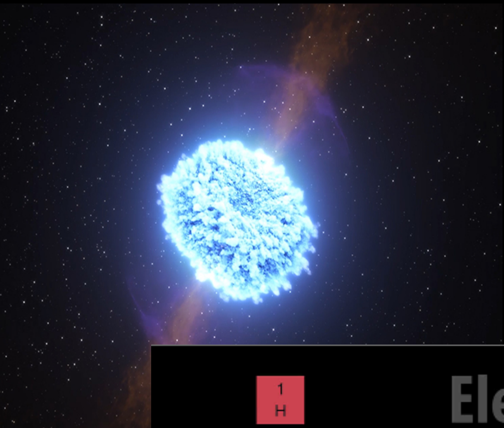




Kilonova

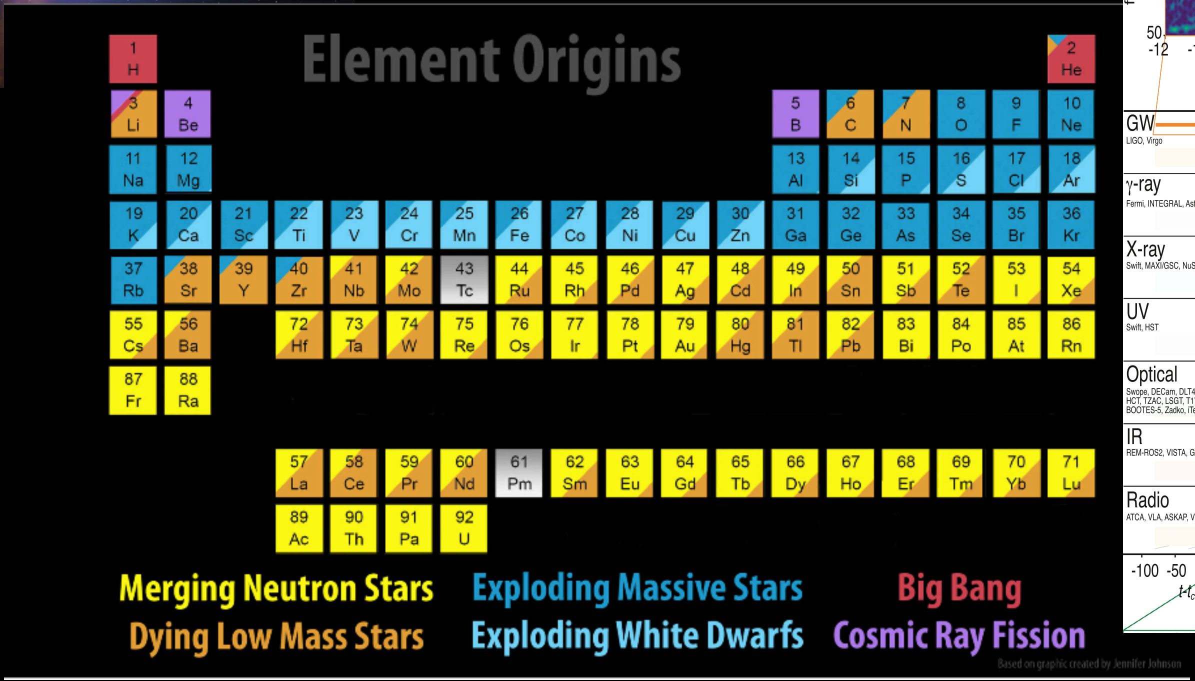


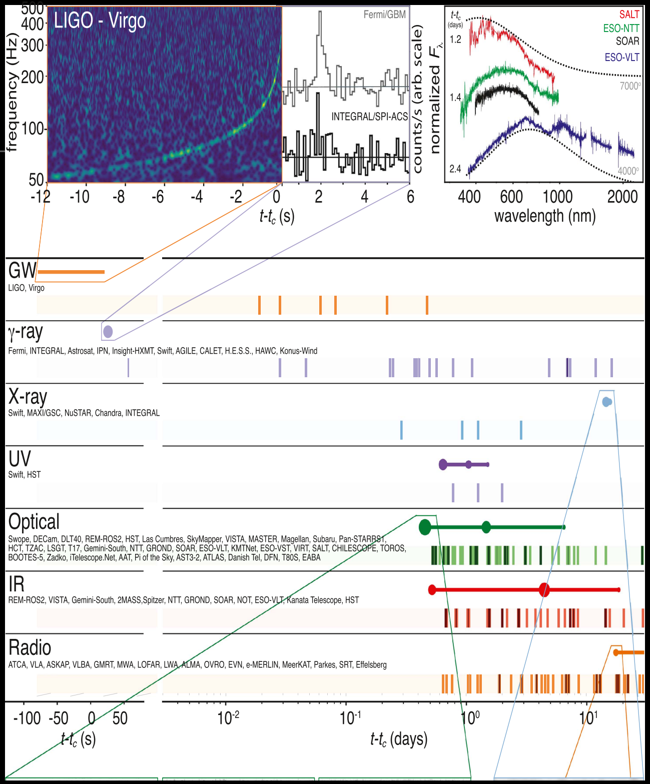
Open the door for studying EoS of neutron stars → data already disfavor some models



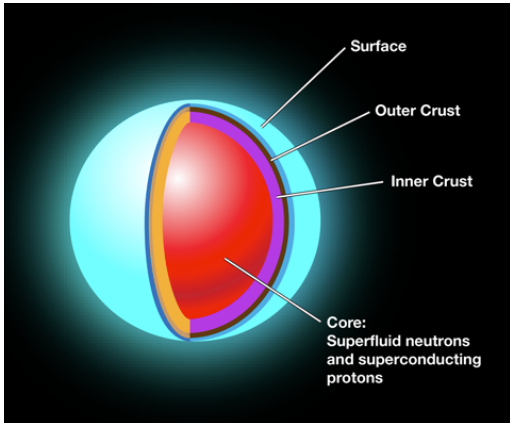
Shows the production mechanism of heavy elements

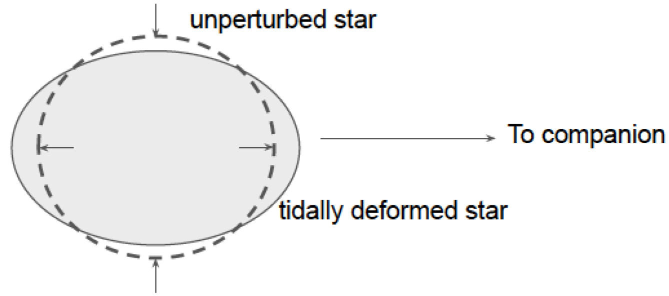
Initiates an era of multi-messenger approach



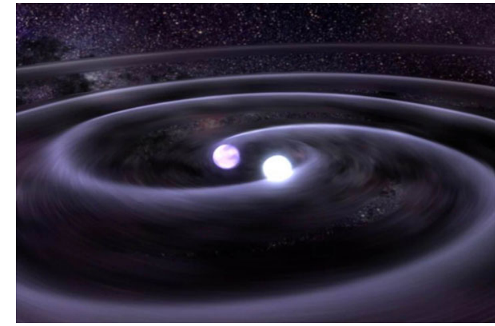


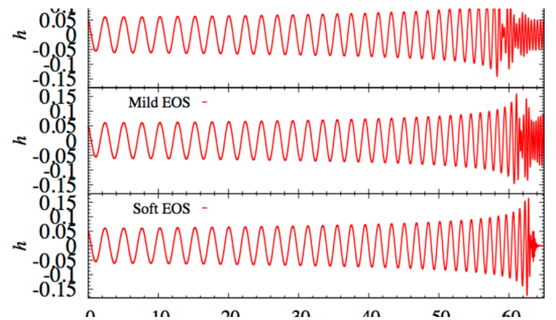
Neutron stars



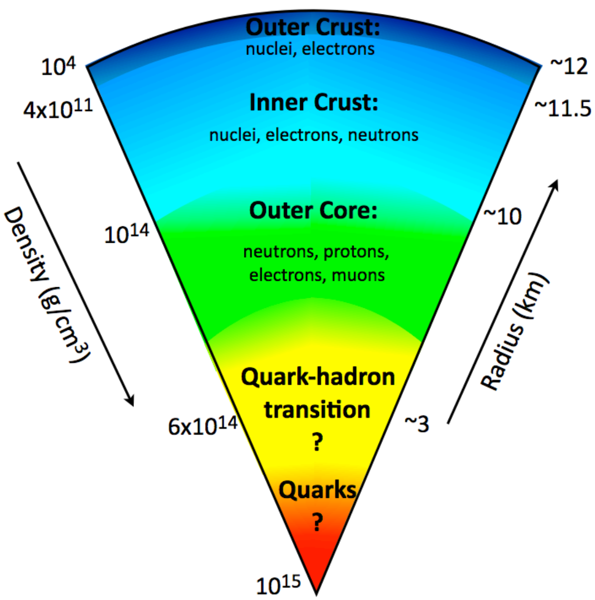


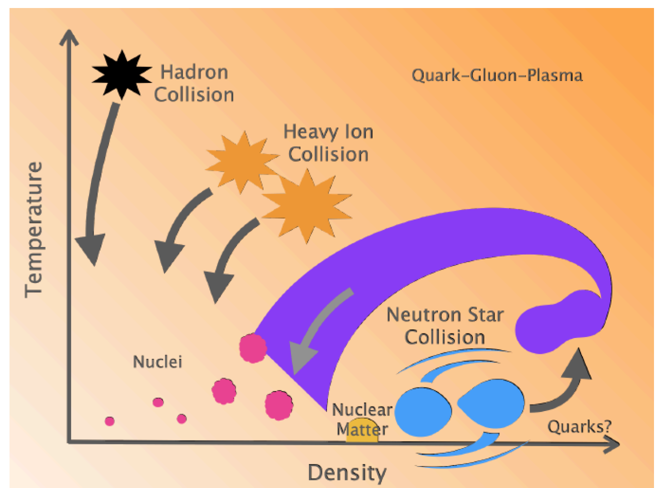
perturbed star changes quadrupole moment of the system
→ tends to radiate more energy as GWs
→ orbit evolves faster





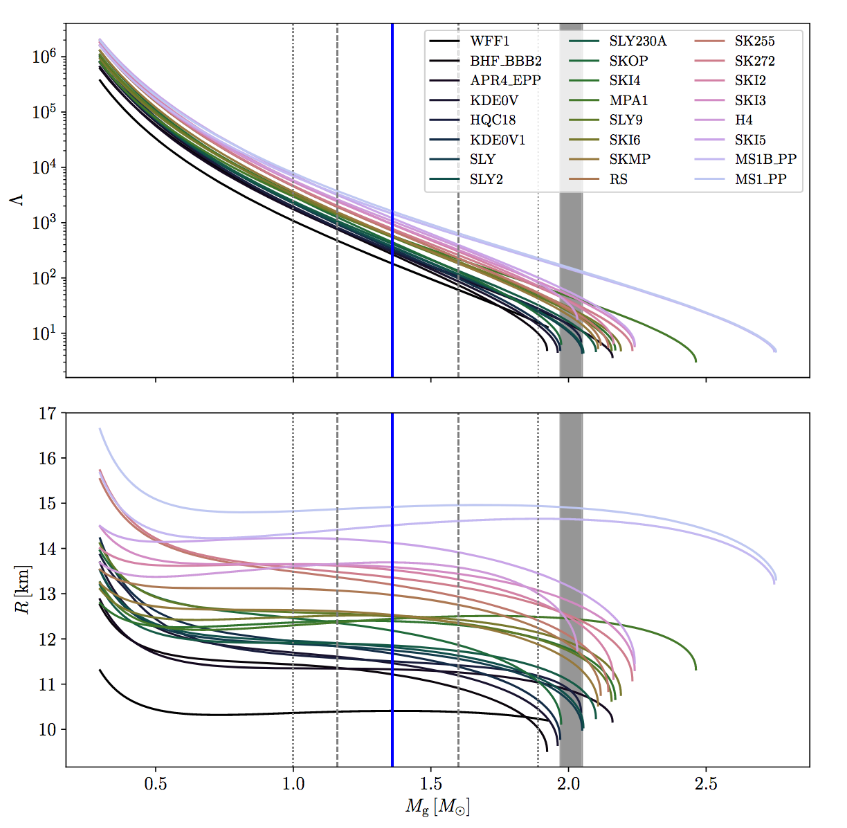
1-2 solar masses is an object with a diameter of 20KM (1/70000 the size of the sun)



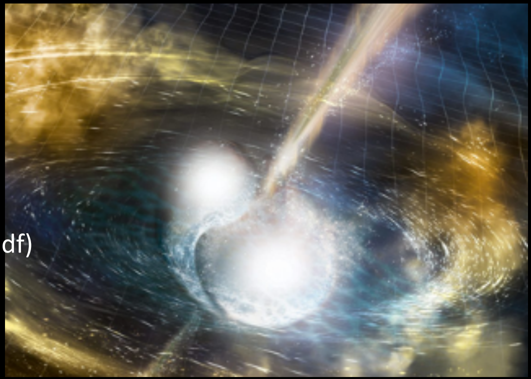


The study of neutron star mergers allows to study the equation of state of the star involving QCD in very dense and high regimes temperatures.

Class. Quantum Grav. 37 (2020) 0450060817



NS EoS

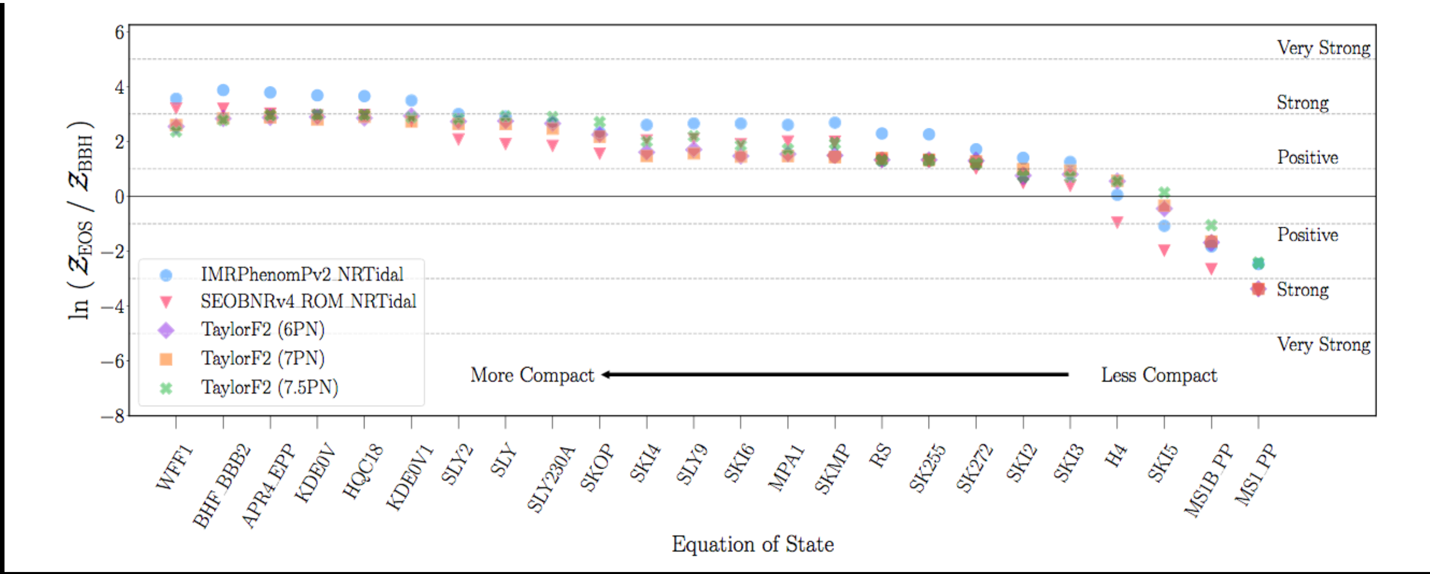


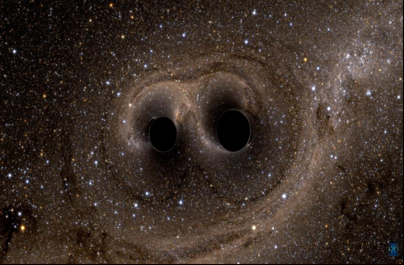
GW170817

(https://arxiv.org/pdf/1805.11581.pdf)

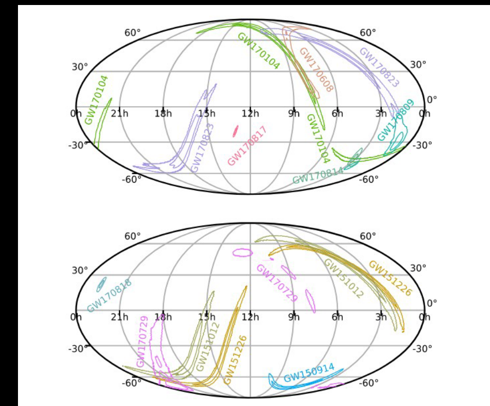
"deformability" and radius vs mass

The data did have the power to exclude some (few) of the EoS models for NS

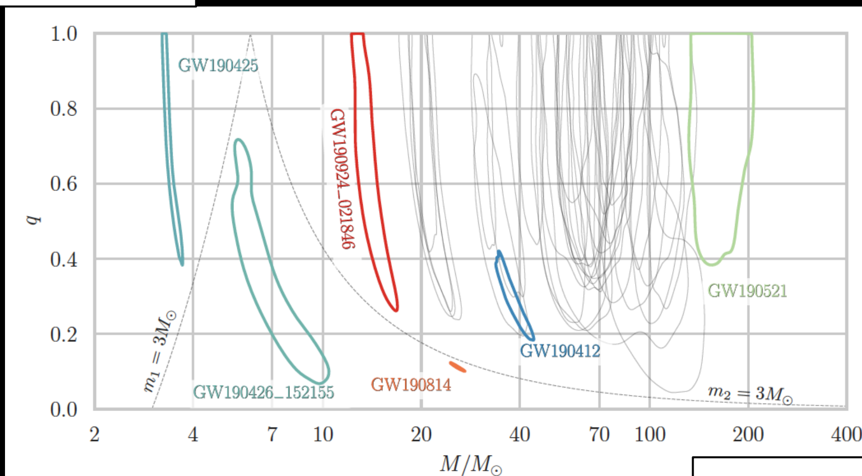




Population Studies (I)

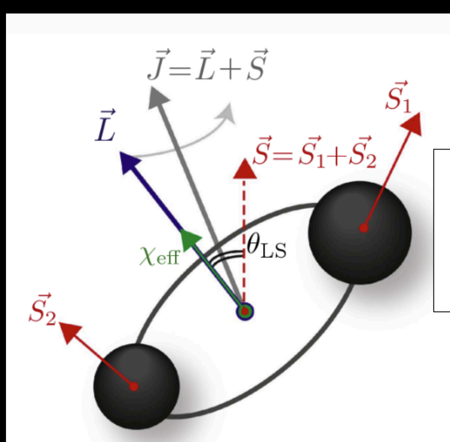


q = m_2/m_1

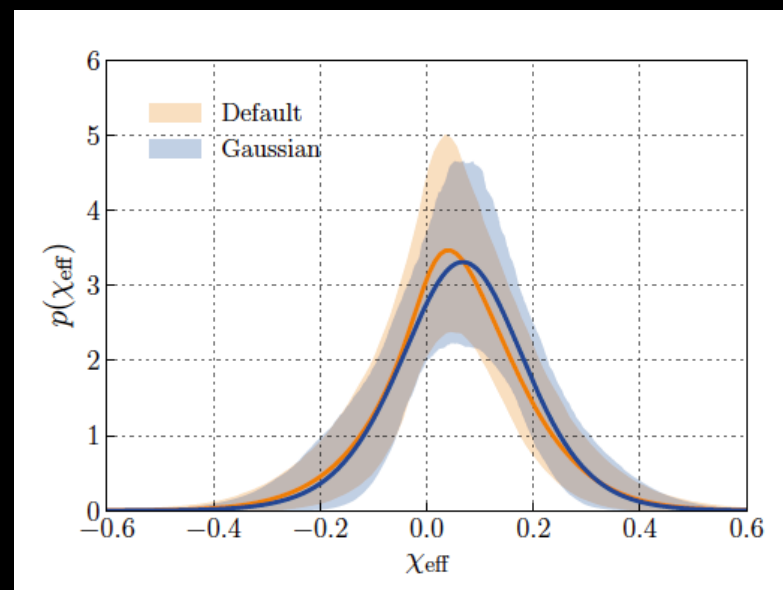


m_1+m_2

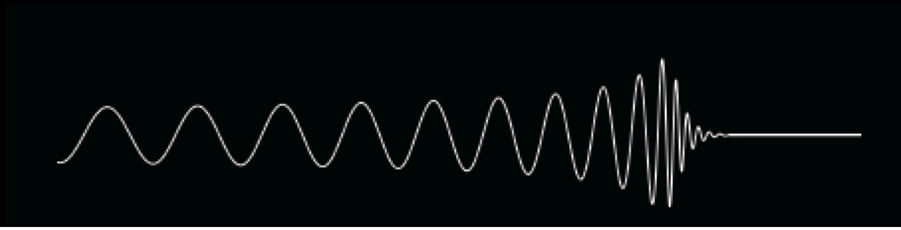
- Still large uncertainty in sky location.
- Binaries with clear asymmetric masses (q < 1).
- Indication of spin-orbit precession.
- Points to different production mechanism.



$$\chi_{\rm eff} = \frac{(m_1\vec{\chi}_1 + m_2\vec{\chi}_2)\cdot\hat{L}_{\rm N}}{M}$$

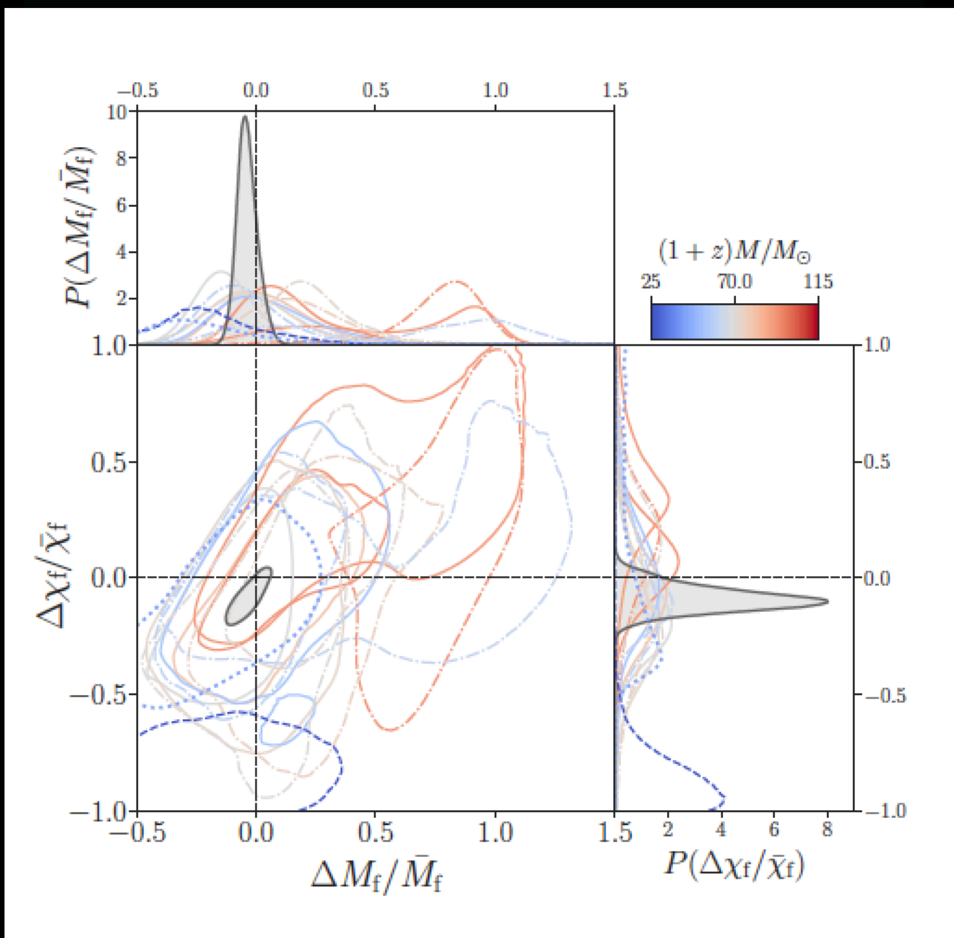


Inspiral–merger–ringdown consistency test

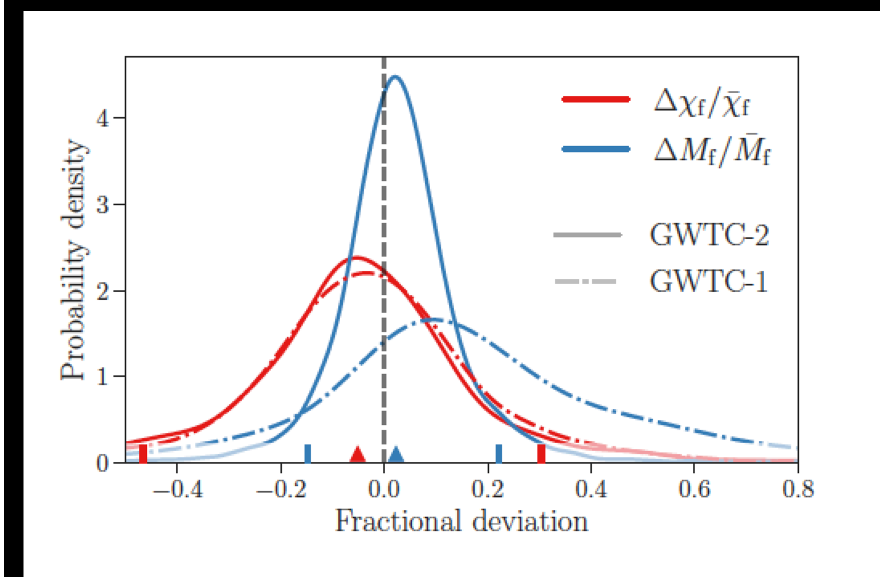


$$\frac{\Delta M_f}{\bar{M}_f} = 2\frac{M_f^{\text{insp}} - M_f^{\text{postinsp}}}{M_f^{\text{insp}} + M_f^{\text{postinsp}}},$$

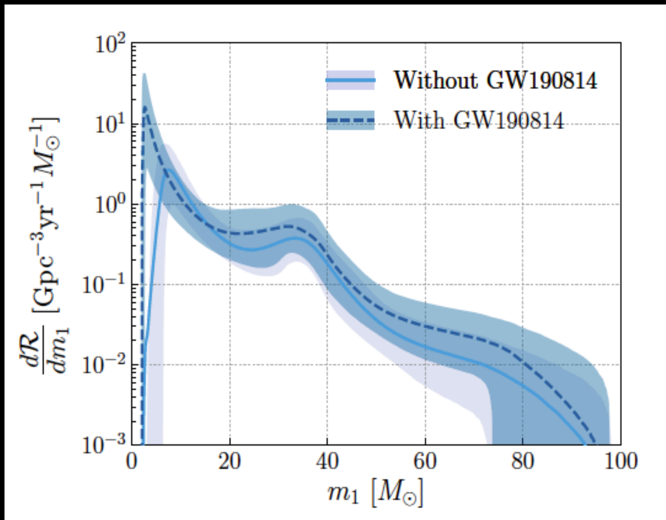
$$\frac{\Delta \chi_f}{\bar{\chi}_f} = 2\frac{\chi_f^{\text{insp}} - \chi_f^{\text{postinsp}}}{\chi_f^{\text{insp}} + \chi_f^{\text{postinsp}}},$$



Determining the remnant mass and
Spin using different parts of the waveform

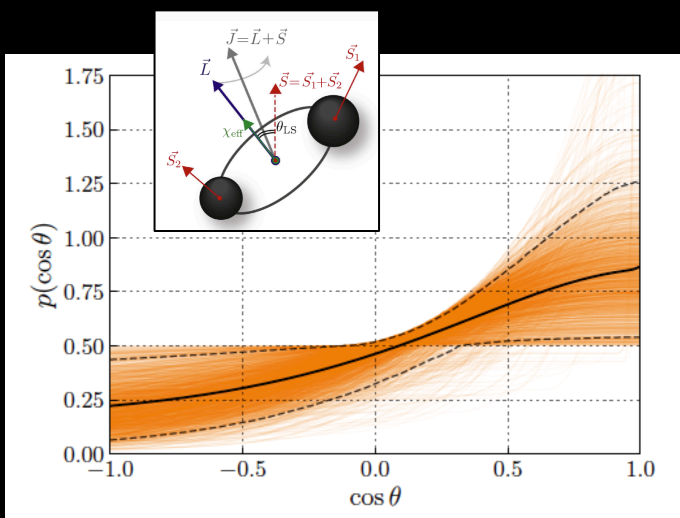


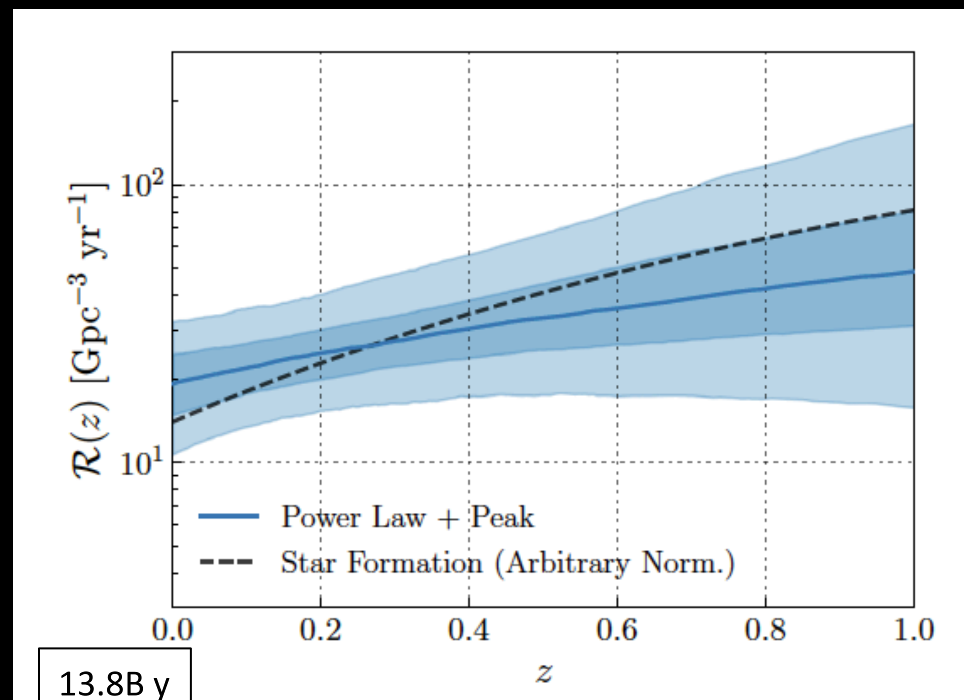
Population studies (II)



First differential distributions in mass and spin

Population vs z indicates consistency with star formation models (limited to small redshifts)





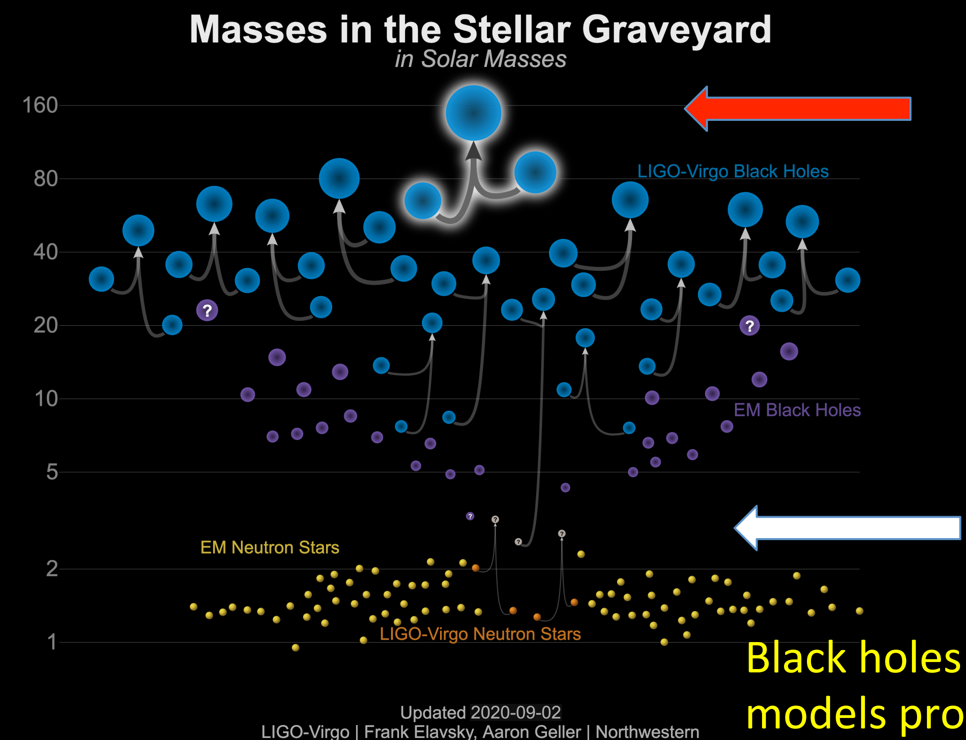
13.8B y

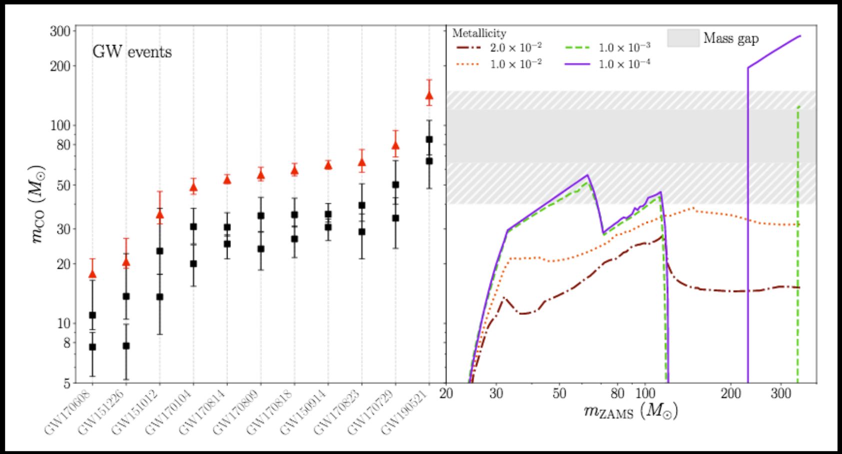
1 Gpcs
11.3B y

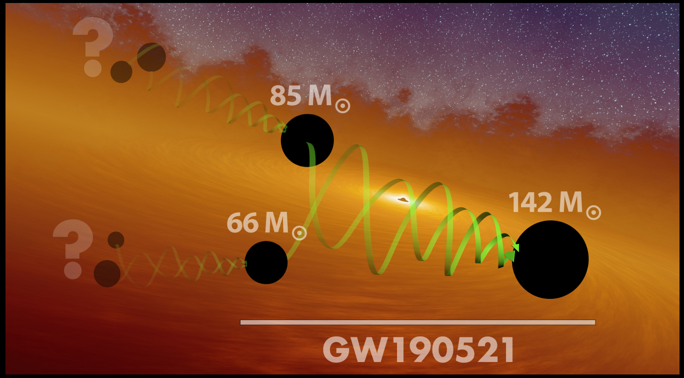
3.6 Gpcs
7.9B y

6.8 Gpcs
5.8B y

Event in the "mass gap"
(GW190521)





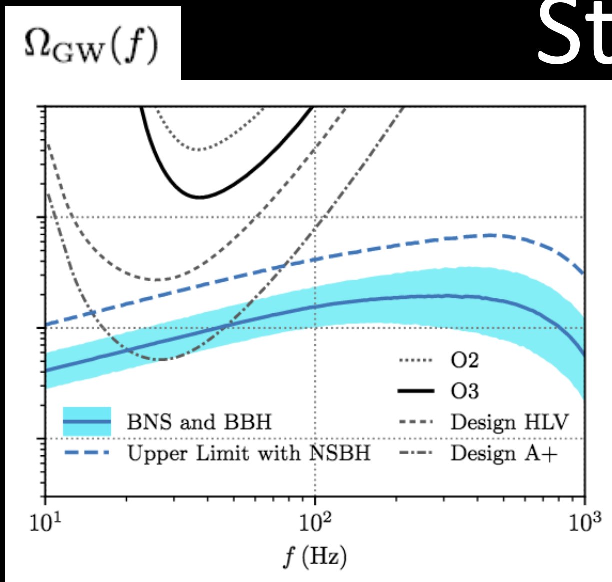


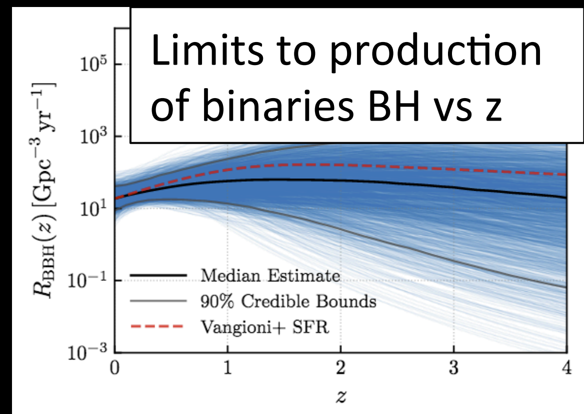
Black holes in the "mass gap" where stellar evolution models prohibit their presence

- Product of successive black hole mergers?
- Review of stellar evolution models?
- Primordial origin of black holes?

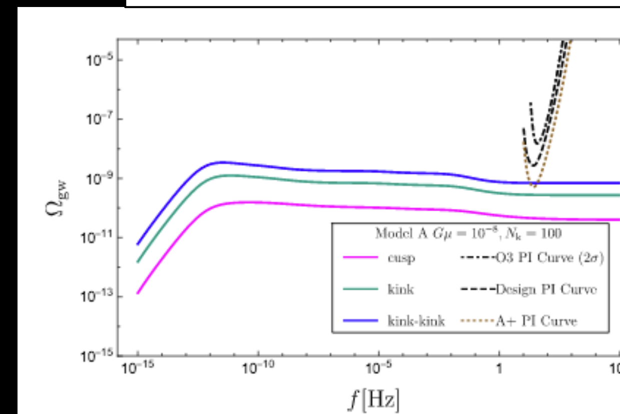
Production of a 142 M_{sun} black hole Illustrates how very massive BH can be produced

Stochastic signals

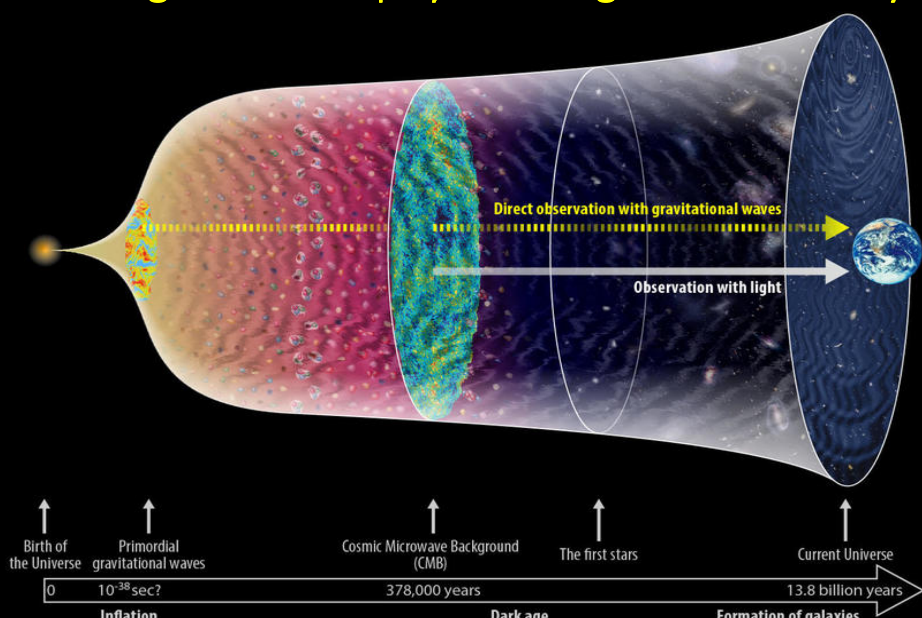




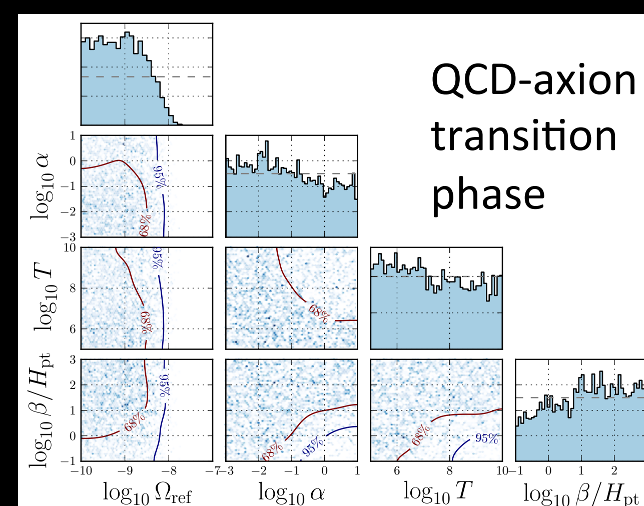
Limits on Cosmic Strings

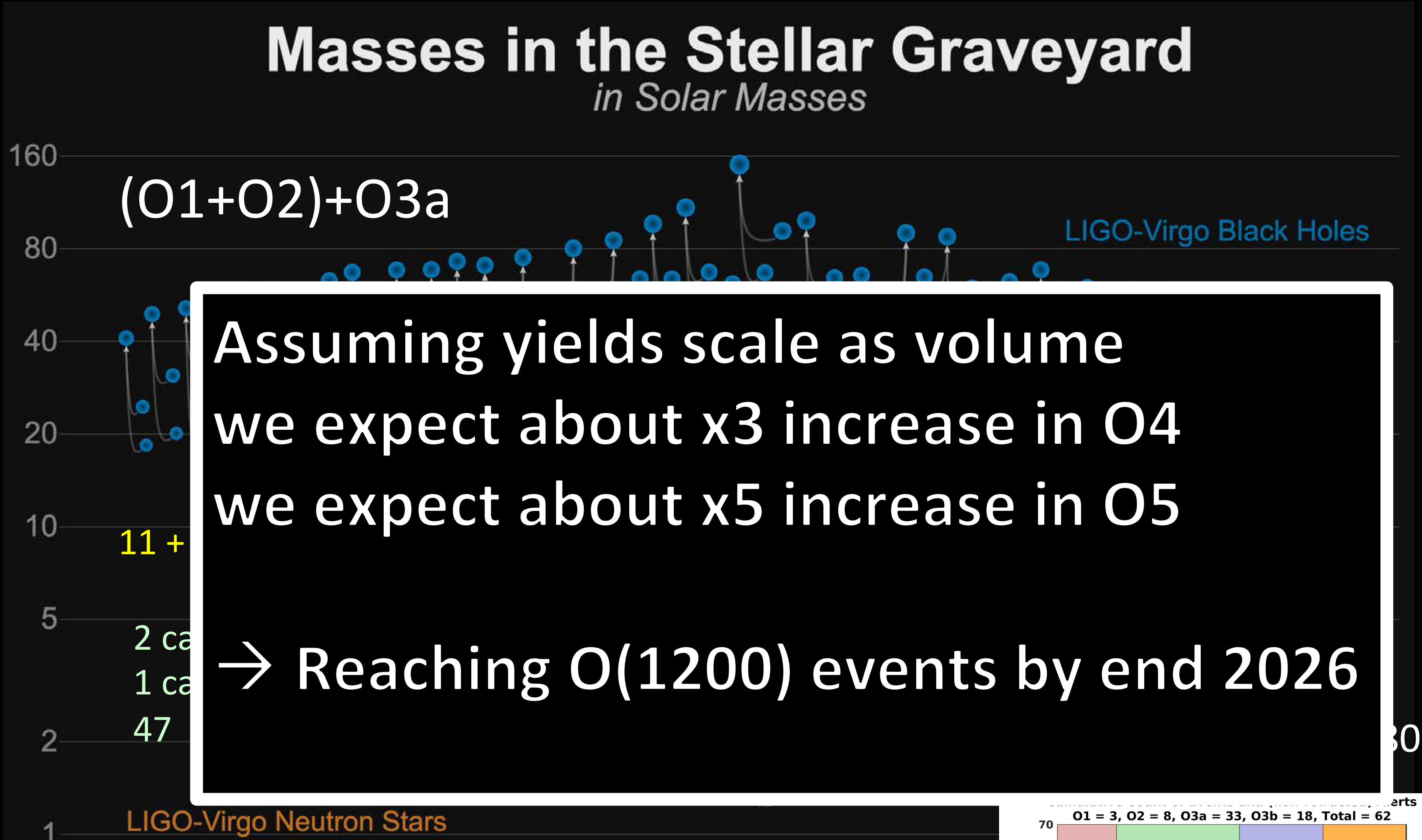


LIGO / Virgo with the sensitivity to observe
first signs of astrophysical origin in the next years.



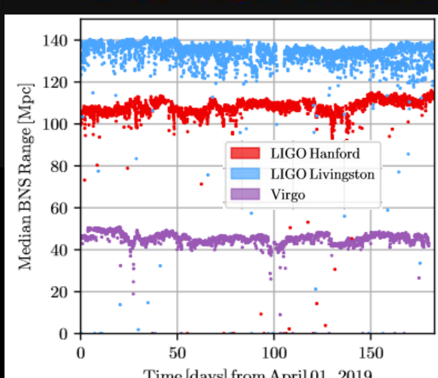
Still no stochastic signals
Data already puts limits on models of
new physics at very high temperatures

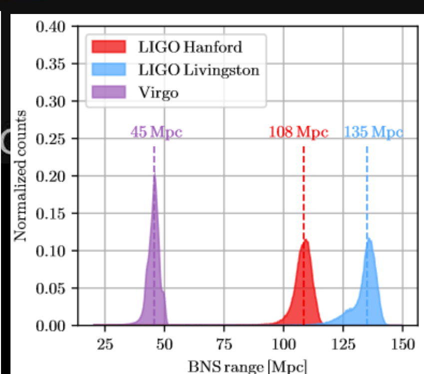


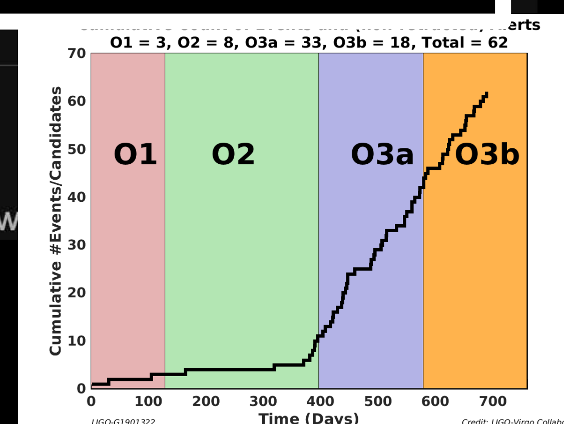


Assuming yields scale as volume
we expect about x3 increase in O4
we expect about x5 increase in O5

→ Reaching O(1200) events by end 2026

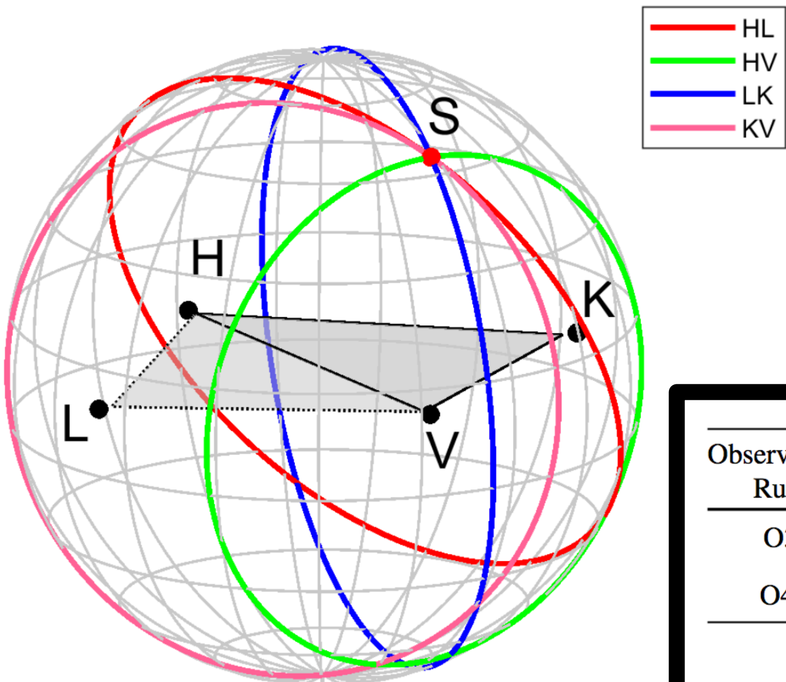






https://arxiv.org/pdf/1304.0670.pdf

Inclusion of KAGRA



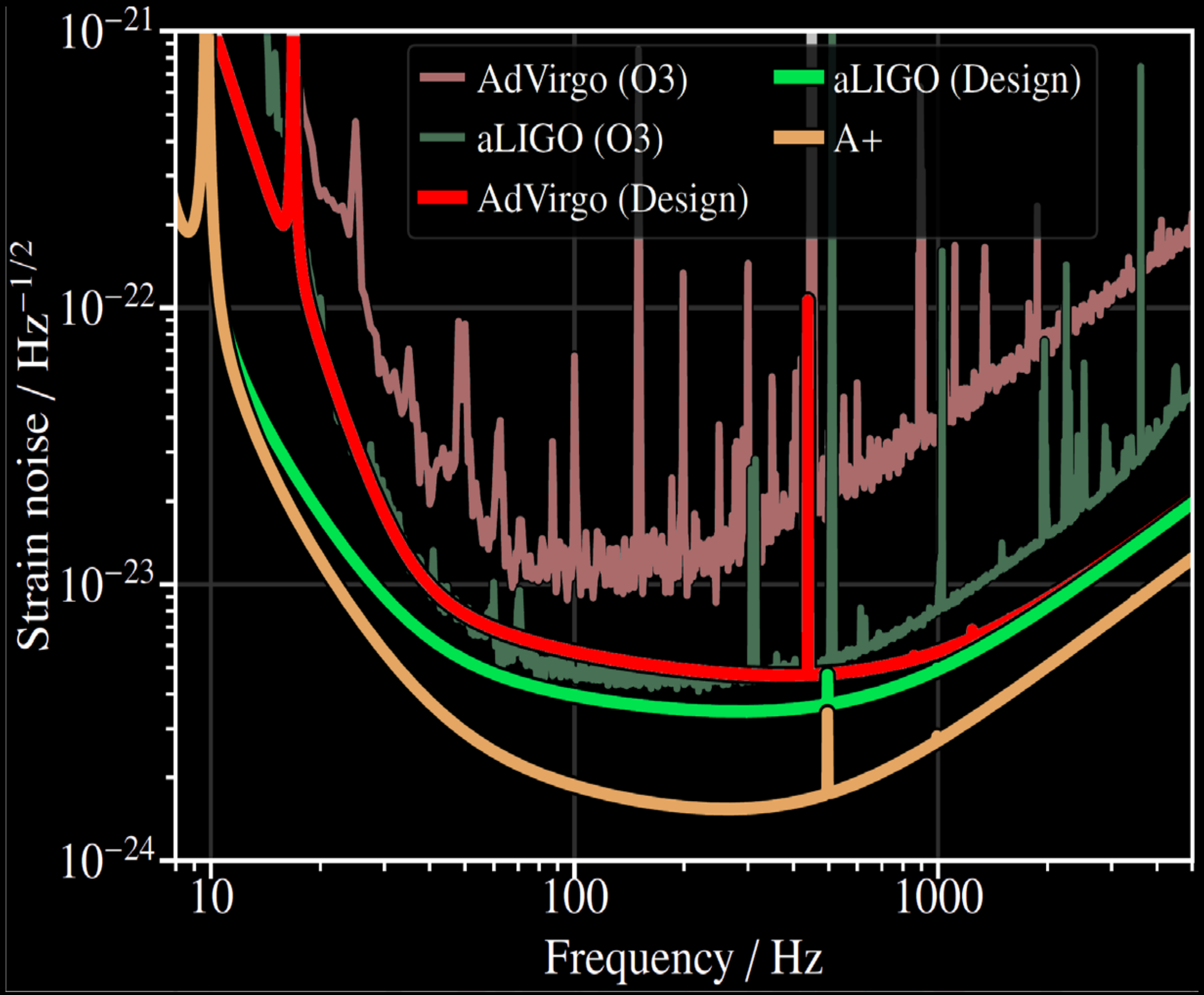
Four ITFs will allow single out sources in sky

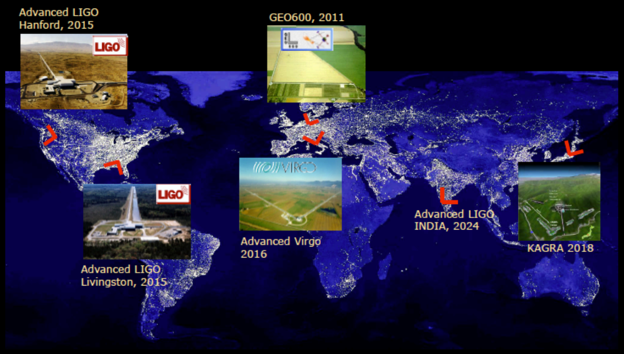
In O4 we expect about 80 BBHs well localized
→ boost to multi-messenger & cosmology
(note those numbers have large uncertainties)

Type	source rate density ($Gpcs^{-3}$ yr^{-1})
BNS	110 – 3840
BBH	25 – 109
NSBH	0.6 – 1000

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	1^{+12}_{-1}	0^{+19}_{-0}	17^{+22}_{-11}
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}
		Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.
O3	HLV	270^{+34}_{-20}	330^{+24}_{-31}	280^{+30}_{-23}
O4	HLVK	33^{+5}_{-5}	50^{+8}_{-8}	41^{+7}_{-6}
		Comoving Volume (10^3 Mpc^3) 90% c.r.	Comoving Volume (10^3 Mpc^3) 90% c.r.	Comoving Volume (10^3 Mpc^3) 90% c.r.
O3	HLV	120^{+19}_{-24}	860^{+150}_{-150}	16000^{+2200}_{-2500}
O4	HLVK	52^{+10}_{-9}	430^{+100}_{-78}	7700^{+1500}_{-920}

2G sensitivity



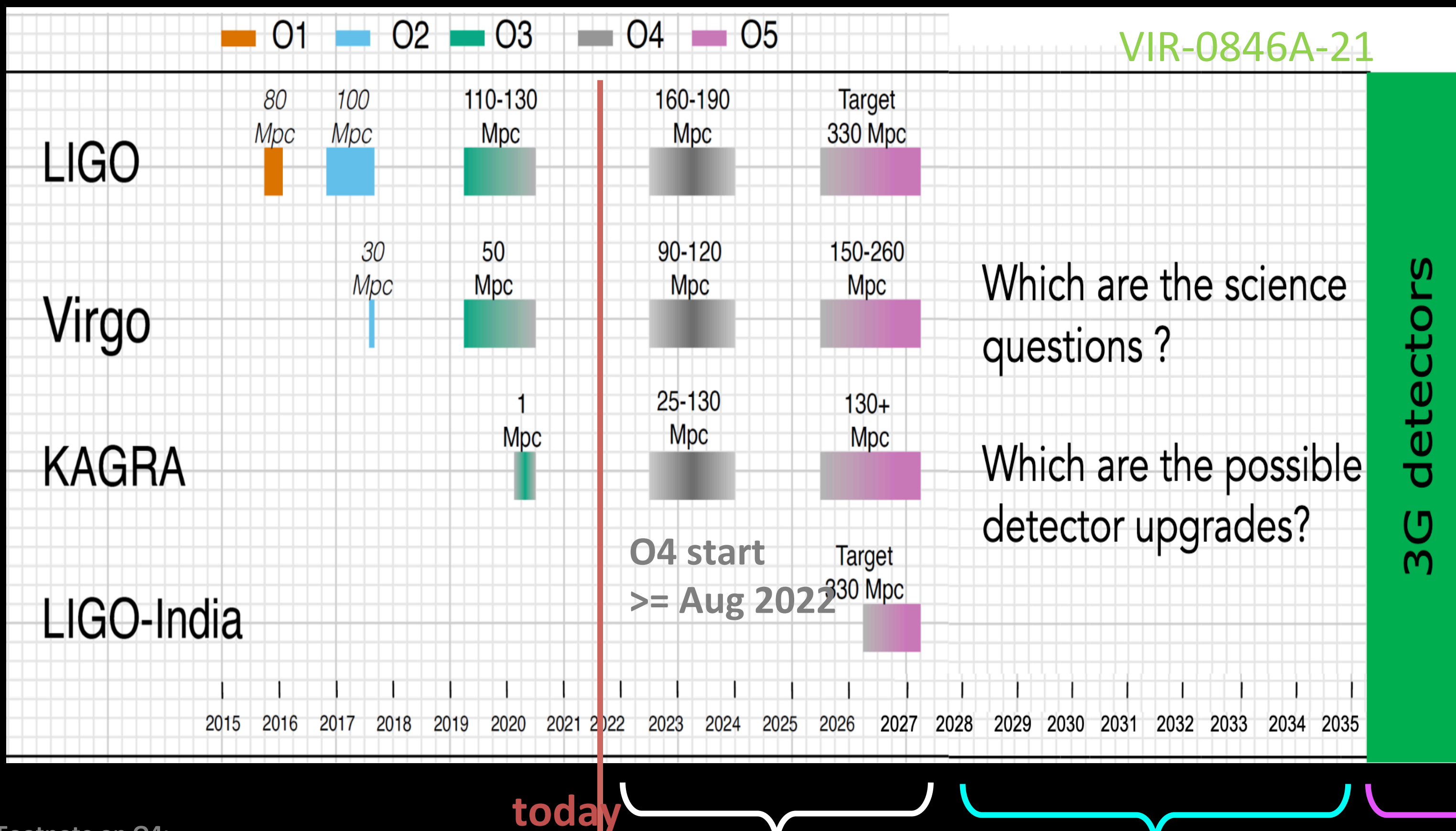


In the next 5 years the 2G Interferometers will reach their design sensitivity…

Ongoing discussion to extend the 2G program towards 2030s

Recommendations by March 2022

What does the future hold?



e.g. ET ESFRI applications mentions operation period of 2035-2085

A+, AdVirgo+, KAGRA, LIGO India **= Well underway**

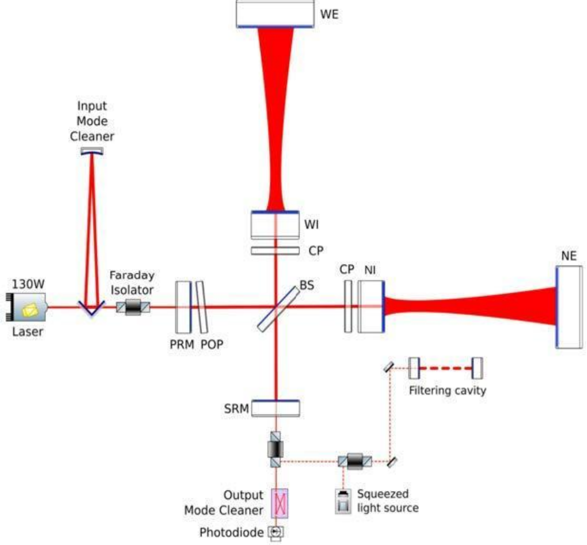
Post O5 planning **= just started**

New facilities **ET, CE, NEMO …**

Footnote on O4:
It is not yet possible to give a definitive start date for O4, as there are some continued supply chain delays and the impact of COVID continues. We can say at this time that the O4 observing run will not begin before August 2022. We expect to be able to give a better estimate for the start of O4 by 15 September 2021 and will issue an update then.

@ M. Barsuglia (VIRGO post-O5 committee)

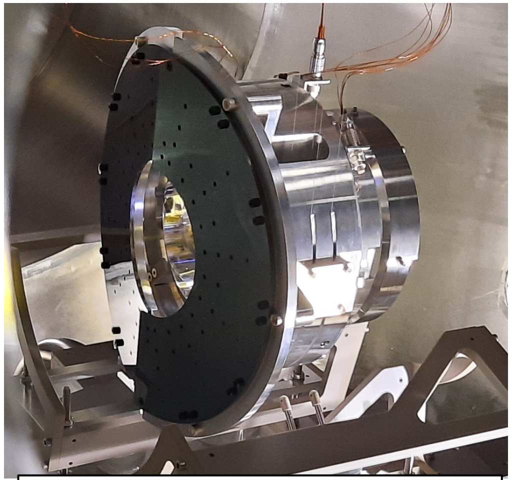
post-O5 Studies



Possible upgrades during the post-O5 era
2027-2036

- Higher input power
- Improved thermal compensation system
- Improved frequency dependent squeezing (losses, control of the filter cavity)
- Changes in the signal recycling (tuning, reflectivity)

quantum technologies, losses, configurations



Novel instrumentation

- New coatings
- Large mirrors/beams on all test masses

materials, stability of the cavities, technology of mirrors

- Control noise improvements
- Enhanced Newtonian noise subtraction
- Suspensions upgrades
- Scattered light mitigation

controls, geophysics modeling, scattering

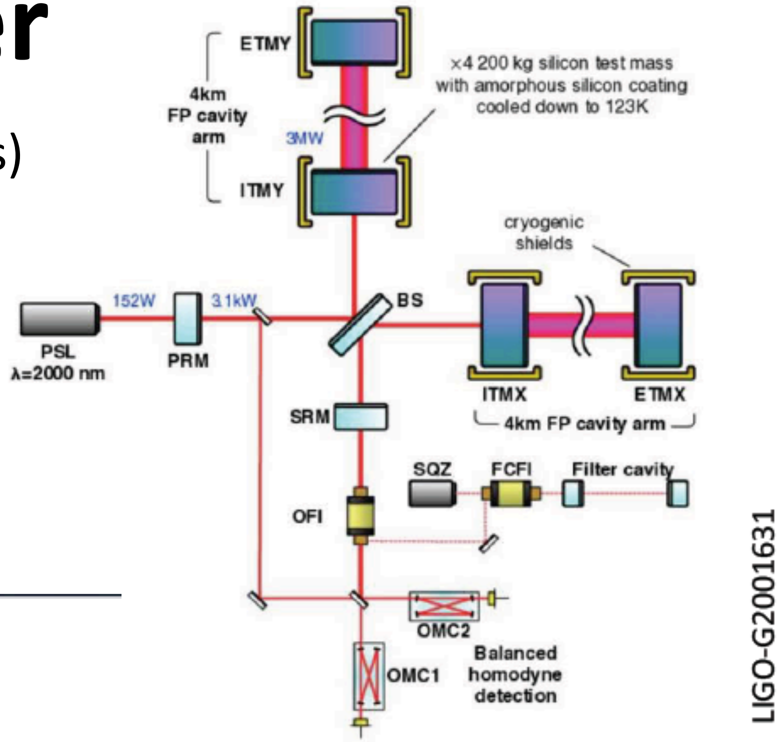
Similar efforts taking place at LIGO and KAGRA with very similar philosophy
→ Higher laser power, larger masses, better coatings (less thermal noise), tuned squeezing….
(in the case of KAGRA cryogenic temperatures at the mirrors is already in place)

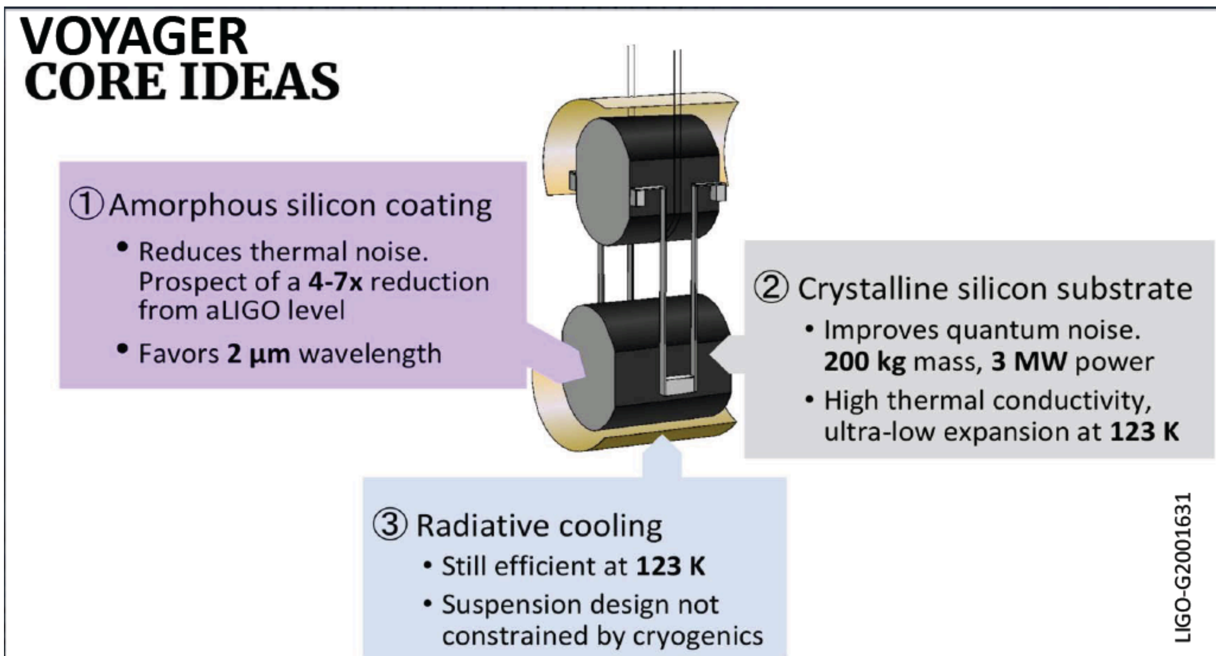
Voyager

Further upgrade or LIGO
Factor x3 improved in reach for BNS (1100 Mpcs)

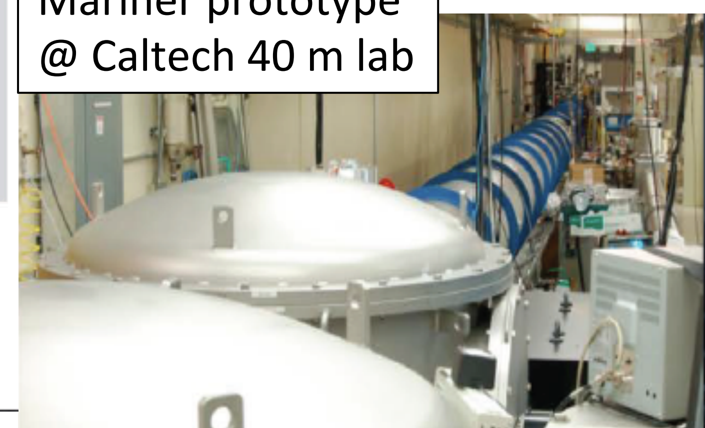
Going cryogenic temperatures (123K)
Larger masses with new substrate material
Different wavelength (2000 nm)

Planned for the next decade (2025 --)





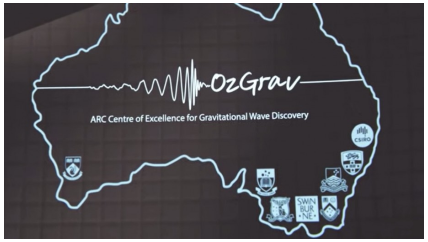
Mariner prototype
@ Caltech 40 m lab

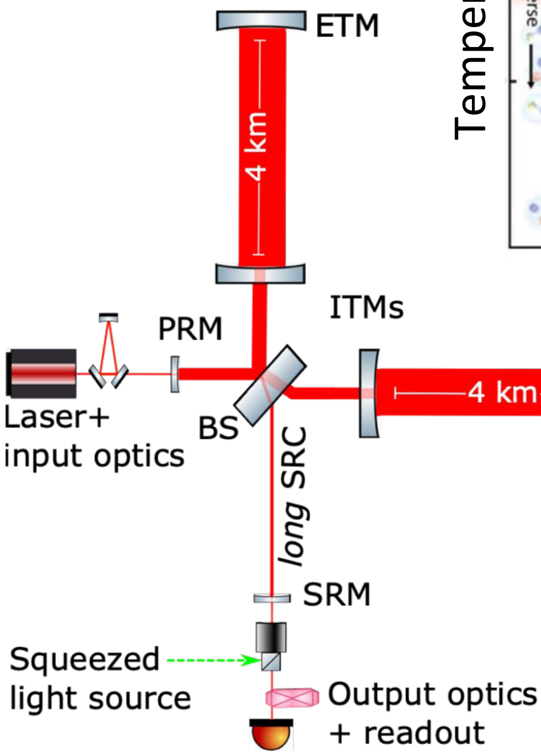


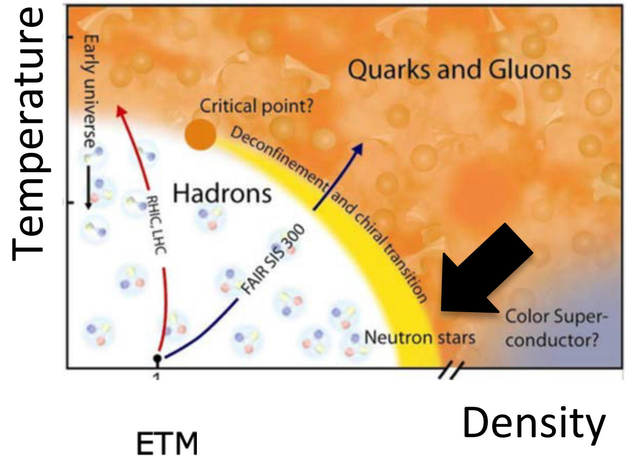
https://dcc.ligo.org/public/0142/T1700231

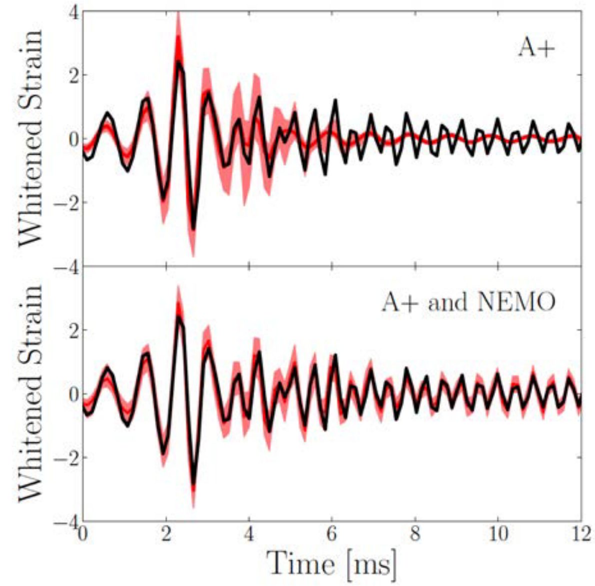
NEMO paper : doi:10.1017/pasa.2020.39

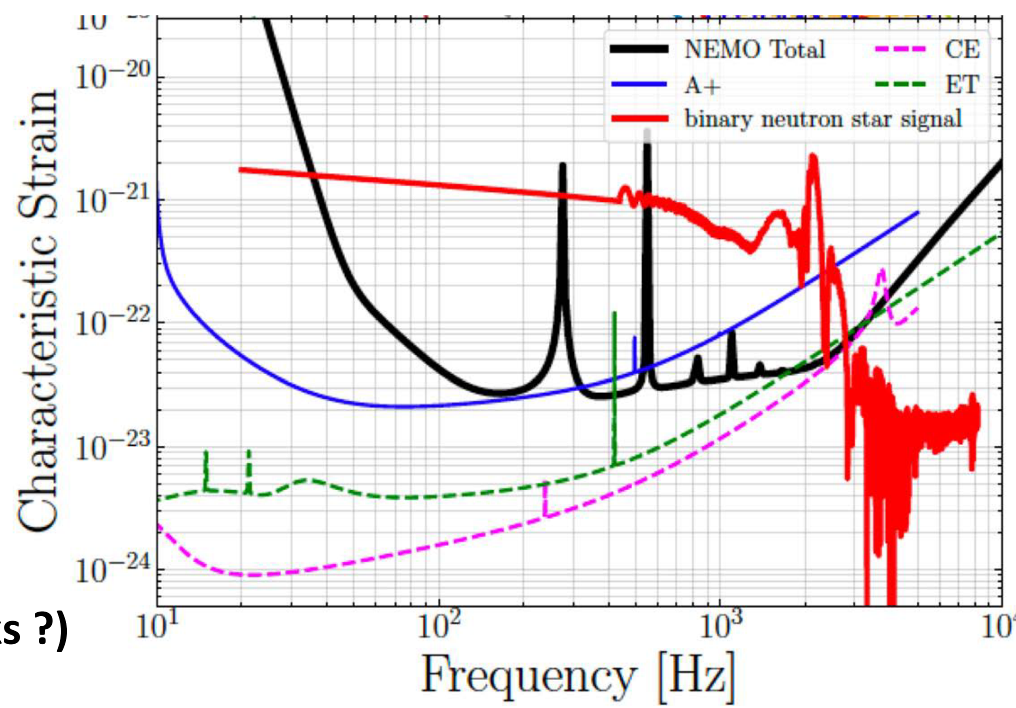
NEMO







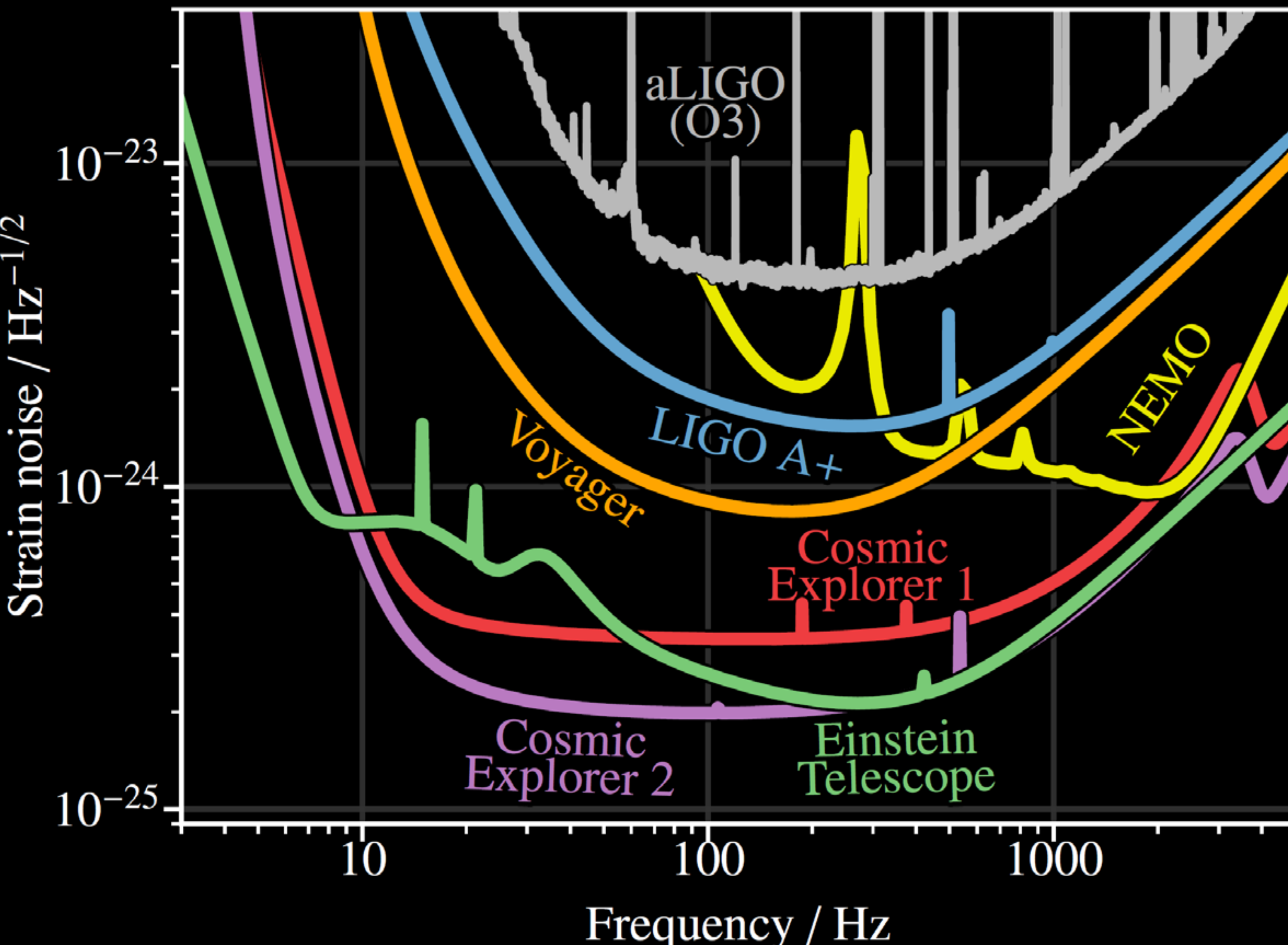




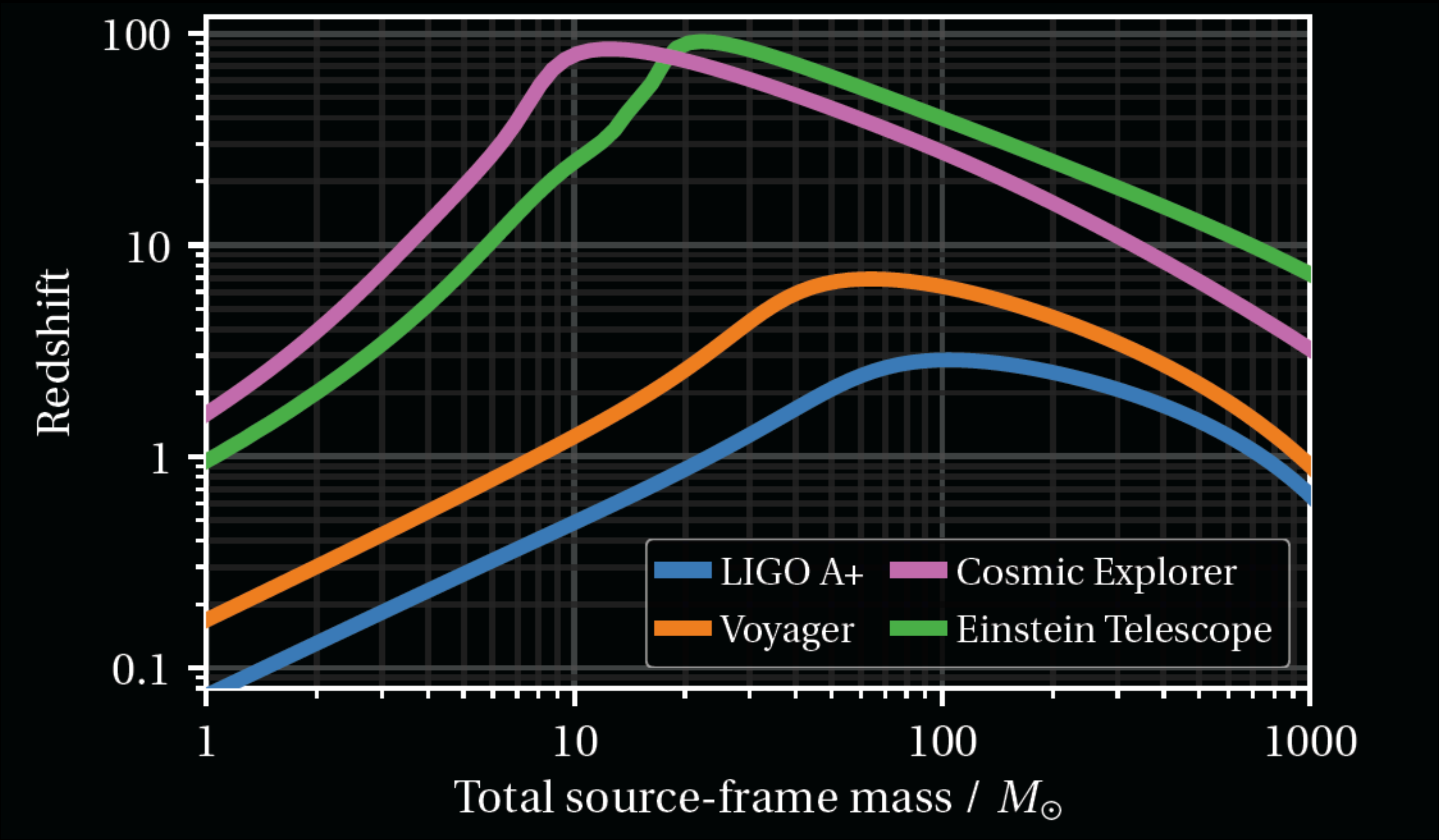
Focused on very high (kHz) frequency and post-merger BNS phenomena

→ QCD in very dense systems

→ Phase transitions (Deconfined quarks ?)



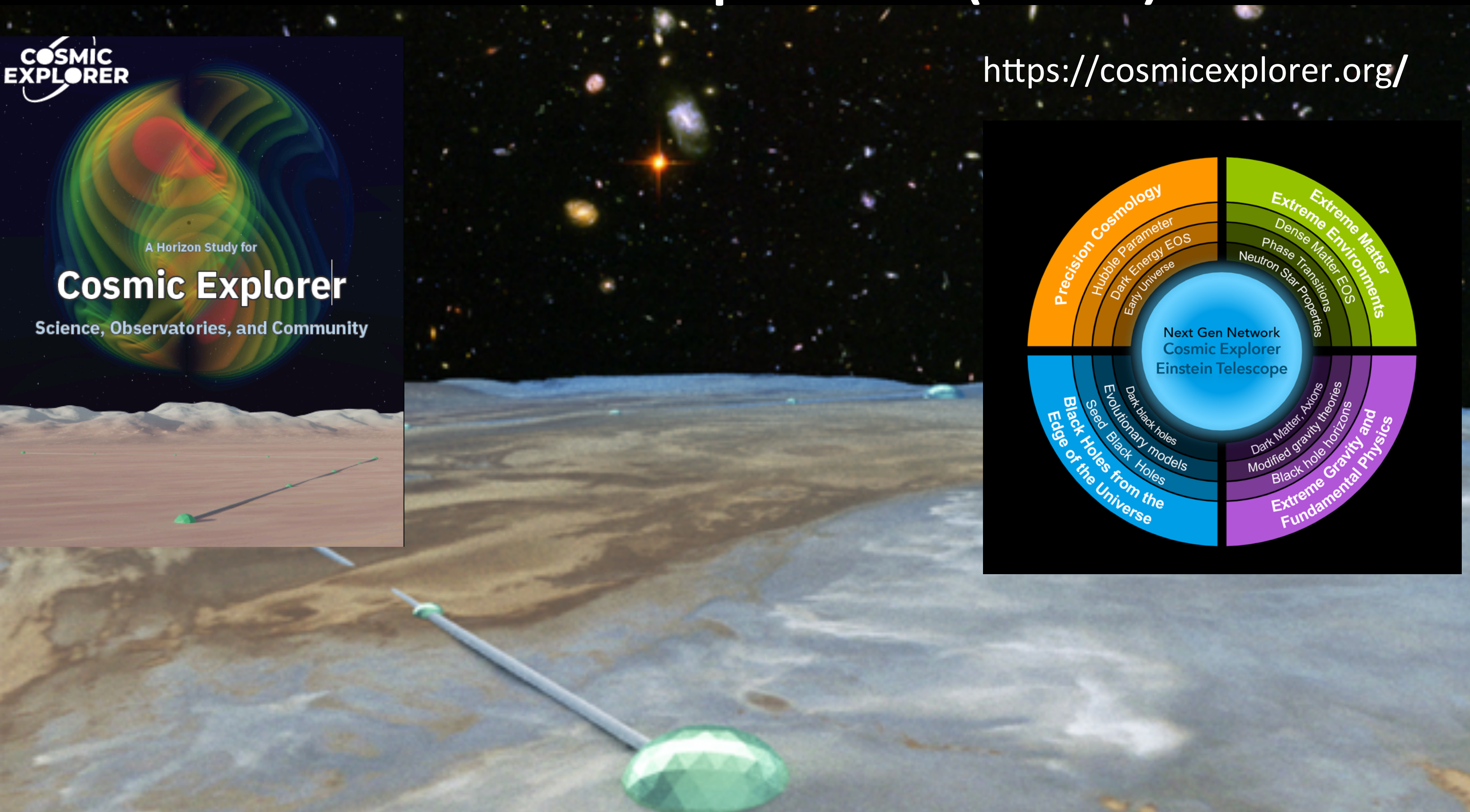
aLIGO
(O3)
LIGO A+
Voyager
NEMO
Cosmic
Explorer 1
Cosmic
Explorer 2
Einstein
Telescope
Strain noise / Hz$^{-1/2}$
10^{-23}
10^{-24}
10^{-25}
10
100
1000
Frequency / Hz



100
10
1
0.1
Redshift
1
10
100
1000
Total source-frame mass / $M_\odot$
LIGO A+
Voyager
Cosmic Explorer
Einstein Telescope

Cosmic Explorer (USA)

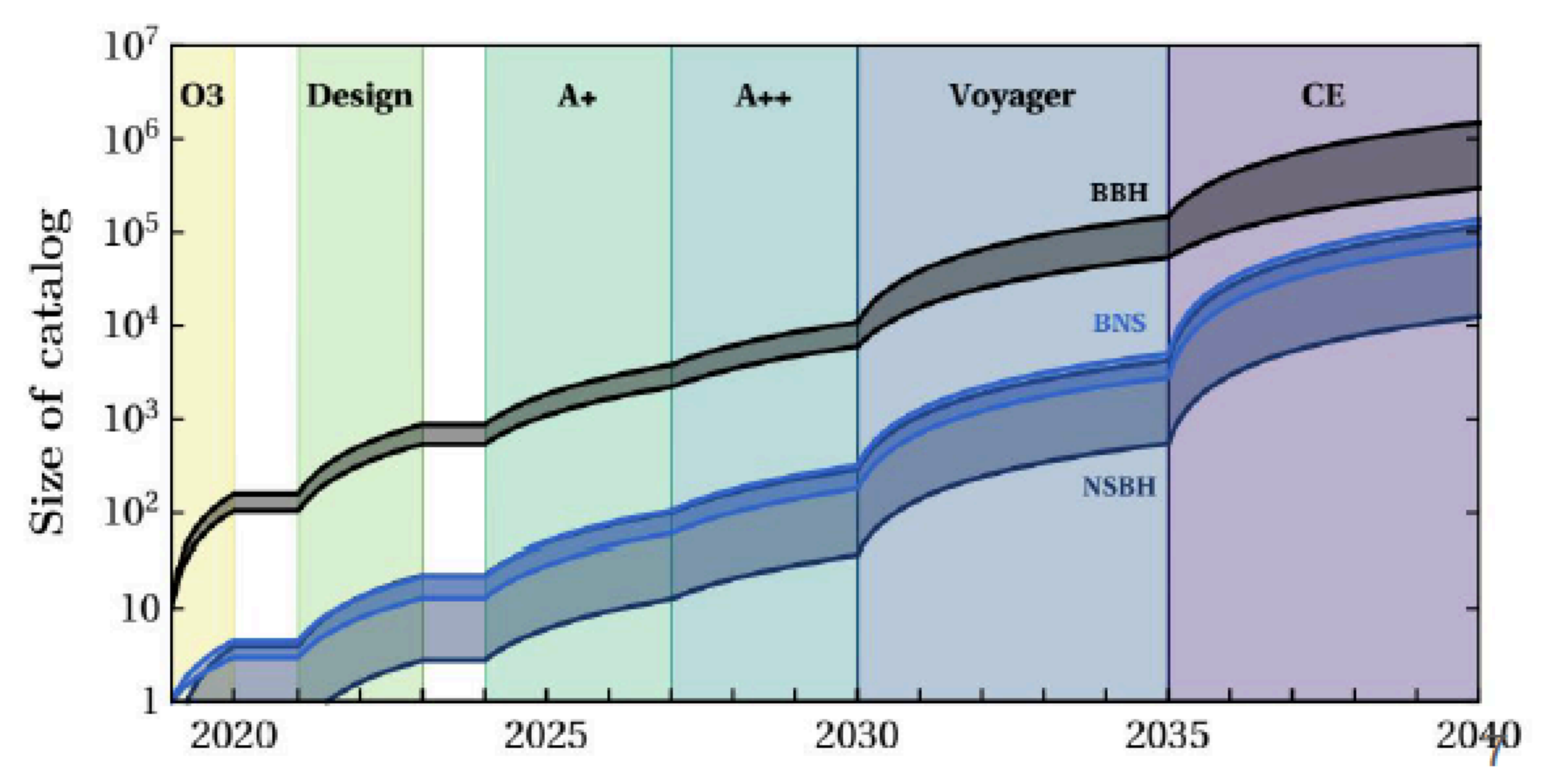
https://cosmicexplorer.org/



http://dcc.cosmicexplorer.org/CE-P2100003/public

Cosmic Explorer (USA)

https://cosmicexplorer.org/



http://dcc.cosmicexplorer.org/CE-P2100003/public

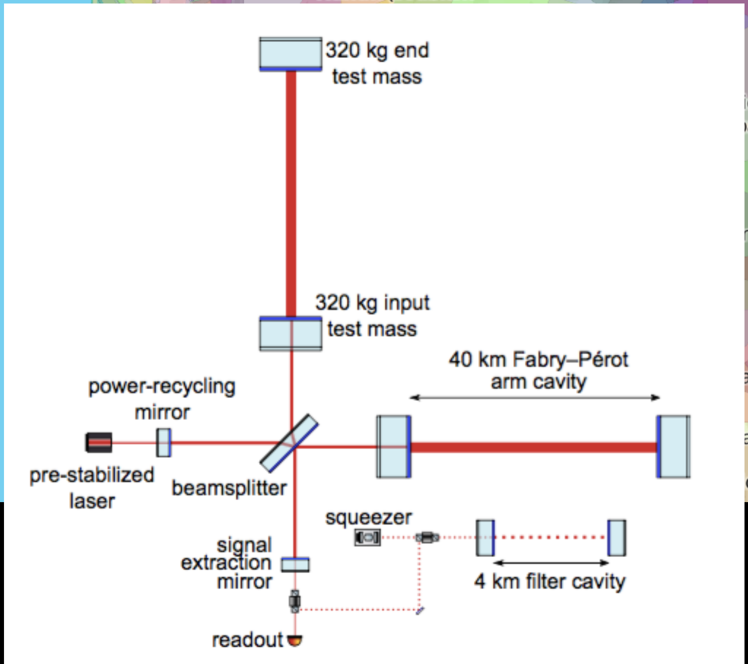
Cosmic Explorer

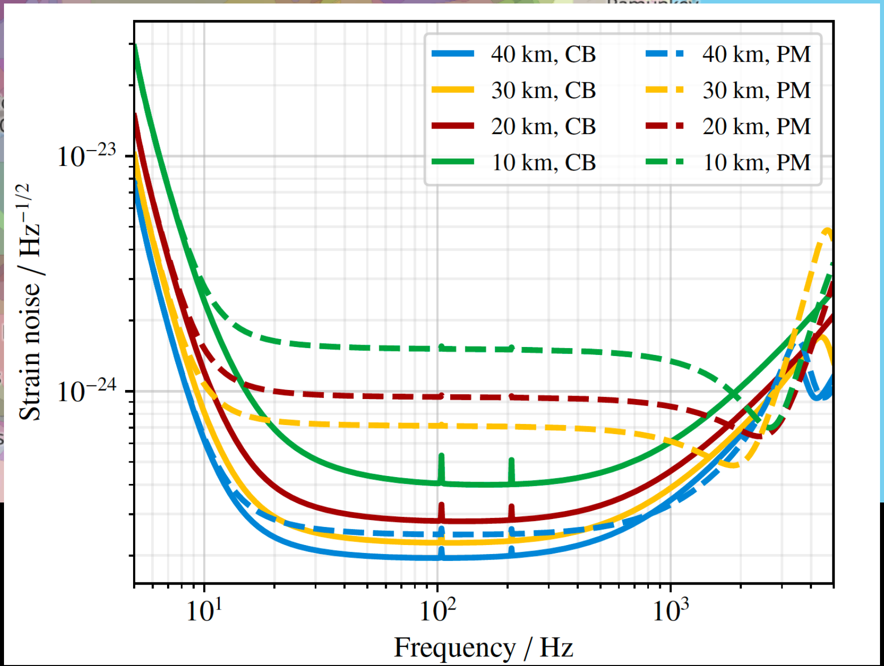
Two widely separated, L-shaped surface facilities in the US:

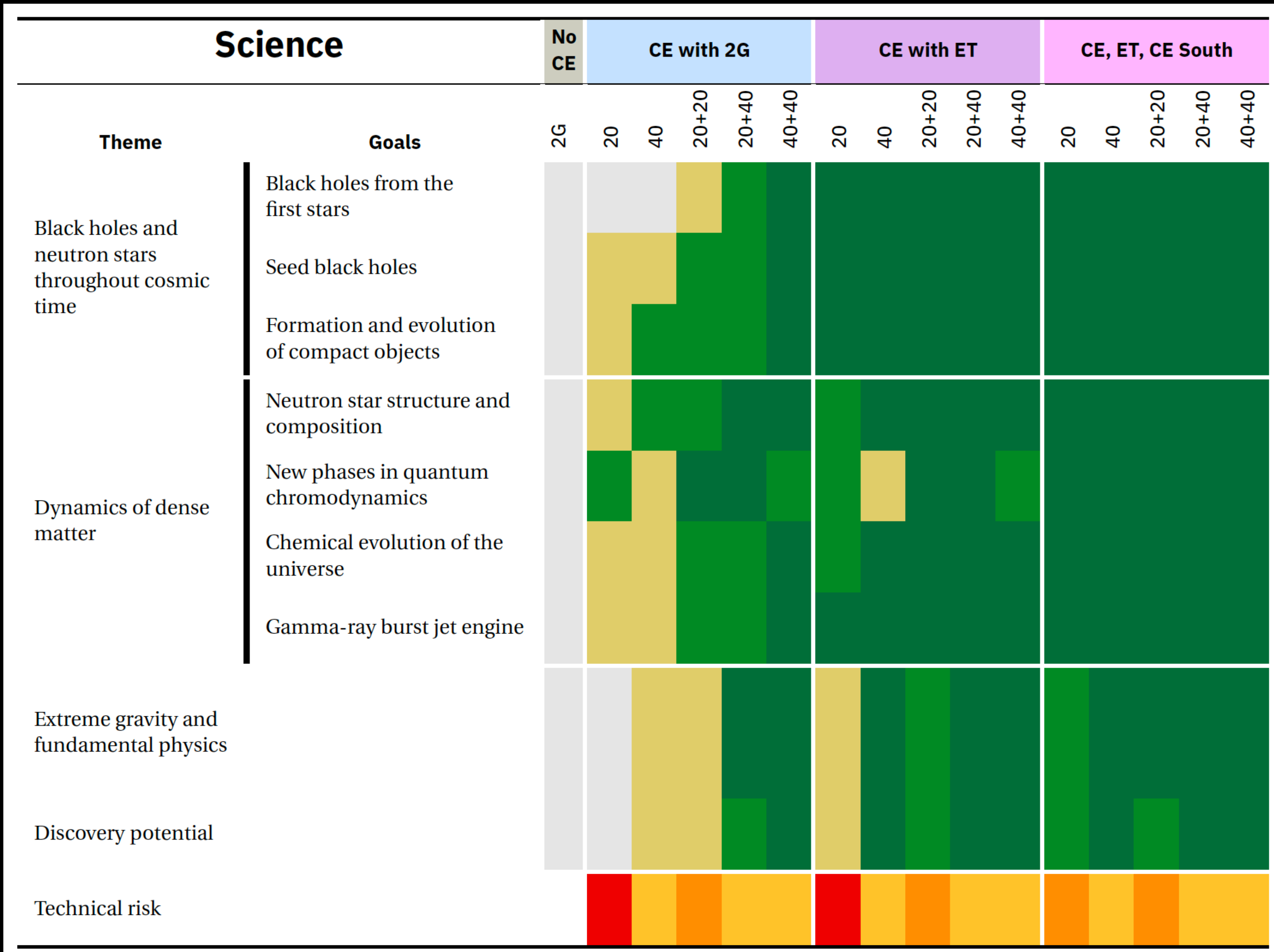
- A 40 km detector optimized for deep, broadband sensitivity
- A 20 km detector tuned to neutron-star post-merger signals

Two facilities improve localization and polarization information

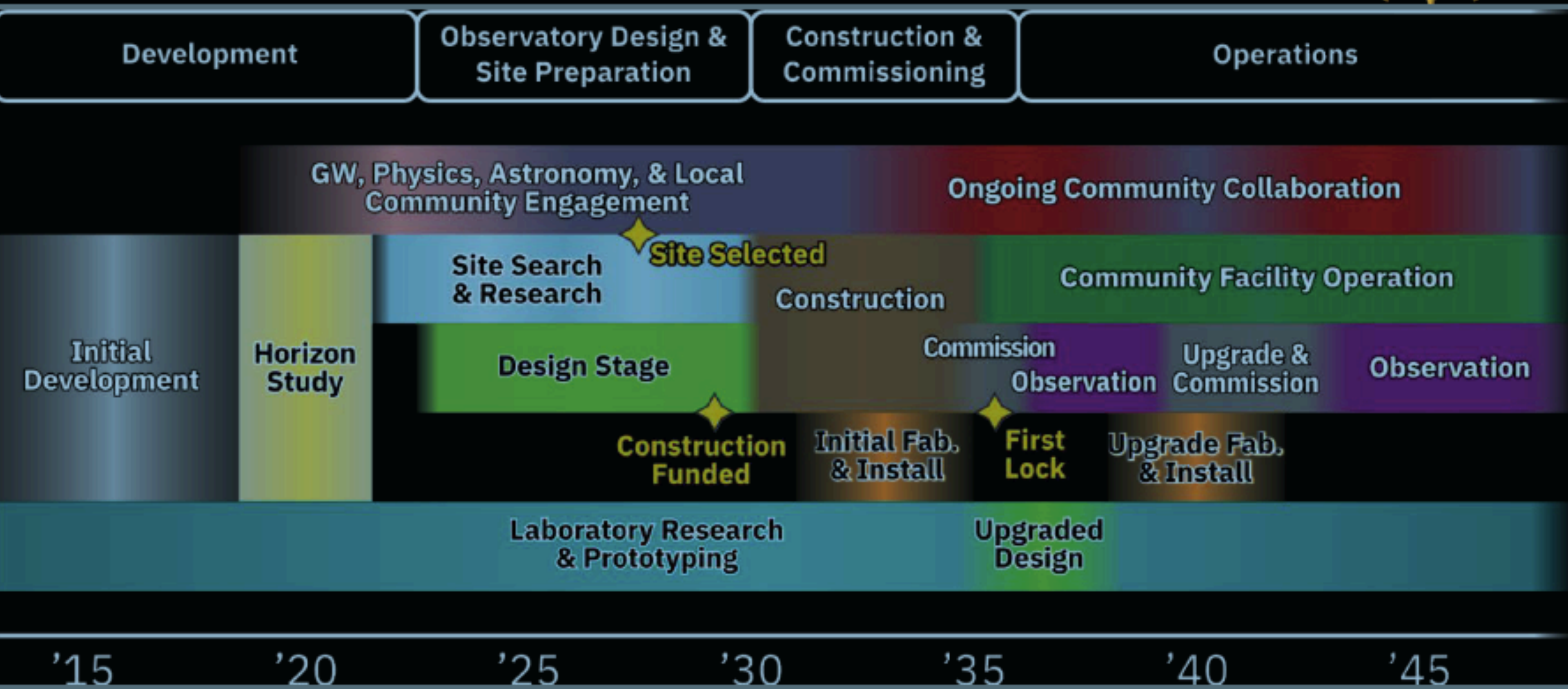
Cosmic Explorer will extend LIGO A+ technology **(room-temp silica, 1 μm laser)**, with Voyager technology **(123 K silicon, 2 μm laser)** as a secondary option






Science
No CE
CE with 2G
CE with ET
CE, ET, CE South
Theme
Goals
2G
20
40
20+20
20+40
40+40
20
40
20+20
20+40
40+40
20
40
20+20
20+40
40+40
Black holes and neutron stars throughout cosmic time
Black holes from the first stars
Seed black holes
Formation and evolution of compact objects
Dynamics of dense matter
Neutron star structure and composition
New phases in quantum chromodynamics
Chemical evolution of the universe
Gamma-ray burst jet engine
Extreme gravity and fundamental physics
Discovery potential
Technical risk

Cosmic Explorer Timeline

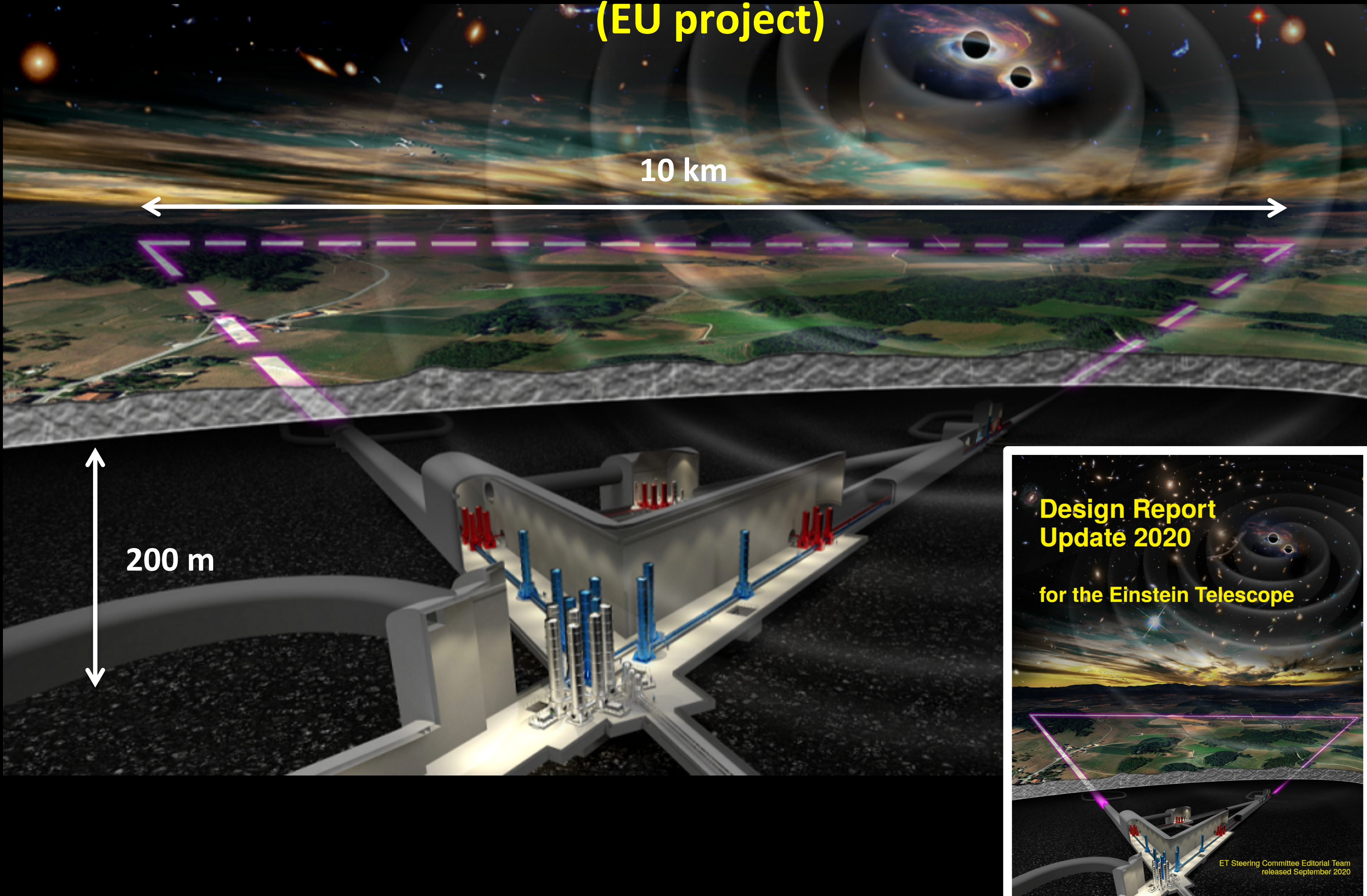


Matthew Evans @ PAX Conference

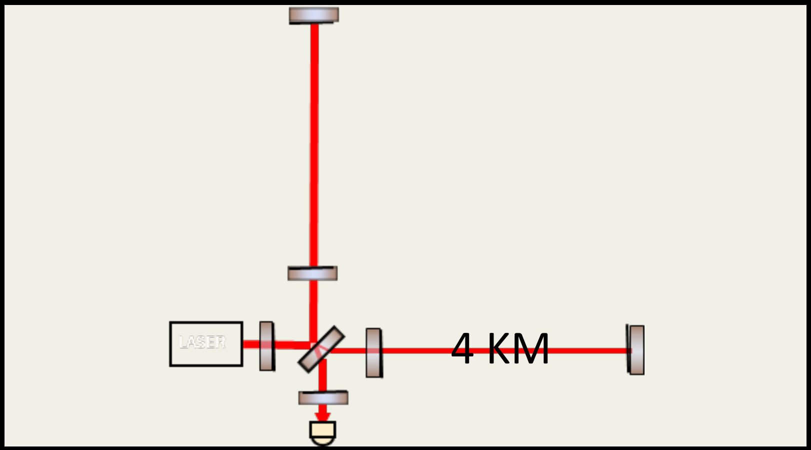
http://www.et-gw.eu/

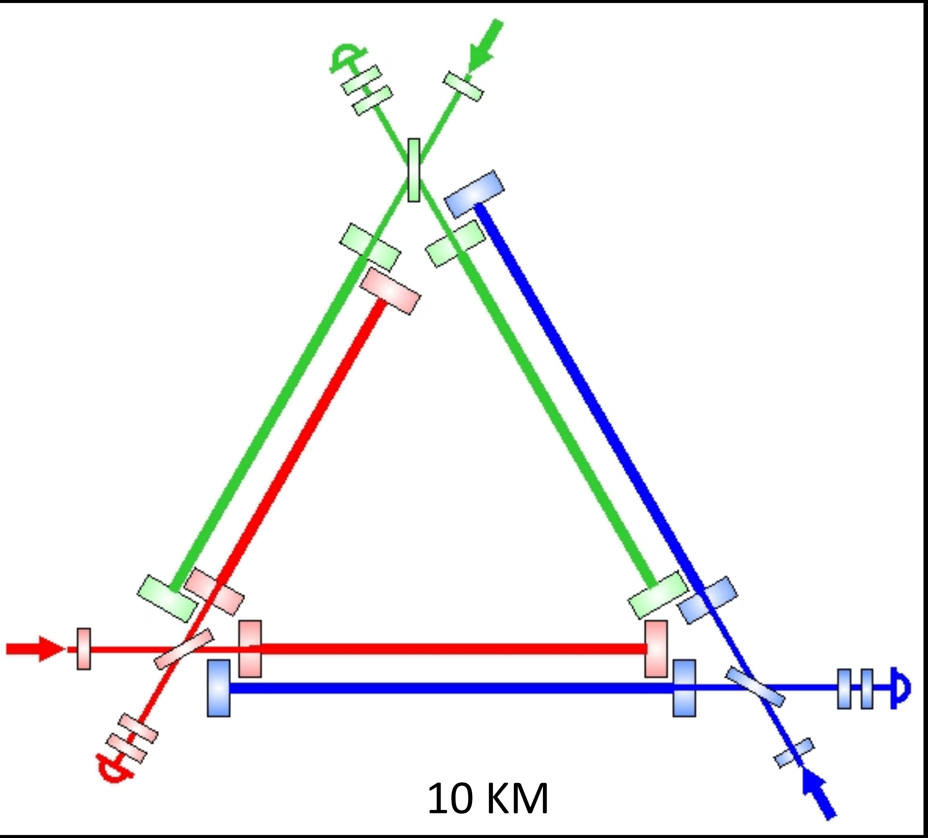
The Einstein Telescope

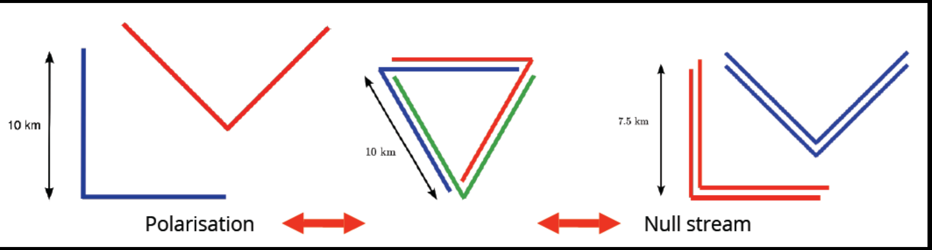
(EU project)



2G → 3G





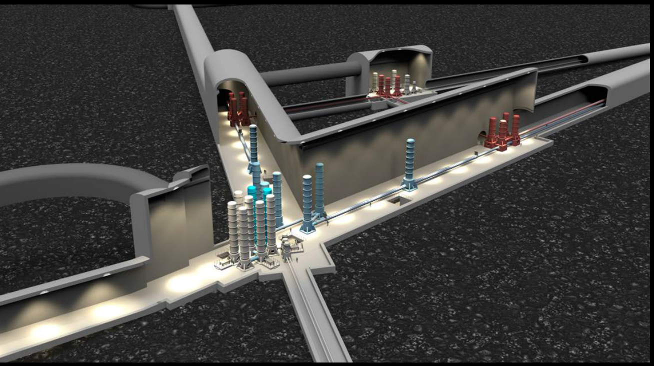


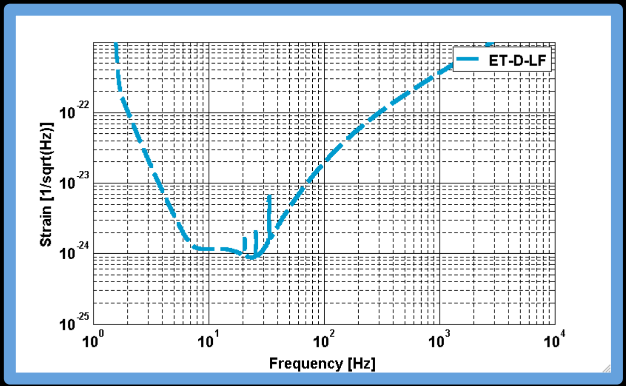
- Underground to suppress seismic and Newtonian noise at low frequencies

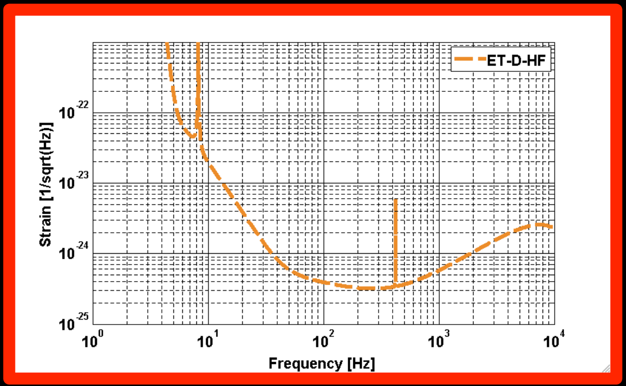
- Longer arms to increase sensitivity

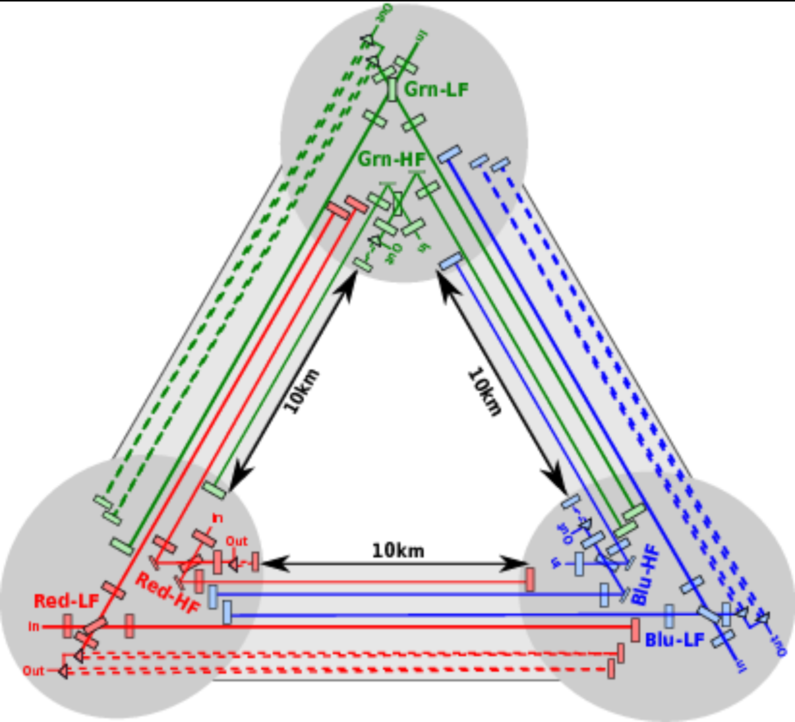
- Triangular E ITF configuration to
  - Measure polarization
  - Auto-calibration / null-stream
  - Redundancy
  - One single big infrastructure (optimization of costs)

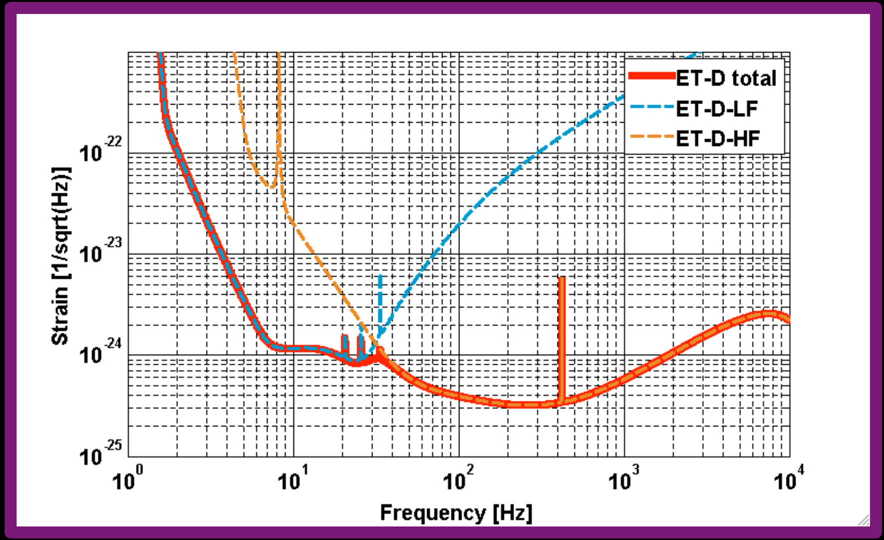
Einstein Telescope (6 in 1) Xylophone



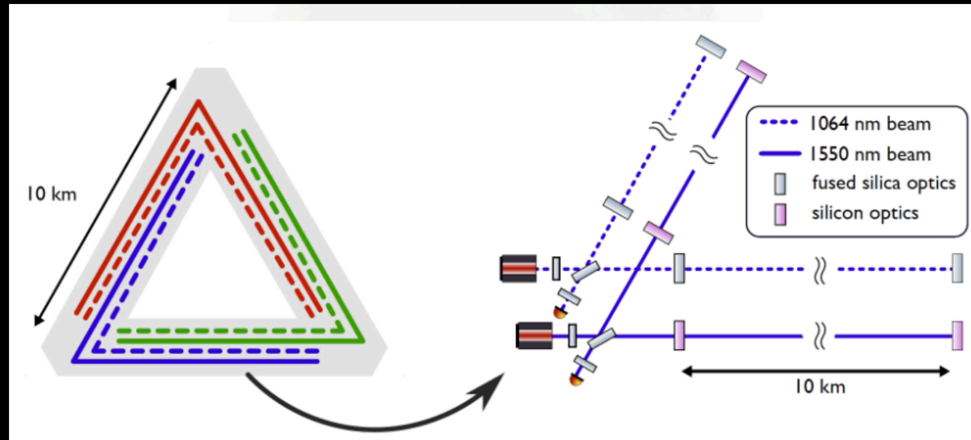


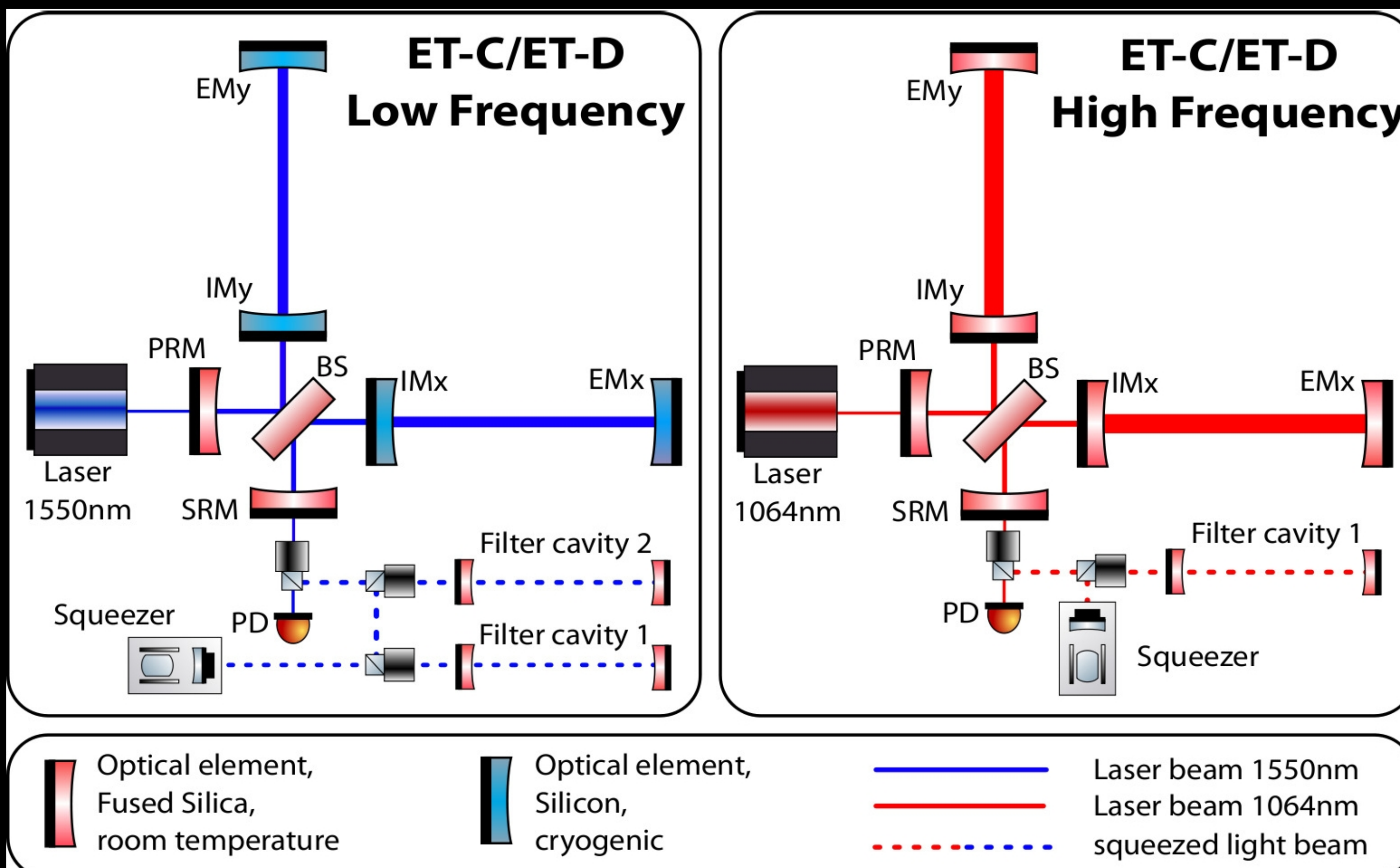




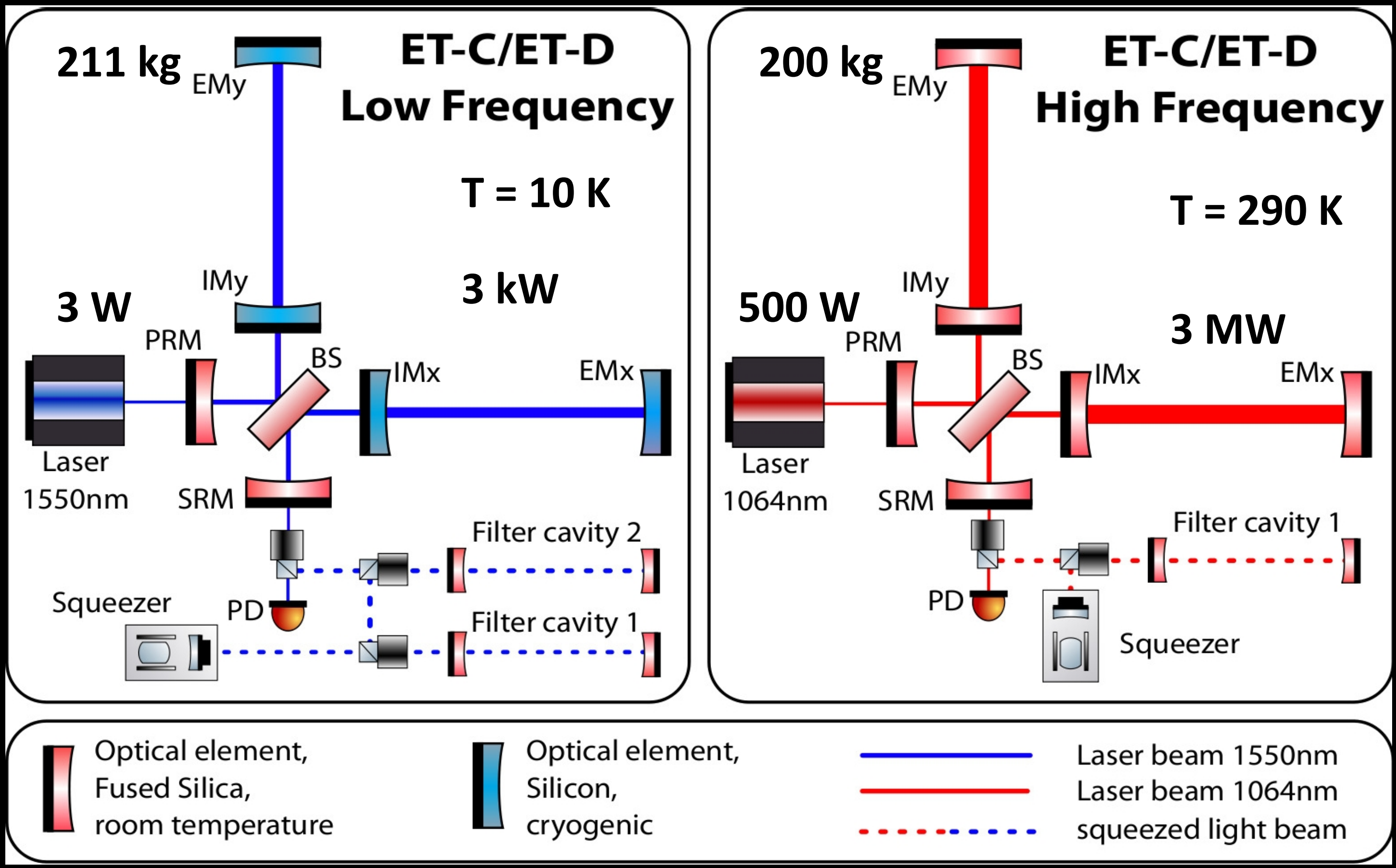


Each interferometer decoupled into 2 devices independent for the best sensitivity to low and high frequency


10 km
1064 nm beam
1550 nm beam
fused silica optics
silicon optics
10 km

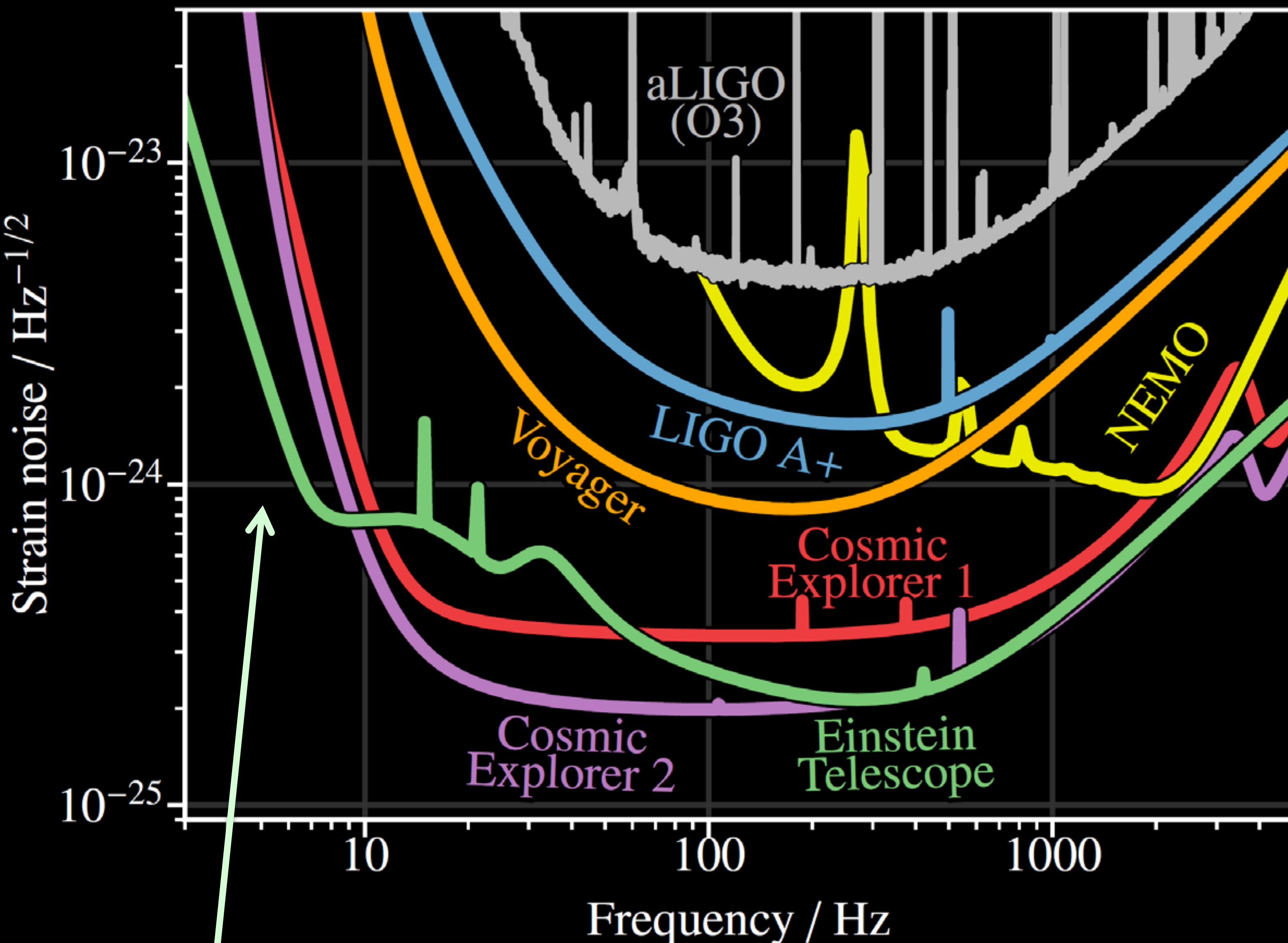

ET-C/ET-D
Low Frequency
EMy
IMy
PRM
BS
IMx
EMx
Laser
1550nm
SRM
Filter cavity 2
Squeezer
PD
Filter cavity 1
ET-C/ET-D
High Frequency
EMy
IMy
PRM
BS
IMx
EMx
Laser
1064nm
SRM
Filter cavity 1
PD
Squeezer
Optical element,
Fused Silica,
room temperature
Optical element,
Silicon,
cryogenic
Laser beam 1550nm
Laser beam 1064nm
squeezed light beam

2G → ET

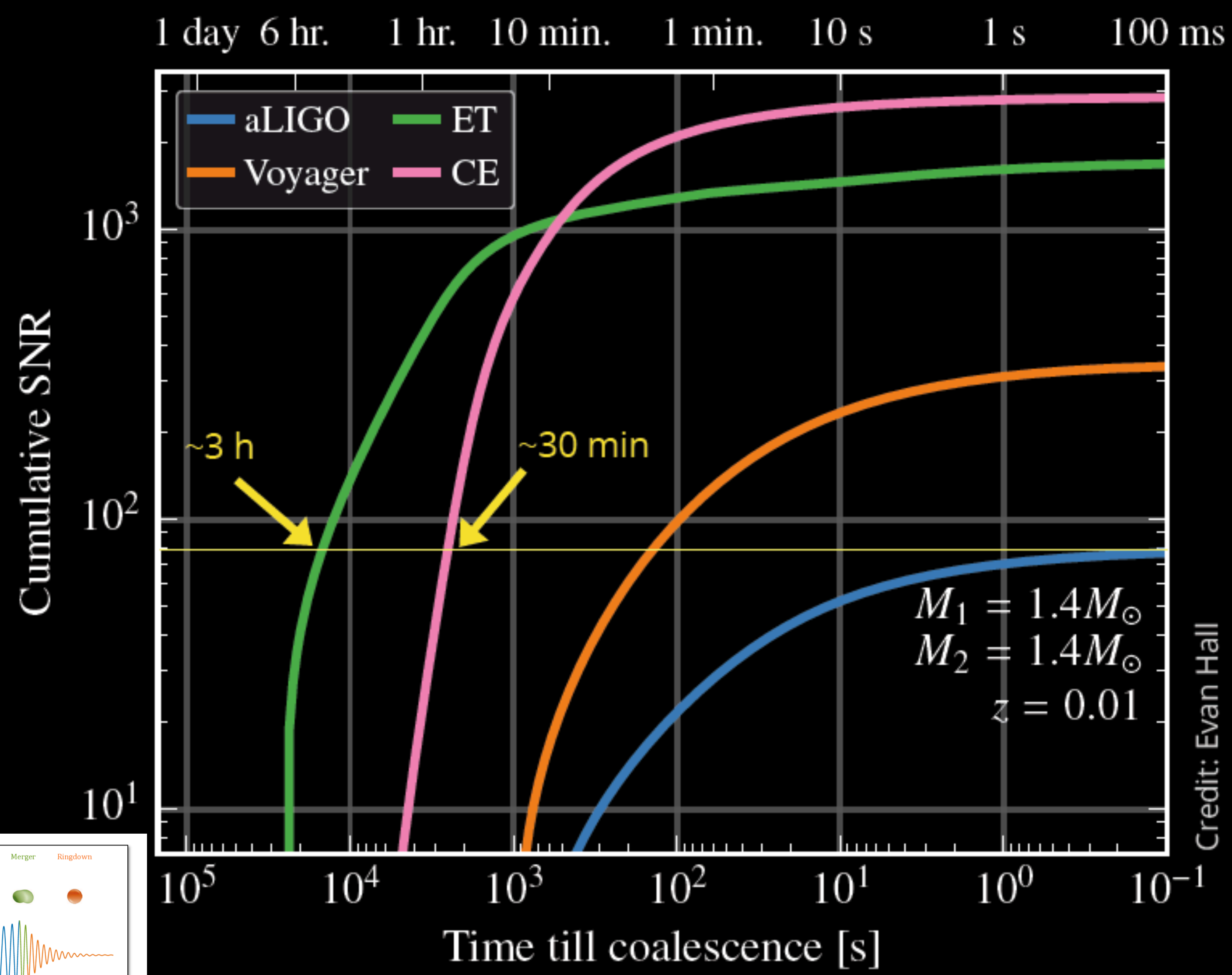


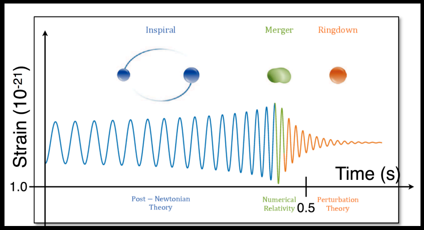
Underground
Cryogenic
Silicon mirrors
1550 nm (Si transparent)
New optical coatings
New suspensions / seismic controls

More powerful lasers
Larger fused silica mirrors
1064 nm (silica transparent)
New optical coatings
New thermal compensation systems



About one order of magnitude improvement w.r.t 2G detectors and an extended sensitivity to low frequencies

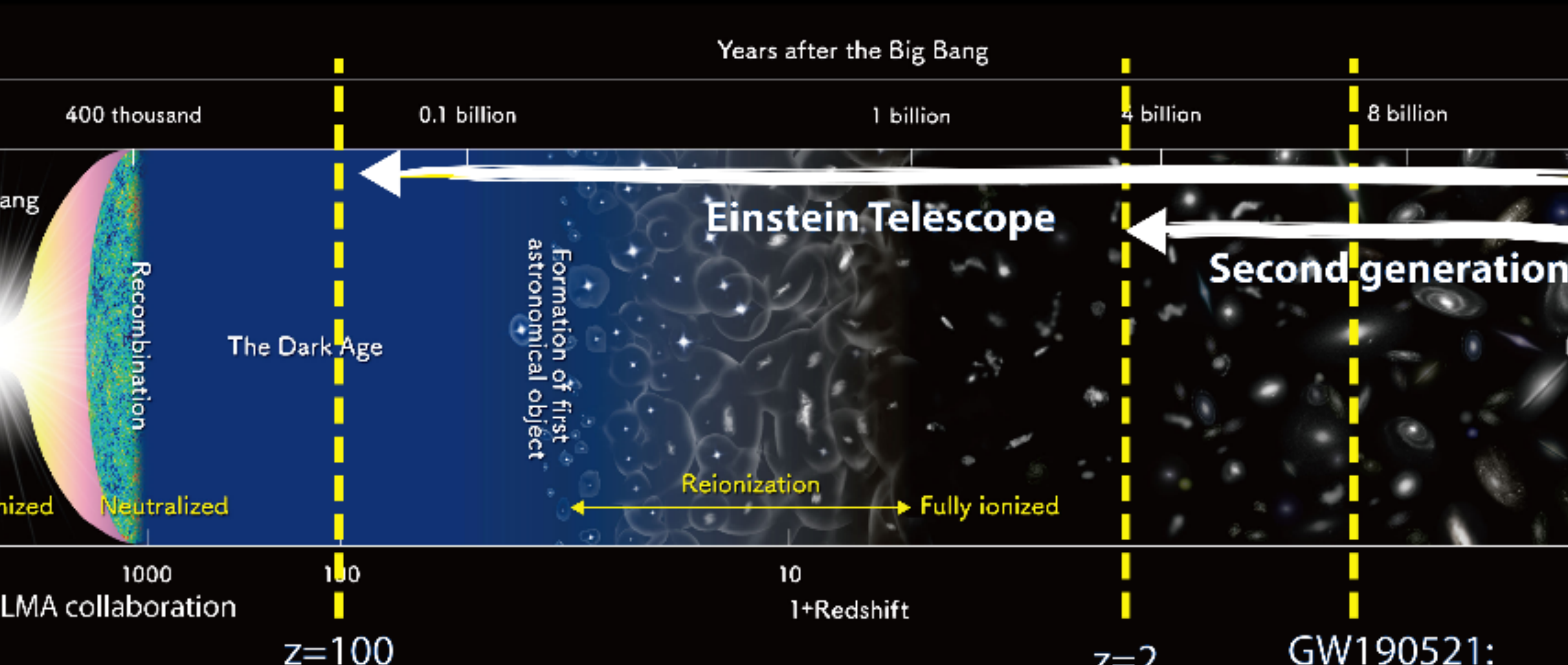




The sensitivity at low frequencies allows for an early detection

→ Very relevant for precise GR tests and facilitates the EM follow-ups.

Detection horizon for black-hole binaries



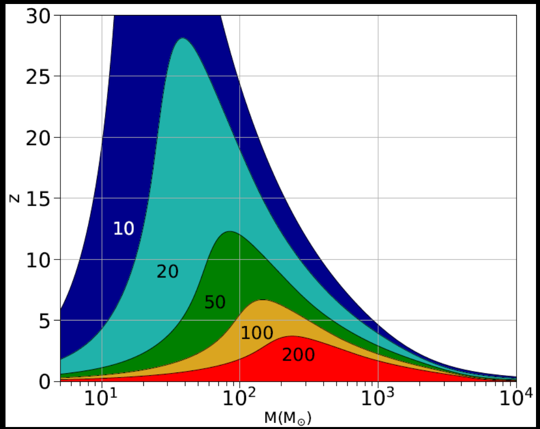
Huge rate of detections (about 1 per minute)

Extended redshift coverage up to the Dark Age

- Test for primordial BH origin
- Cosmology & Cosmography

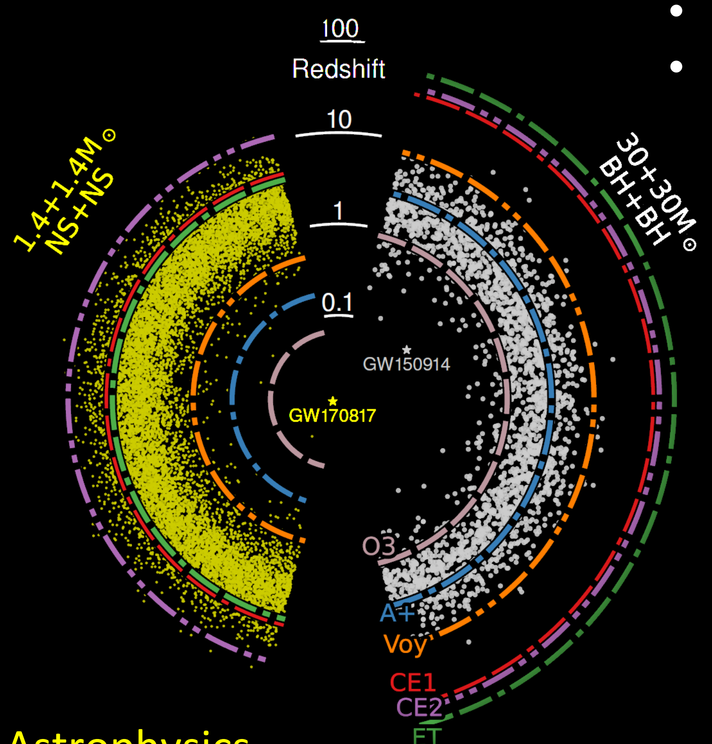
Many events with very large Signal-to-Noise ratios

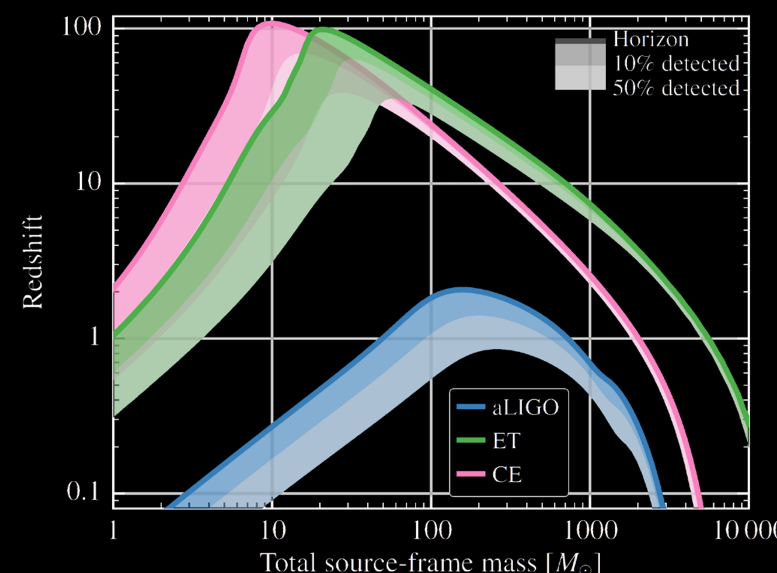
- Precision tests of GR predictions and detailed BH studies



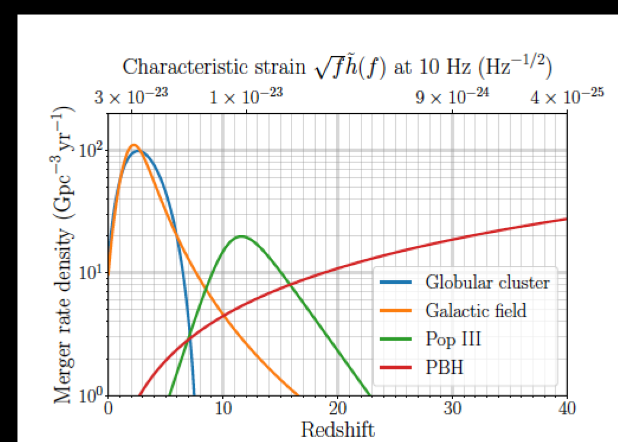
Listening the whole Universe

- 10^6 BH-BH / year up to z ~20 (230 Gpcs) and 10^3 M_{sol}
- 10^5 NS-NS / year up to z~2

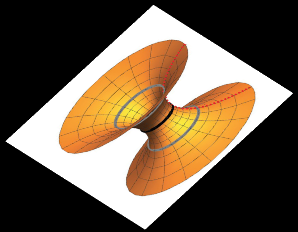


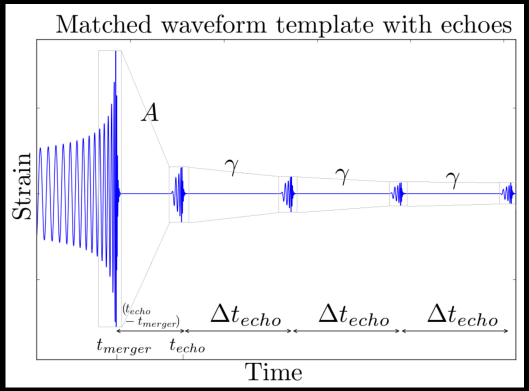


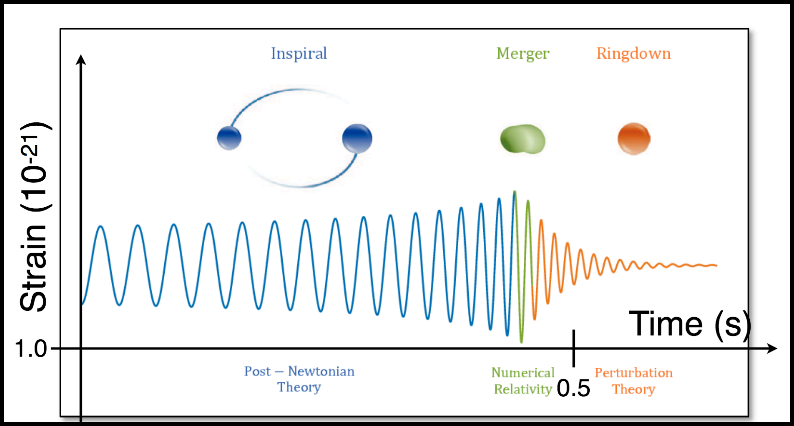
Astrophysics
- BH demography and evolution
- Primordials? Stellar?
- Are BHs part of the dark matter?
- Supernovae, Pulsars, Stochastic signals
- Properties of neutron stars
- Multi Messenger: Optical, Neutrinos, Gamma Rays



General Relativity Tests (I)



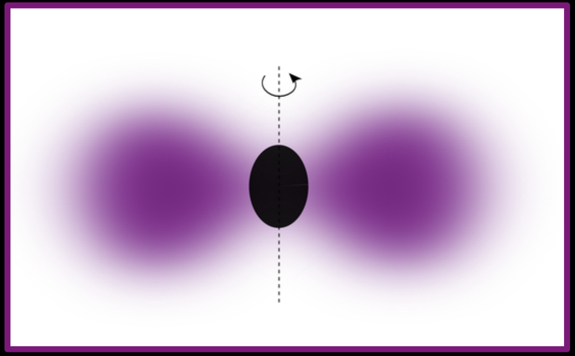


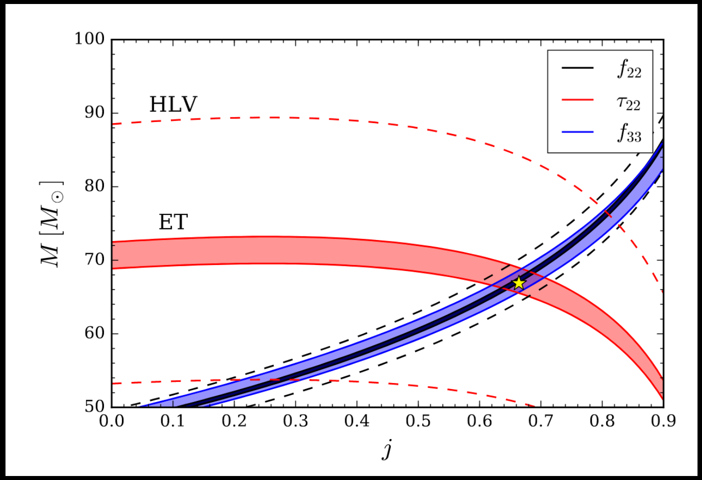


Study of the "ringdown" phase allows for

- GR test near the BH horizon
- "no-hair" theorem test
- Search for exotic objects
- Access to quantum theoretical effects on the event horizon.

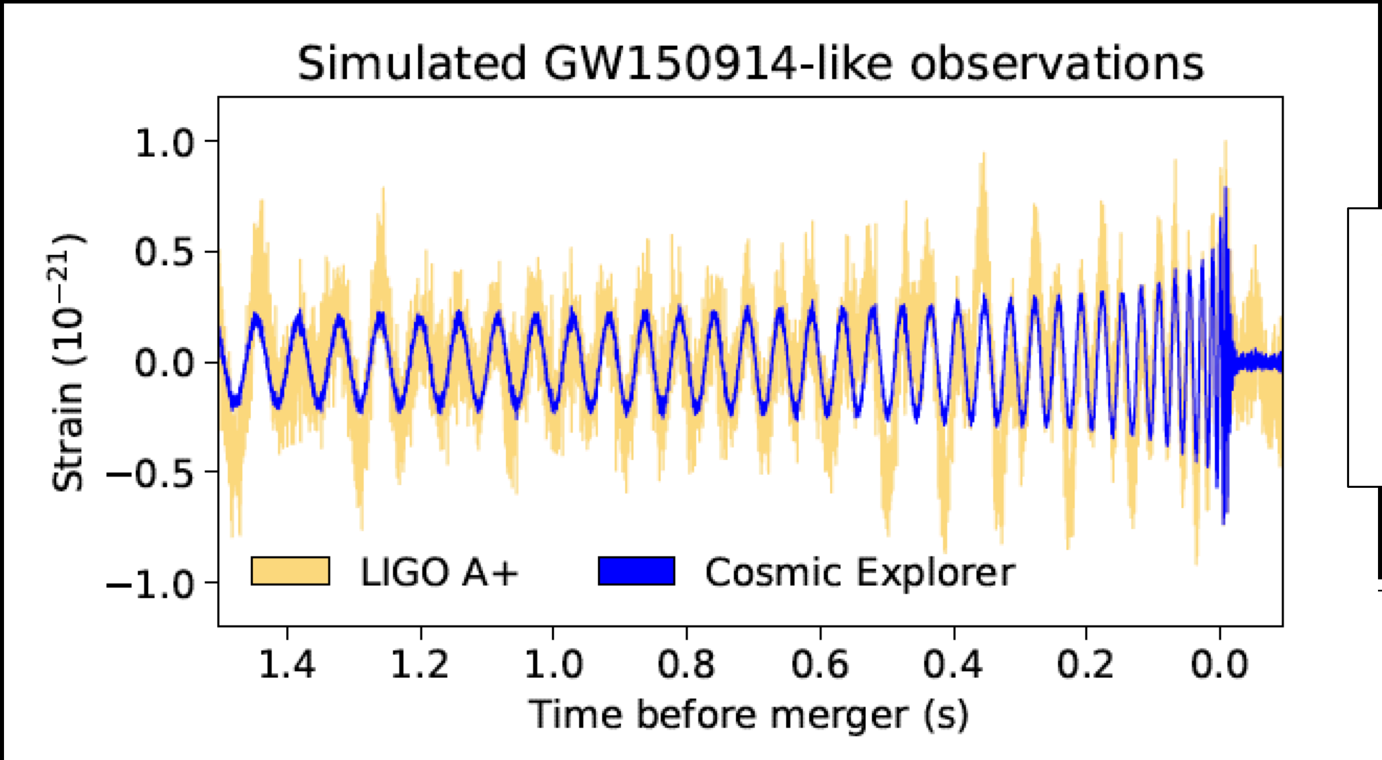
Accurate test of GR predictions in the inspiral phase





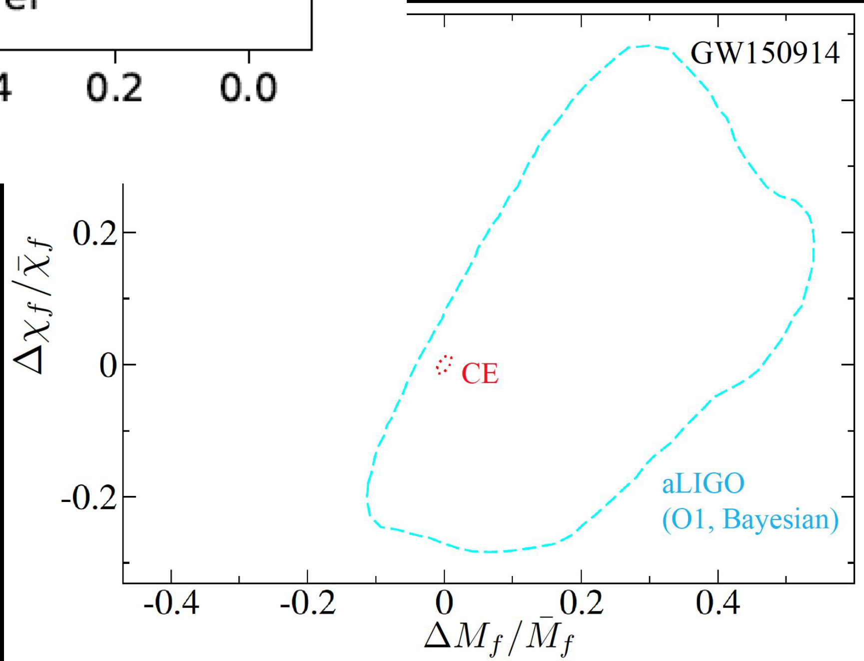
Presence of axion clouds (dark matter)?
Monochromatic gravitational wave signals

General Relativity Tests (cont.)

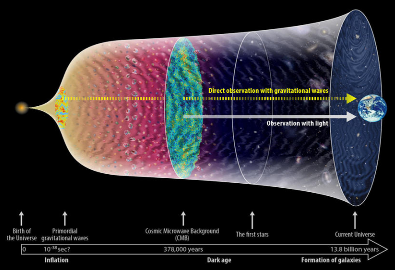


$$\frac{\Delta M_{\rm f}}{\bar{M}_{\rm f}} = 2\frac{M_{\rm f}^{\rm insp} - M_{\rm f}^{\rm postinsp}}{M_{\rm f}^{\rm insp} + M_{\rm f}^{\rm postinsp}},$$

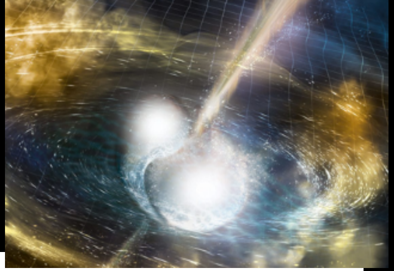
$$\frac{\Delta \chi_{\rm f}}{\bar{\chi}_{\rm f}} = 2\frac{\chi_{\rm f}^{\rm insp} - \chi_{\rm f}^{\rm postinsp}}{\chi_{\rm f}^{\rm insp} + \chi_{\rm f}^{\rm postinsp}},$$



The huge boost in sensitivity and SNR allows for precise tests of GR improving by 2 orders of magnitude compared to 2G results.



Cosmology (I)

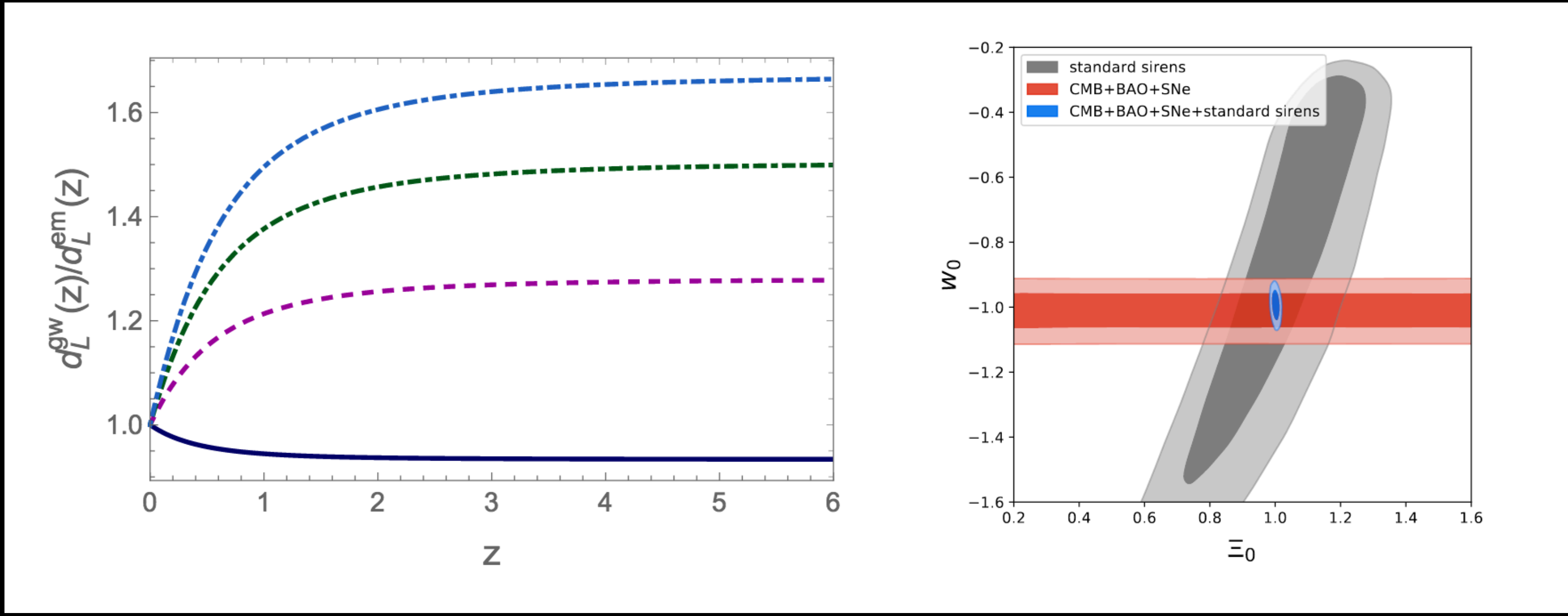


$$d_L(z) = \frac{1+z}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_M (1+z')^3 + \frac{\rho_{\rm DE}(z')}{\rho_0}}},$$

Relationship between light distance and redshift contains information on high redshift cosmology

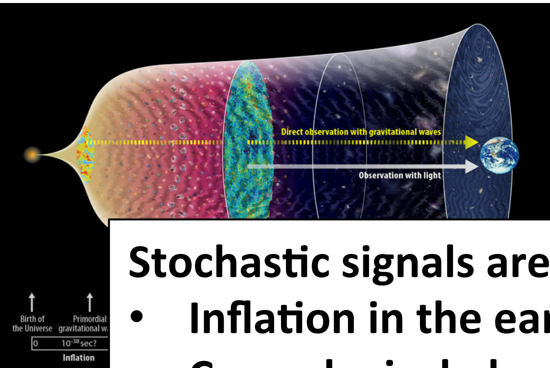
$$\frac{d_L^{\rm gw}(z)}{d_L^{\rm em}(z)} = \Xi_0 + \frac{1-\Xi_0}{(1+z)^n}$$

in models beyond GR

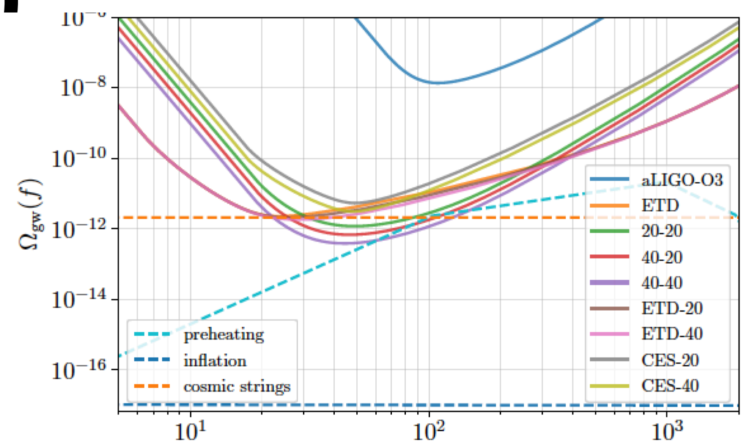


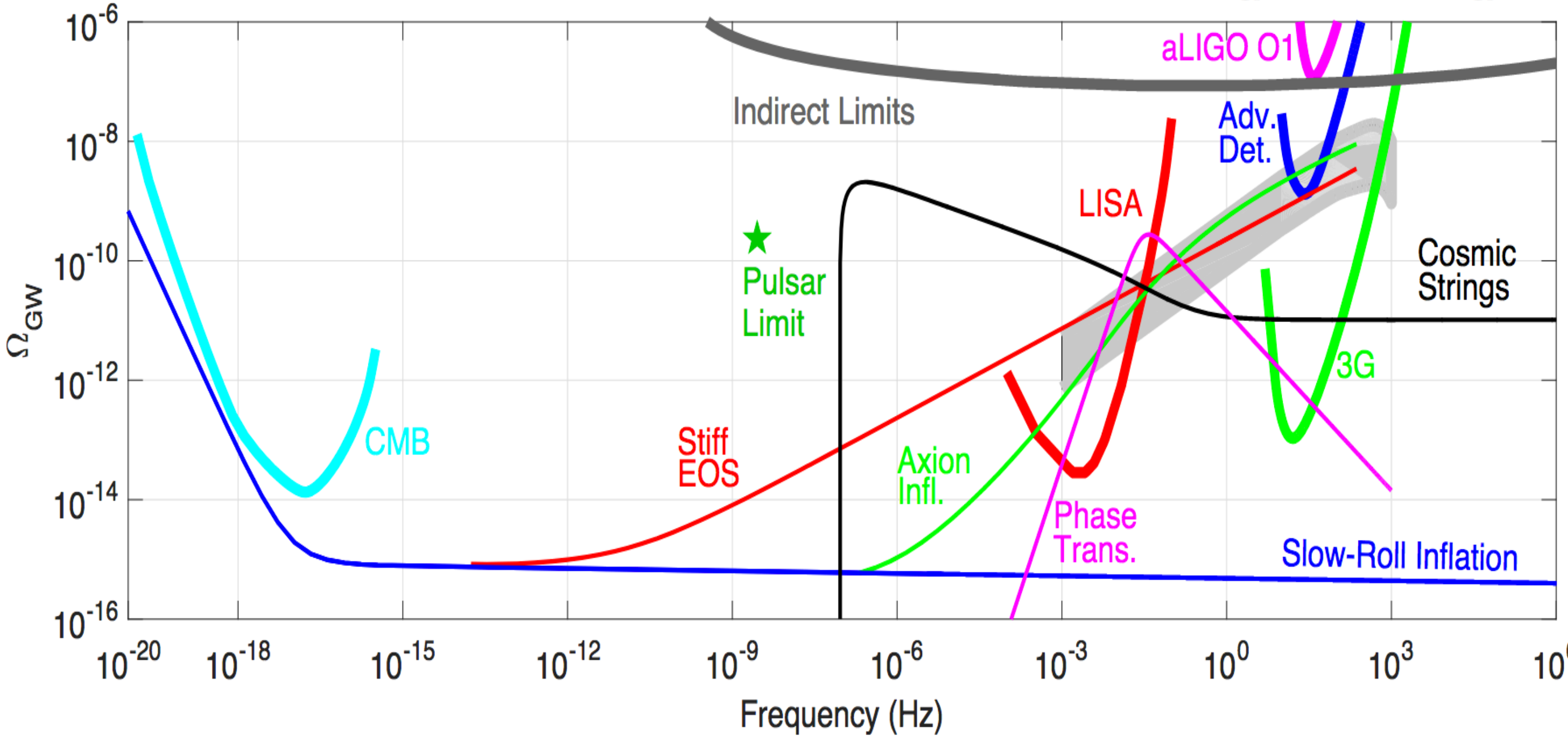
After a few years and collecting a few hundred BNS events ET can do a rigorous test.

Cosmology (II)



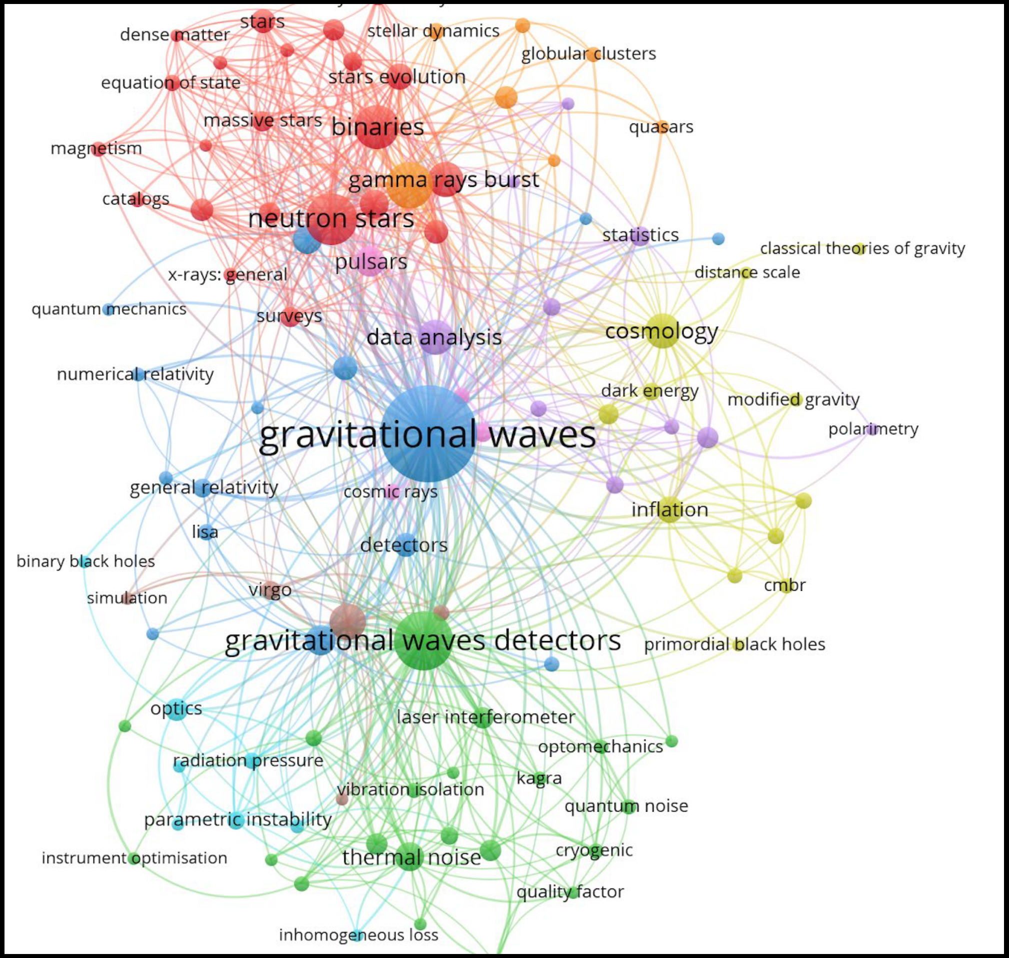
Stochastic signals are a single gate to:
- **Inflation in the early universe**
- **Cosmological phase transitions**
- **Presence of topological defects, cosmic strings**

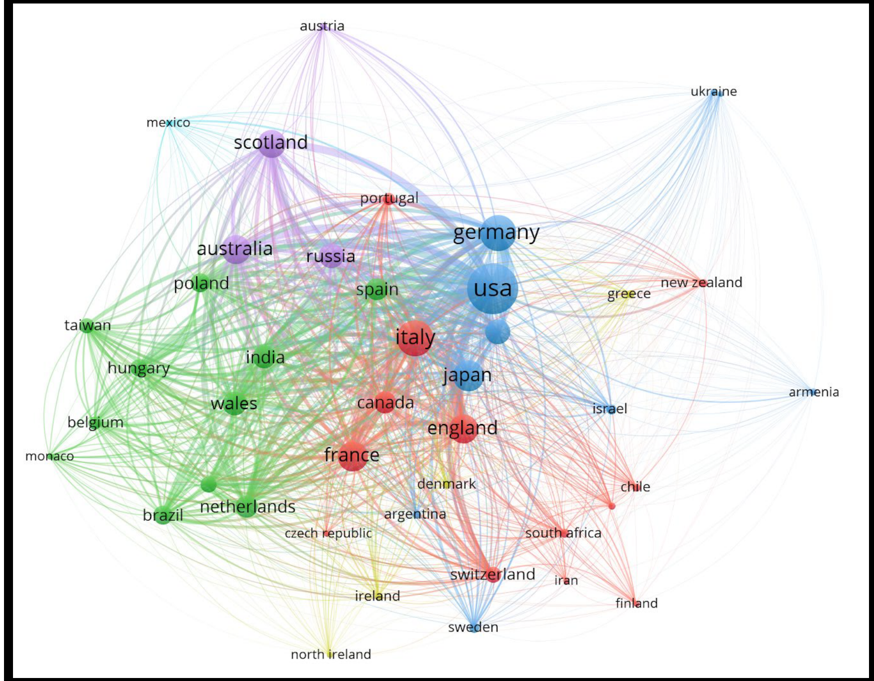




ET and CE provide a window at high frequency → high temperatures

Relation with other communities



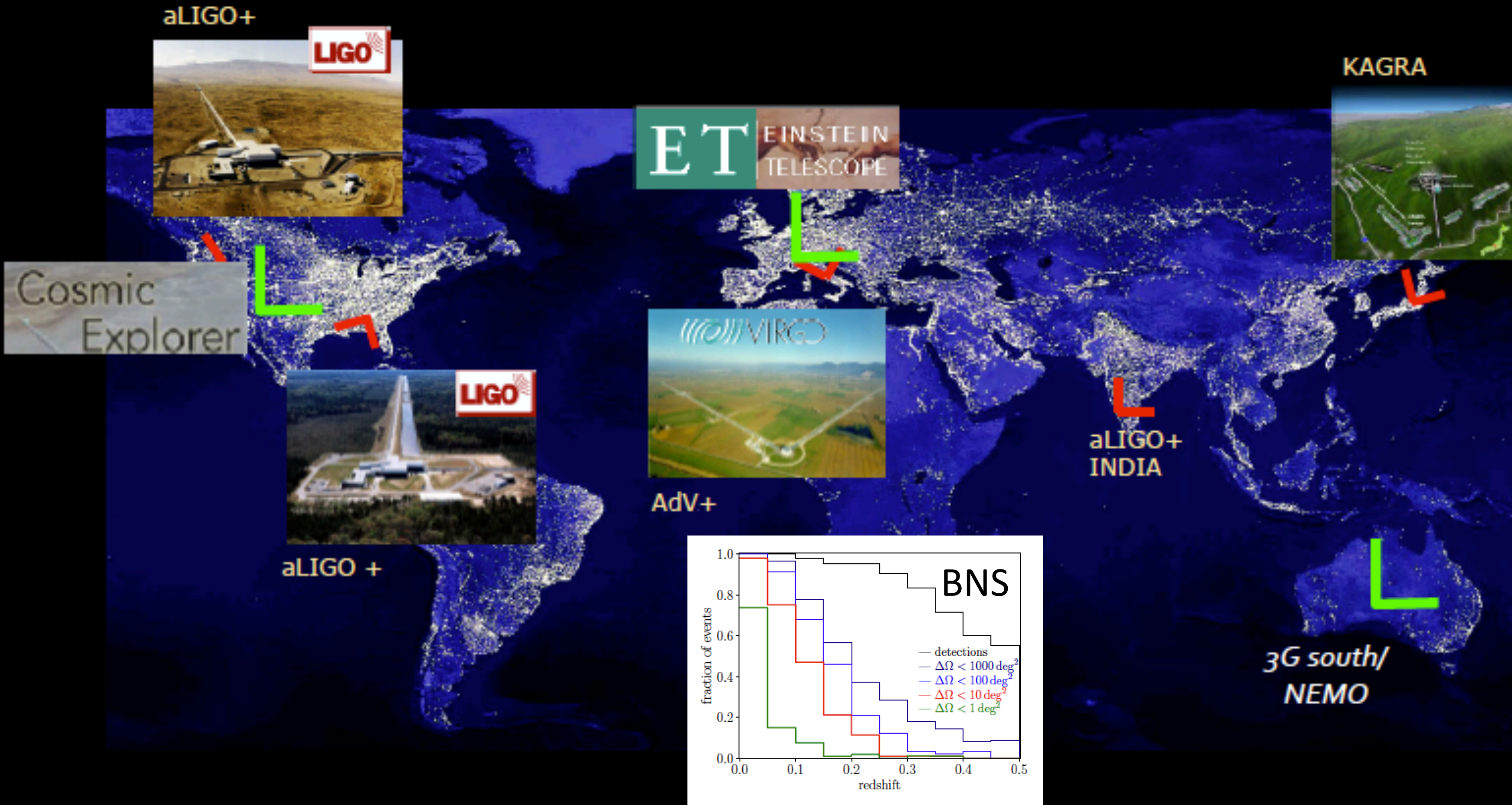


ET have a marked multidisciplinary character and an extensive network of interested communities

Multi-messenger

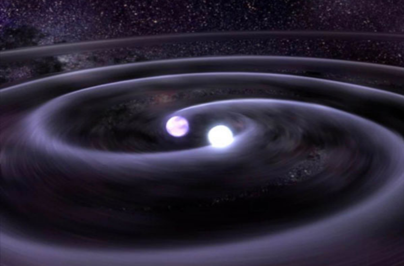
ET will operate in synergy with a number of large infrastructures

15-year scenario



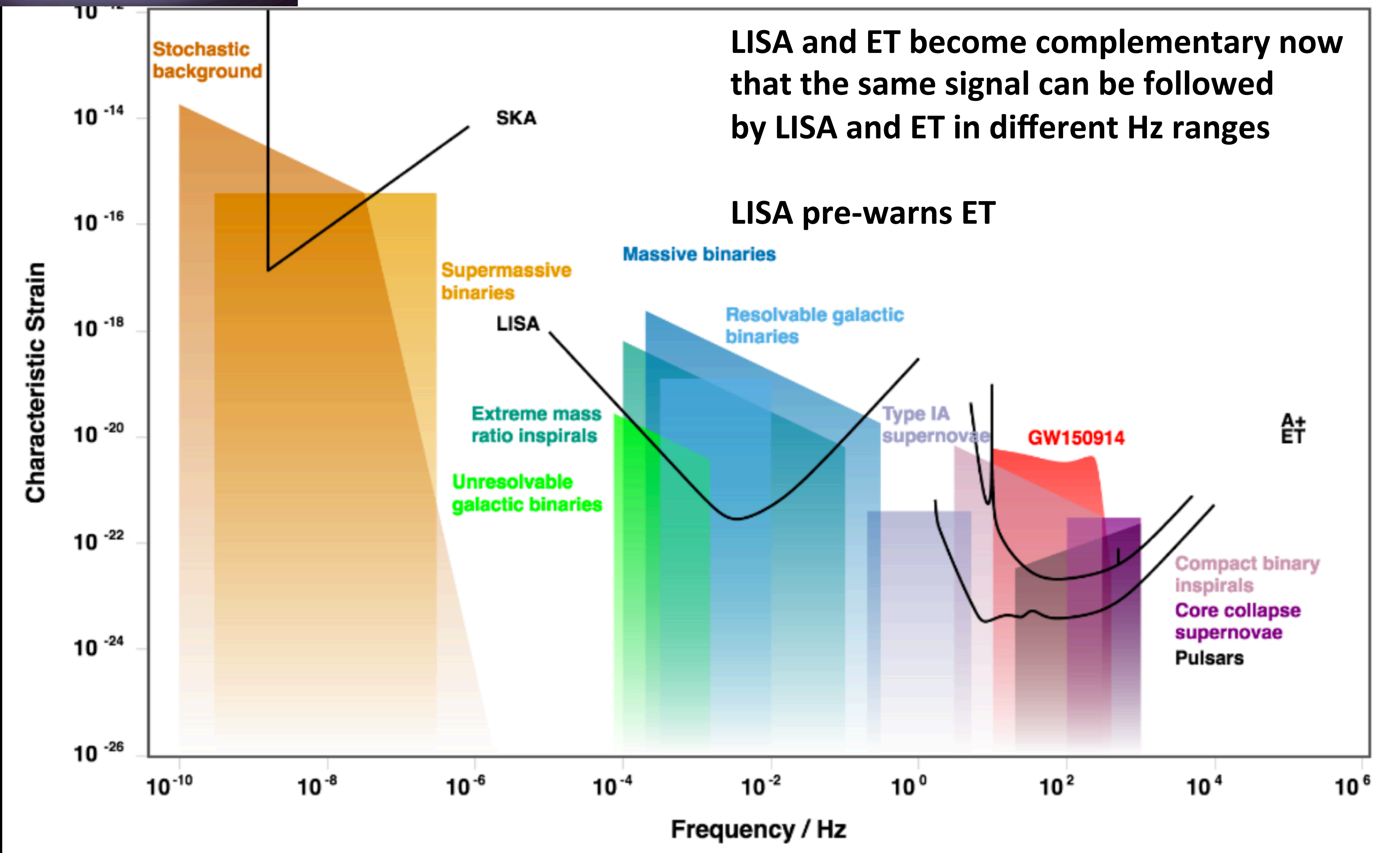
The presence of 2G + ET will allow tracking events in the sky until there is a 3G network

Complementarity



LISA and ET become complementary now that the same signal can be followed by LISA and ET in different Hz ranges

LISA pre-warns ET

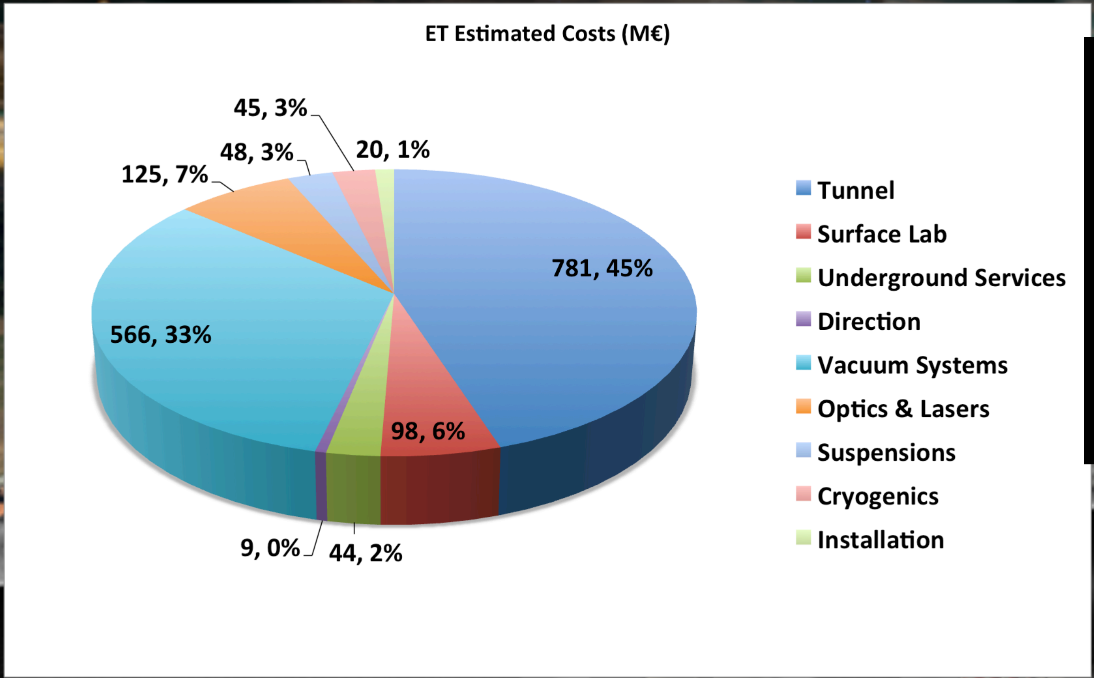


Einstein Telescope timeline

EINSTEIN TELESCOPE

- 2010 ET conceptual design completed
- **2021 Design update, forming the ET collaboration, ESFRI approval** ✓
- 2021 – 2025 stagewise technical report updates (…, preliminary, detailed, …)
- 2021 – 2024 Detailed site characterisation, refine cost evaluation
- **2024/2025 Site Selection**
- 2026 Full Technical Design
- 2027 Infrastructure realisation start (excavation, vacuum system, ….)
- 2032+ detector installation / commissioning / operation (50+ years)

Estimated cost



Preparatory phase (170M€)

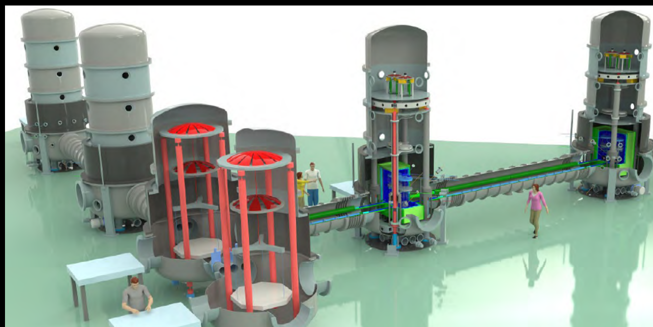
1. Site qualification (funded)
2. Site preparation (50 – 60 M€)
   Covered by host country
3. R&D on technology (95 M€)
   (how much Spain can contribute ?)

Host country is expected to contribute with > 50% of the total cost

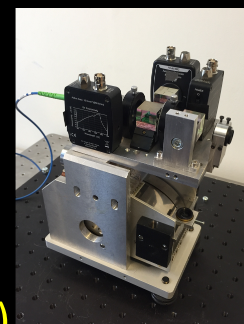
N and Nikhef
ng of O(100M€) each
ts in recent grant applications
aly and The Netherlands

Construction : 1900 M€ (in 10 years)
M&O : 37M€ /year

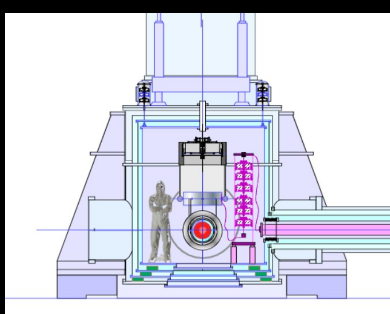
R&D for 3G (examples)



R&D for the production of mirrors up to 200kg based on silica or silicon of high purity and homogeneity.

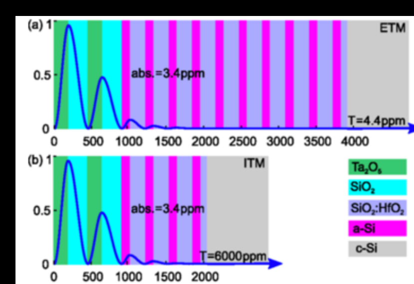


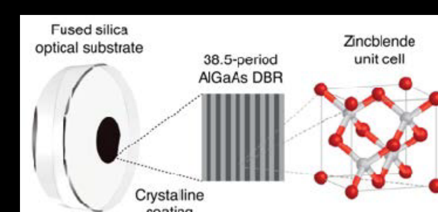
@ Maastricht small-scale prototype
in order to study the operations in
cryogenics with silicon optics at 1550 nm
and with mirrors up to 100 kg (relevant for ET-LF)



R&D in active mitigation
of seismic / Newtonian noise

R&D in optical coatings reflective
with low absorption and reduced
thermal noise.

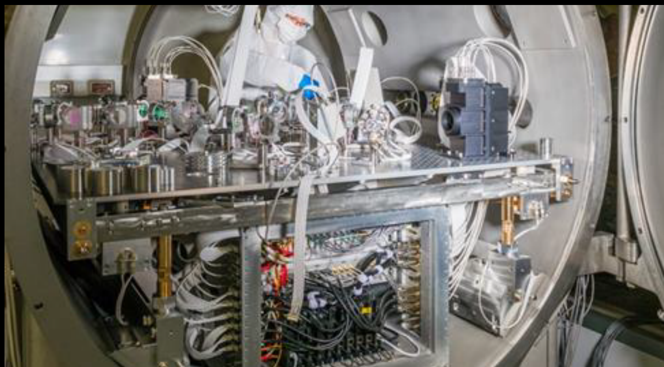




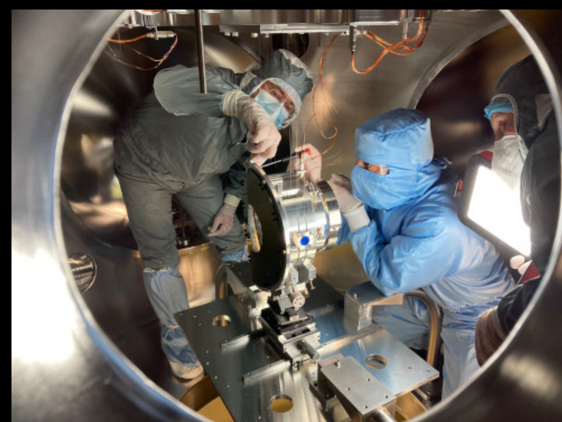
AlGaAs crystalline coatings

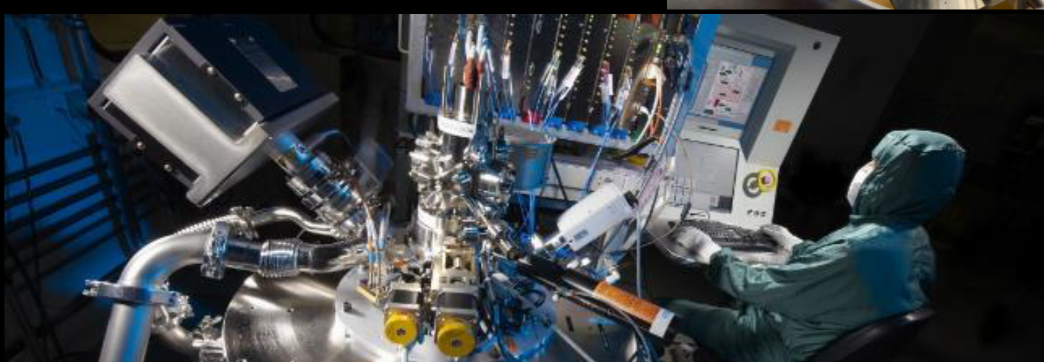
@ Rome and other R&D places
in cryogenic suspension

R&D (technologies)



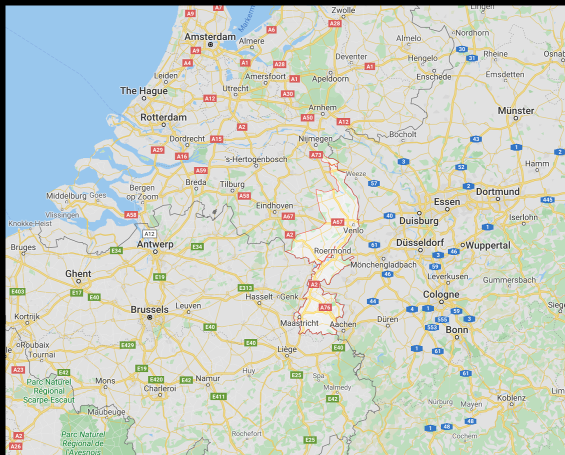
Measure and attenuation of vibrations
Optics, special materials, coatings, lasers
Active IR detection and monitoring
Cryogenics
Vacuum technologies
→ Altogether to reach the O(10^{-21}) precision





Locations ?

30 M€ investment
Lab in construction



30 M€ investment
ETparthfinder

Intensive studies
@ Limburg and
@ Sardinia for
characterize seismic,
environmental noise, etc ...

@ Limburg area (border NL-B-D)
→ Promoted by Nikhef

@ Sardinia
→ Promoted by INFN

?

@ Germany is very present in ET and ETpathfinder
They foresee a large investment in the following years

→ This might become a game changer

Discussions taking place with other countries like France and UK

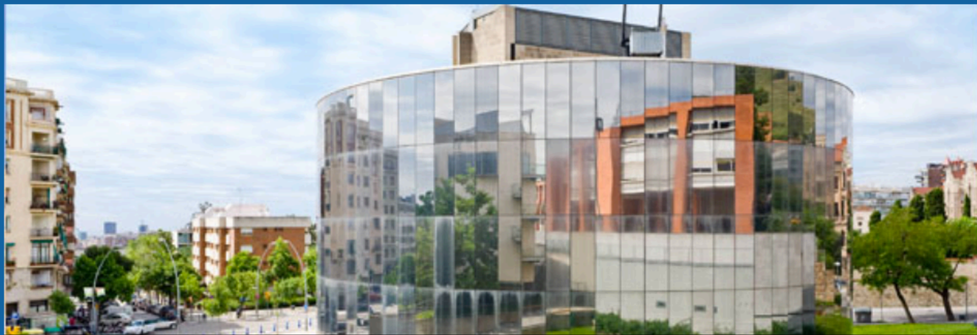
https://www.deutscheszentrumastrophysik.de/de
https://nachrichten.idw-online.de/2021/05/17/wissenschaftsinitiative-plaediert-fuer-deutsches-zentrum-fuer-astrophysik-in-der-lausitz/

News from Germany

German Center of Astrophysics in Saxony

→ Big Data for Astroparticle physics
→ Technology (Si-sensors, Optics)
→ One of the main missions related to ET

Thirdly, the settlement of the European gravitational wave observatory "Einstein Telescope", which is already being planned, is to be examined in the granite stock of Upper Lusatia. **"The granite stock offers ideal conditions, the construction of the telescope under the earth's surface would tie in with the mining tradition of the region and would be an international lighthouse project,"** explains **Christian Stegmann, DESY director for astroparticle physics and supporter of the DZA.**



Spanish Meeting on ET ESFRI proposal preparation

Sponsored by ICE-CSIC-IEEC and IFAE

Back in February 2020 we led the effort to integrate support for the Einstein Telescope across Spain

→ Up to 23 institutions, including 4 "Singular Research Infrastructures" expressed interest

→ Translated into Spain politically supporting ET

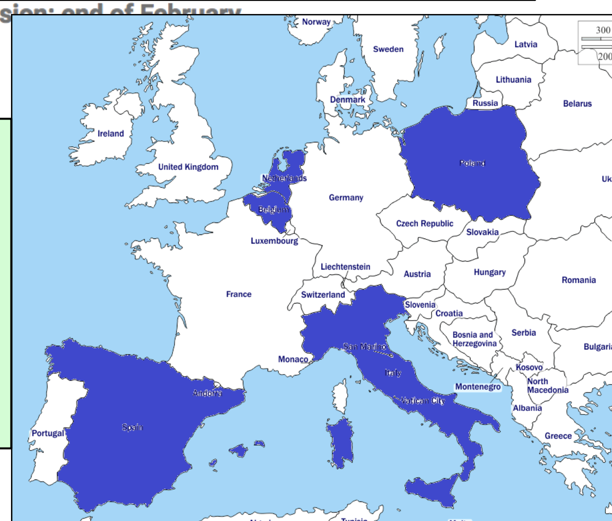
41 institutions in the ET Consortium now

Deadline for submission: end of February

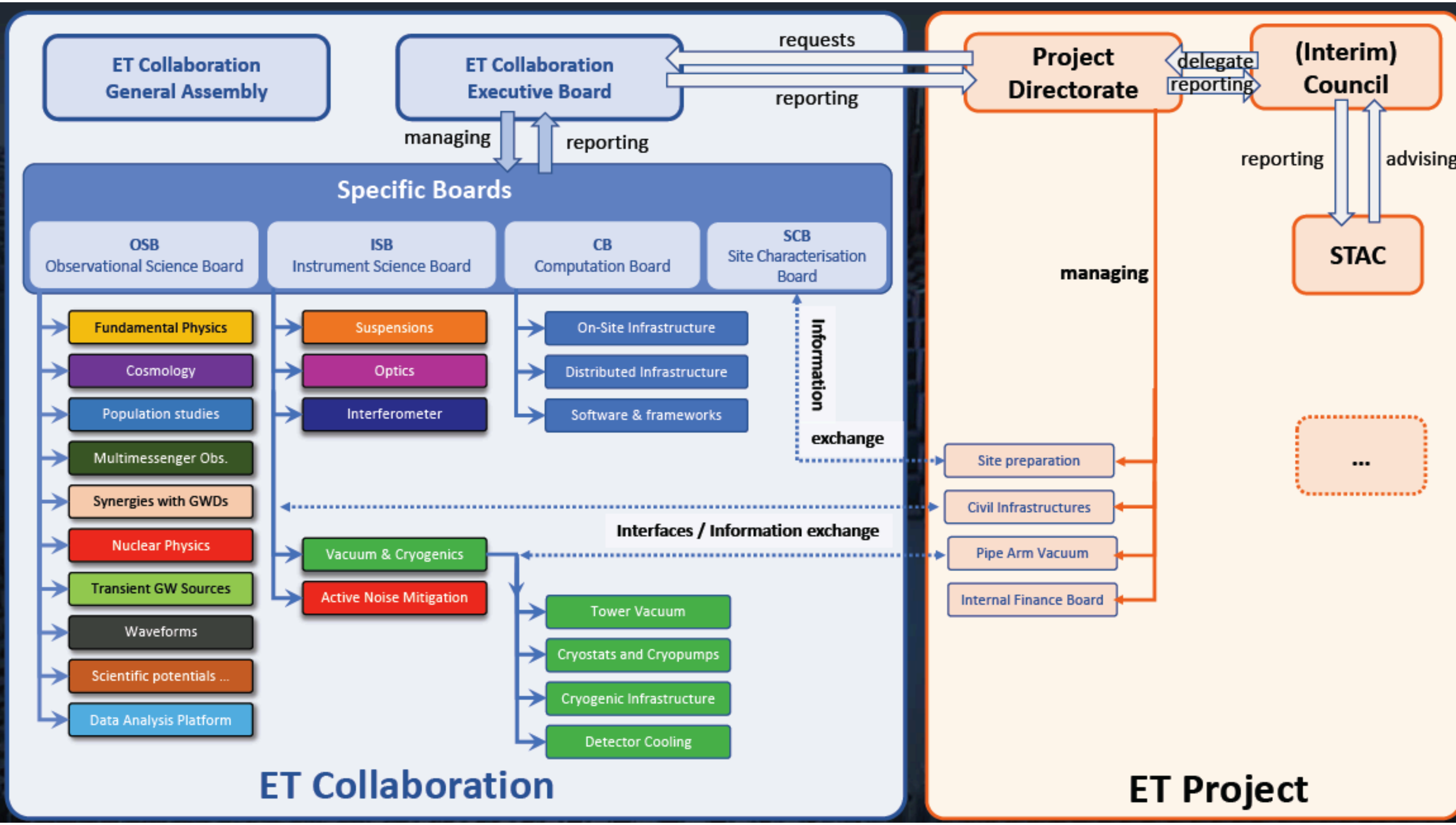
INSTRUCTIONS FOR INSTITUTIONS

June 30th 2021: The Einstein Telescope is included in the 2021 ESFRI roadmap !!

MINUTES of the MEETING



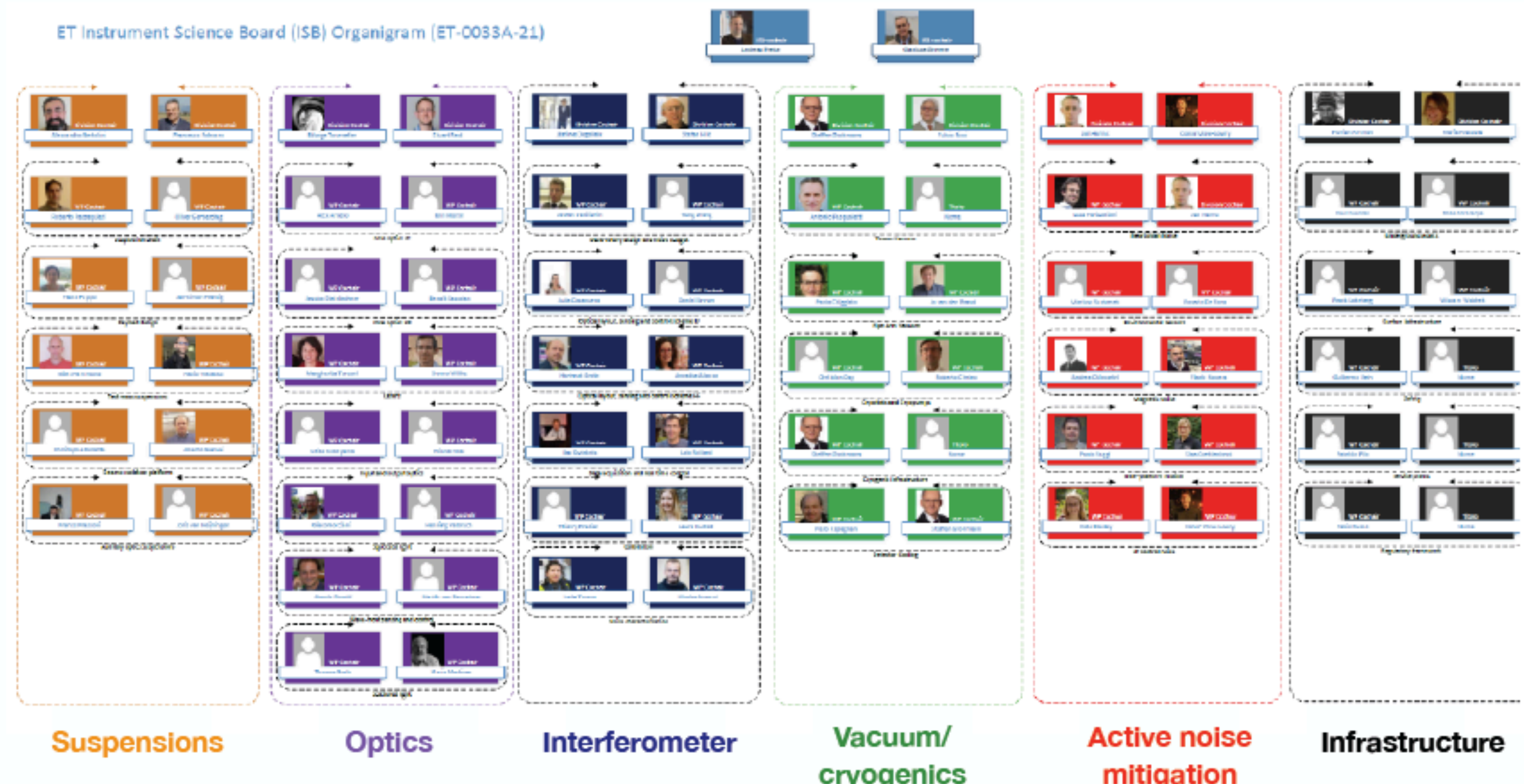
Governance



Ongoing discussion with all the countries that supported ESFRI candidature (France, Germany and UK also present) → Interim Council being formed now

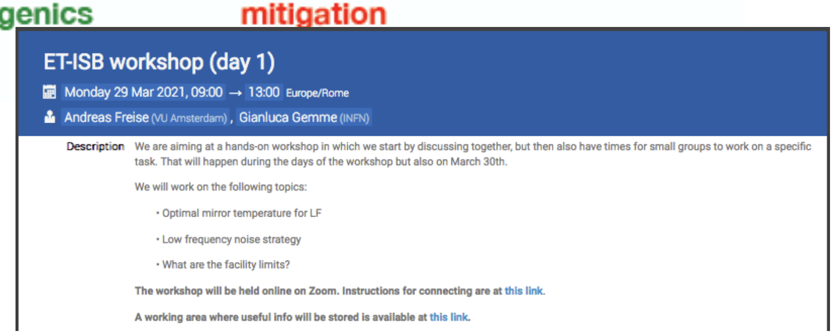
Instrument science board (ISB)

https://wiki.et-gw.eu/ISB/WebHome



A first workshop took place on 29th – 31st March
https://indico.ego-gw.it/event/173/

Second workshop on Sept 3rd and Sept 16th
https://indico.in2p3.fr/event/24903/



ET-ISB workshop (day 1)

Monday 29 Mar 2021, 09:00 → 13:00 Europe/Rome

Andreas Freise (VU Amsterdam), Gianluca Gemme (INFN)

Description: We are aiming at a hands-on workshop in which we start by discussing together, but then also have times for small groups to work on a specific task. That will happen during the days of the workshop but also on March 30th.

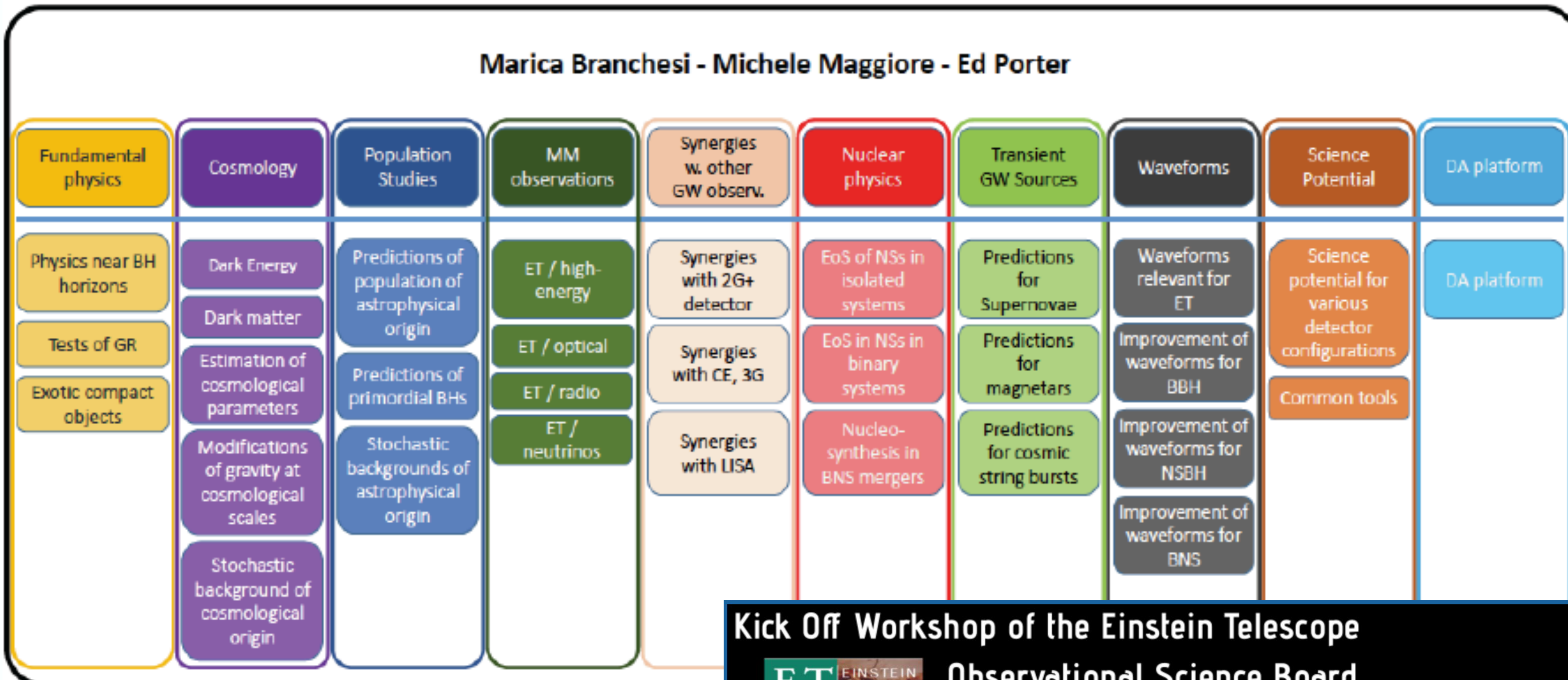
We will work on the following topics:

- Optimal mirror temperature for LF
- Low frequency noise strategy
- What are the facility limits?

The workshop will be held online on Zoom. Instructions for connecting are at this link.

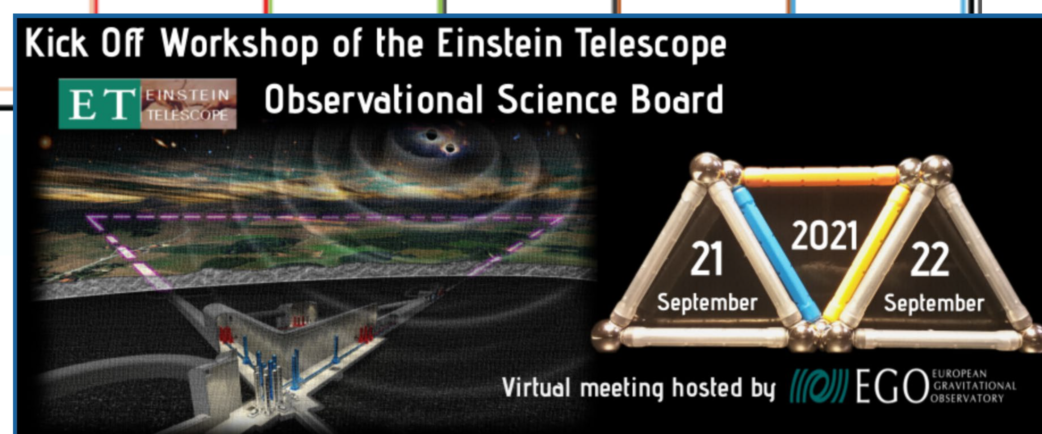
A working area where useful info will be stored is available at this link.

Observational science board (OSB)



Science Board being organized

September 21st and 22nd
https://indico.ego-gw.it/event/240/



Spain

Growing tendency in Spain to support GW

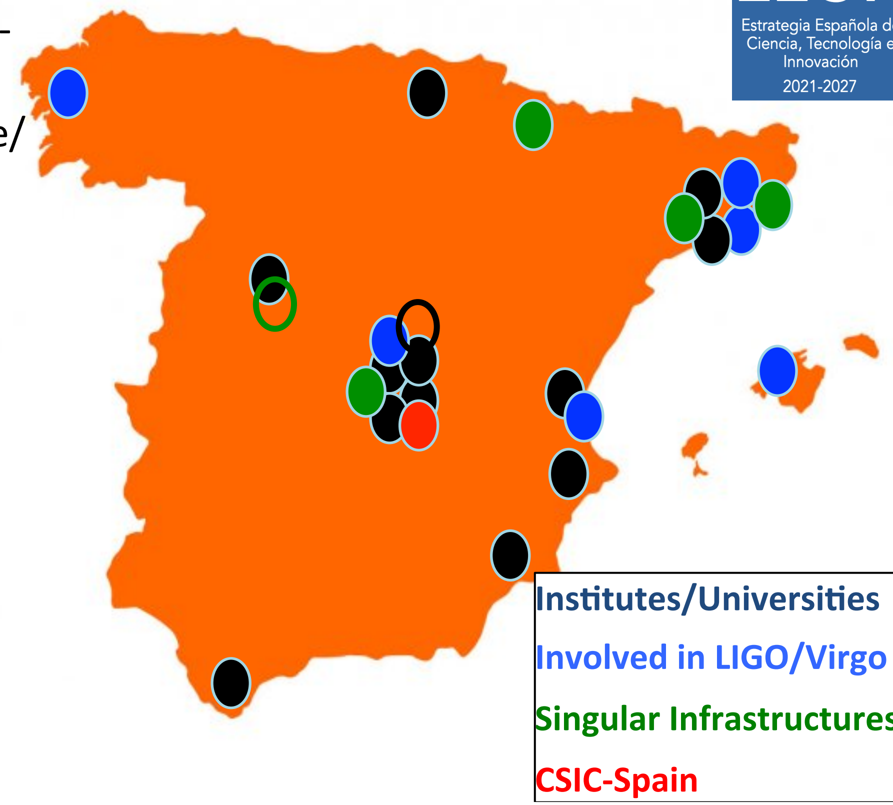
- Letter of support for ET signed by 23 Spanish institutions, including the Spanish Research Council (CSIC) and “four singular infrastructures as the BSC-Super-Computing Center or the ALBA-Synchrotron in Barcelona” that can provide significant hardware/computing resources.
- Other centers being recently contacted like the Laser Singular infrastructure in Salamanca or the Institute for Optics in Madrid

After ESFRI approval GW community may request significant funding for Preparatory phase

→ Community getting organized to act coherently

The research on GWs has been included explicitly in the Spanish Strategic plan for Science, Technology and Innovation (EECTI) 2021-2027

EECTI Estrategia Española de Ciencia, Tecnología e Innovación 2021-2027



Besides Univ. Valencia also Barcelona Univ. and IFAE Barcelona joined Virgo in preparation of ET.

Latest addition was Autonomous University of Madric

Other centers in LIGO and LISA also interested in ET.

ET-Spain Meeting 8th October
(CSIC headquarters)

10:30 → 12:00 **Overview**

- 10:30 **Welcome** — 15m
  Speaker: CSIC Management
- 10:45 **Science Case** — 25m
  Speaker: Juan Garcia-Bellido (IFT-CSIC/UAM)
- 11:10 **Overview ET project & Experimental Challenges** — 30m
  Speaker: TBC
- 11:40 **ET Computing and challenges** — 20m
  Speaker: Stefano Bagnasco (INFN)

Register to the Event

12:00 → 12:20 Coffee break — 20m

12:20 → 13:20 **Interaction with funding agency**

13:20 → 14:20

1h slot reserved for feedback from IAE-Ministry / CDTI

14:20 → 16:40 **Contributions from Groups**

16:40 → 17:00 Coffee break — 20m

17:00 → 17:40 **Organization**

- 17:00 **ET-Spain organization**
- 17:20 **Final Discussion and Closeout**

Discussion on organization as a community
In preparation for Horizon 2020 calls
In view of Spain taking leadership in some WPs

https://indico.ifae.es/event/1171/

Horizon ESFRI Initiatives

Will be used to define the project office (not so much for R&D on technology)

But technical work for

1. Cost Estimates
2. Governance
3. Project planning
4. Enlarge ET community
5. ENV impact
6. Enhance interest in the Society
7. .....

O(5M€) grant

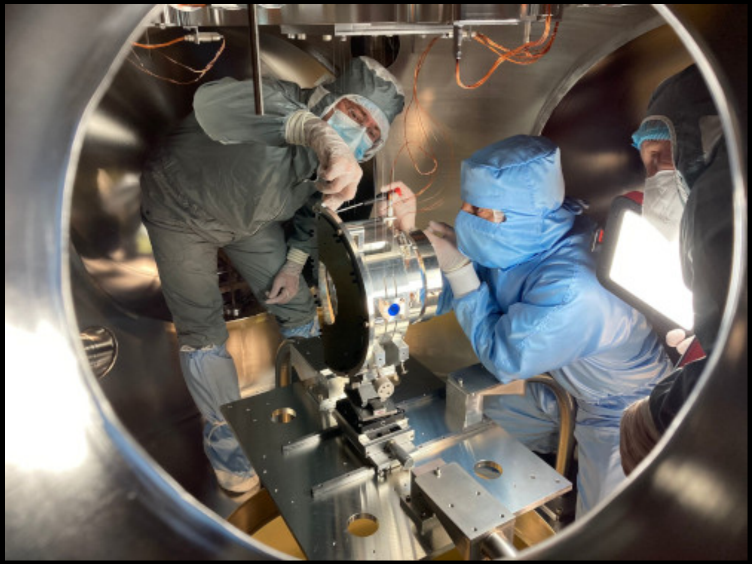
Work packages being defined now

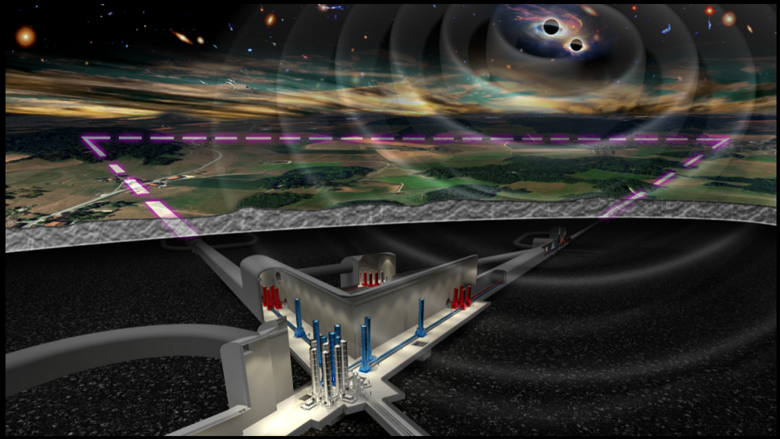
In close contact with Ministry : Spain will need to determine the strategy to follow

- Portfolio of Industrial Capacities
- Landscape of potential returns at long term
- Technologies involved and roles of the search groups

→ Will need full involvement of ET interested community in Spain

Opening new window.....





- The field of gravitational waves is / will be one of the main lines of research in Fundamental Physics, Astrophysics and Cosmology in the coming decades.
- New window to the early universe and inflation.
- Detailed study of BHs and NSs.
- Towards the understanding of Gravity at the quantum level?
- After the success of LIGO / Virgo, it is time to prepare for the next generation.
- ET is the leading EU 3G projects today… and Spain will be part of it[!!?].


¡Gracias por su atención !

Einstein Telescope's science in a nutshell

ET will serve a vast scientific community: fundamental physics, astronomy, astrophysics, particle physics, nuclear physics and cosmology

ASTROPHYSICS

- **Black hole properties**
  - origin (stellar vs. primordial)
  - evolution, demography
- **Neutron star properties**
  - interior structure (QCD at ultra-high densities, exotic states of matter)
  - demography
- **Multi-band and -messenger astronomy**
  - joint GW/EM observations (GRB, kilonova,...)
  - multiband GW detection (LISA)
  - neutrinos
- **Detection of new astrophysical sources**
  - core collapse supernovae
  - isolated neutron stars
  - stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS & COSMOLOGY

- **The nature of compact object**s
  - near-horizon physics
  - tests of no-hair theorem
  - exotic compact objects
- **Tests of General Relativity**
  - post-Newtonian expansion
  - strong field regime
- **Dark matter**
  - primordial BHs
  - axion clouds, dark matter accreting on compact objects
- **Dark energy and modifications of gravity on cosmological scales**
  - dark energy equation of state
  - modified GW propagation
- **Stochastic backgrounds of cosmological origin**
  - inflation, phase transitions, cosmic strings

SPB: ET sites under characterisation

Euregio Meuse-Rhine

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

Sardinia

- Long standing characterisation of the mine in one of the corners continuing
  - Seismic, magnetic and acoustic noise characterisation ongoing at different depth in the mine
- Underground laboratory under construction (SarGrav)
- Two ~290m boreholes have been excavated and they will be equipped in the next weeks
- Intense & international surface investigations programme in Summer/Fall 2021
- ~30M€ funding through national and regional funds