European strategy from Virgo to Einstein Telescope

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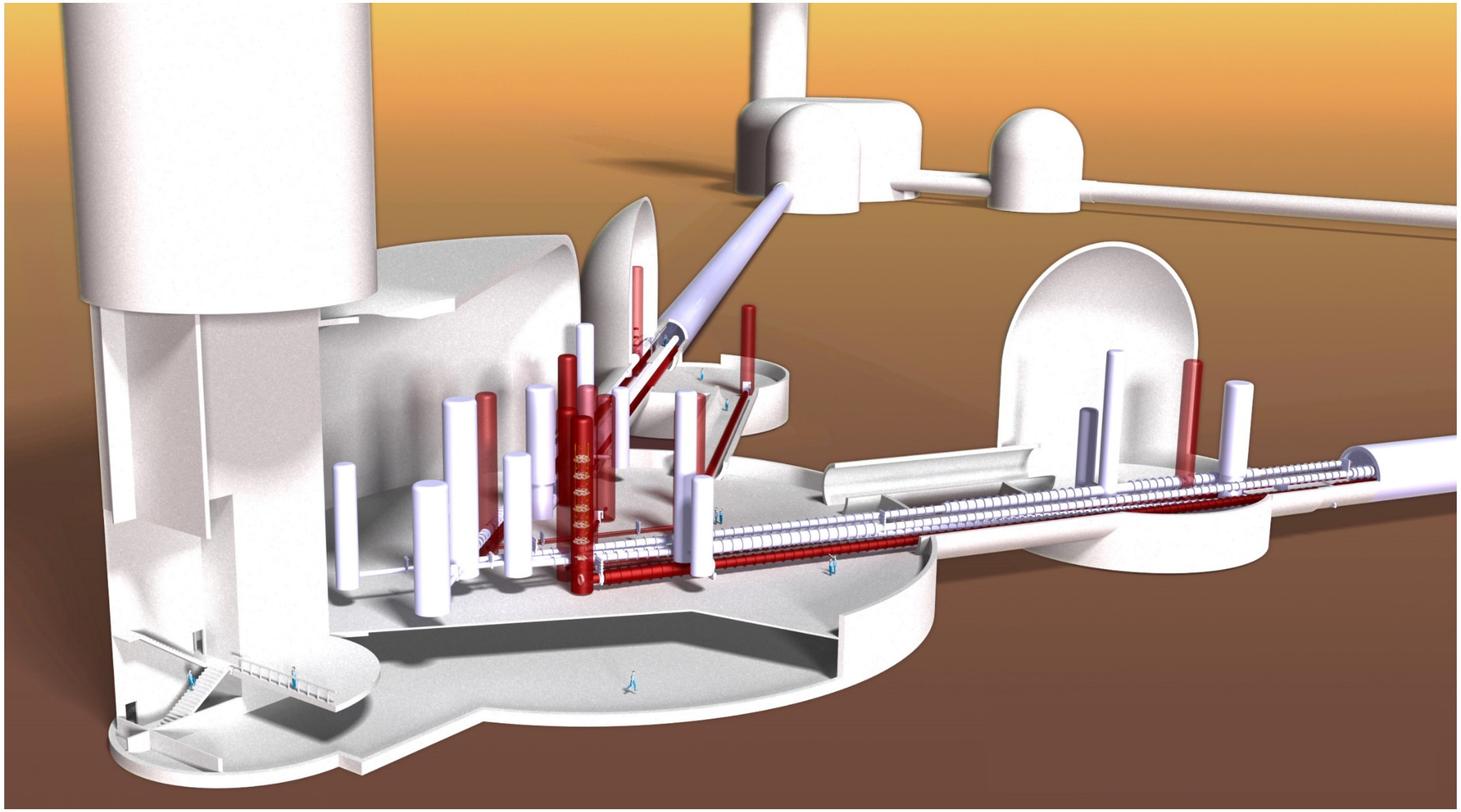
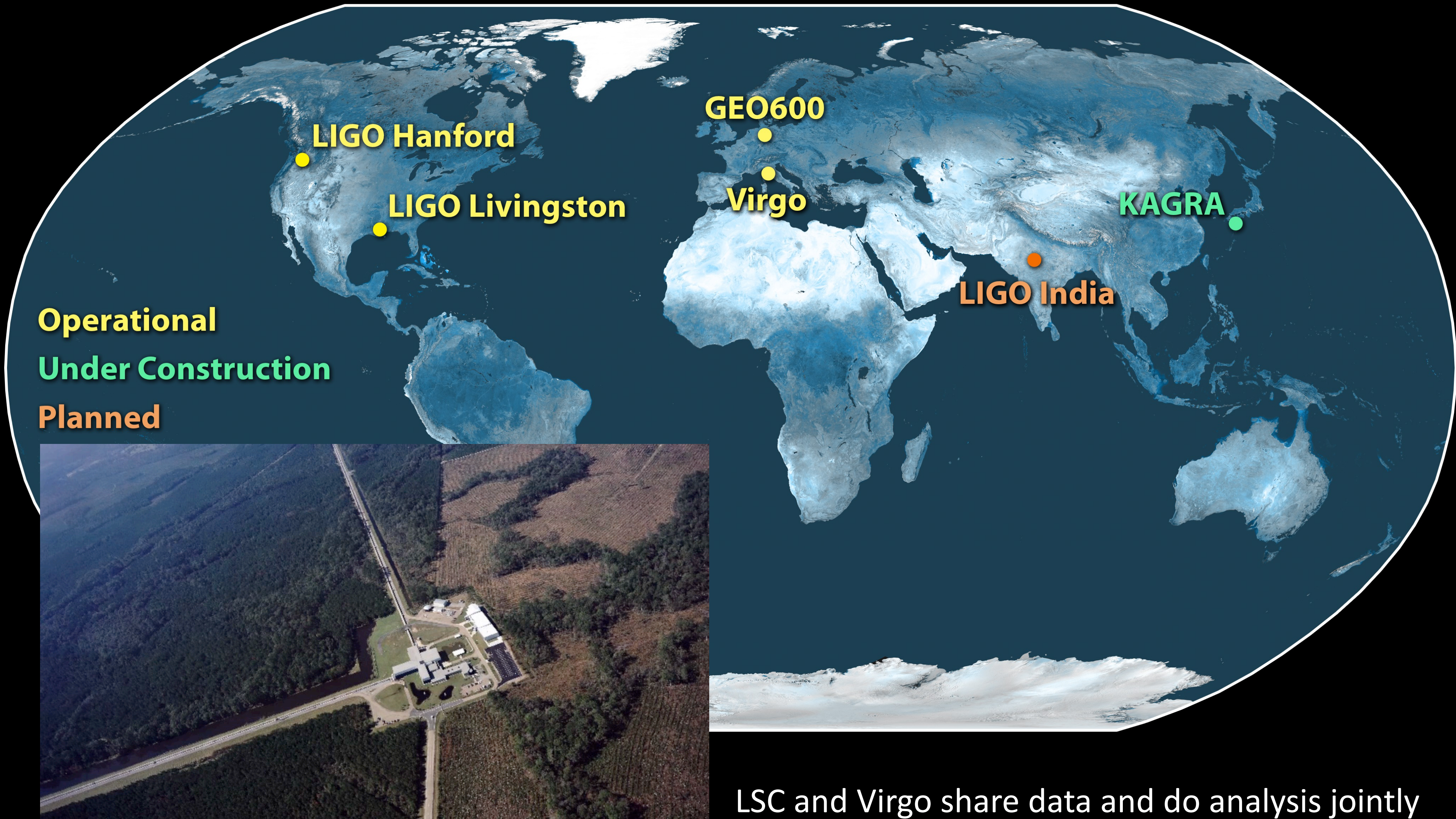


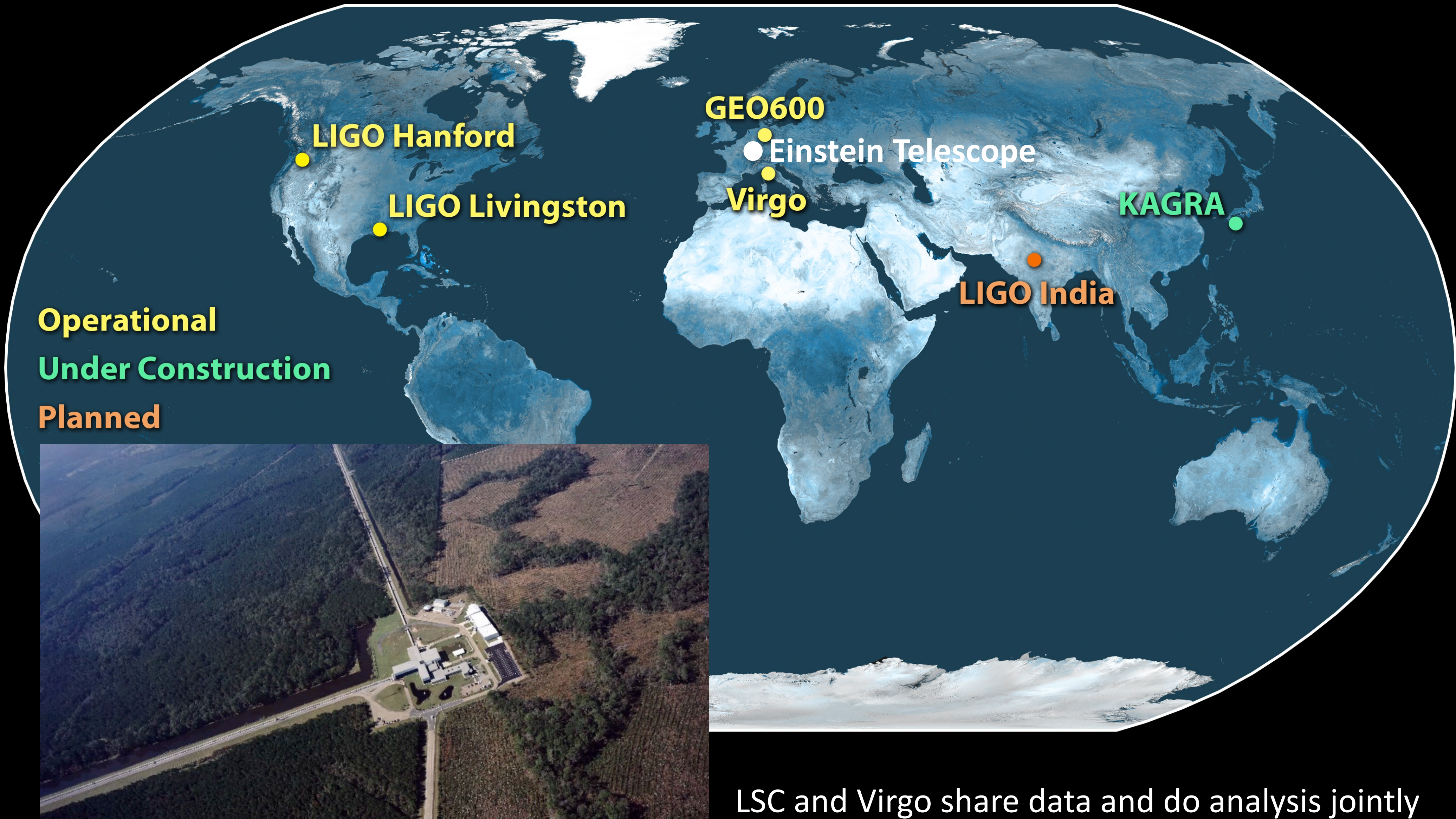
Liège, January 30, 2018

Towards a global GW research infrastructure



LSC and Virgo share data and do analysis jointly

Towards a global GW research infrastructure



LSC and Virgo share data and do analysis jointly

Towards a global GW research infrastructure

LSC and Virgo share data and do analysis jointly

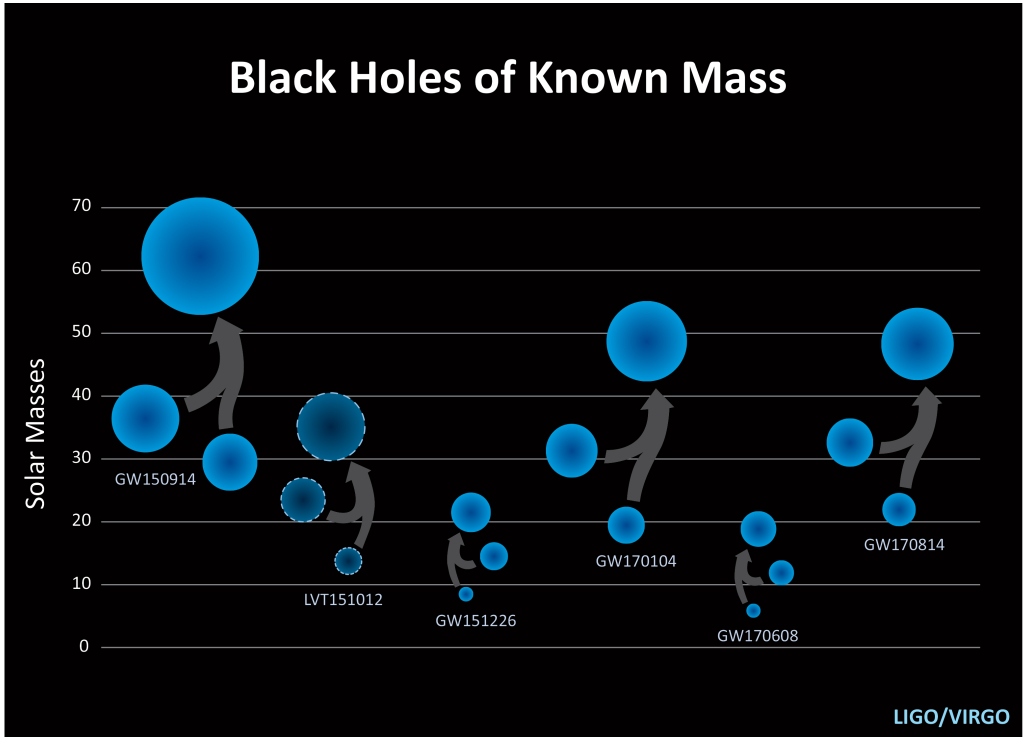
Scientific achievements: properties of black holes

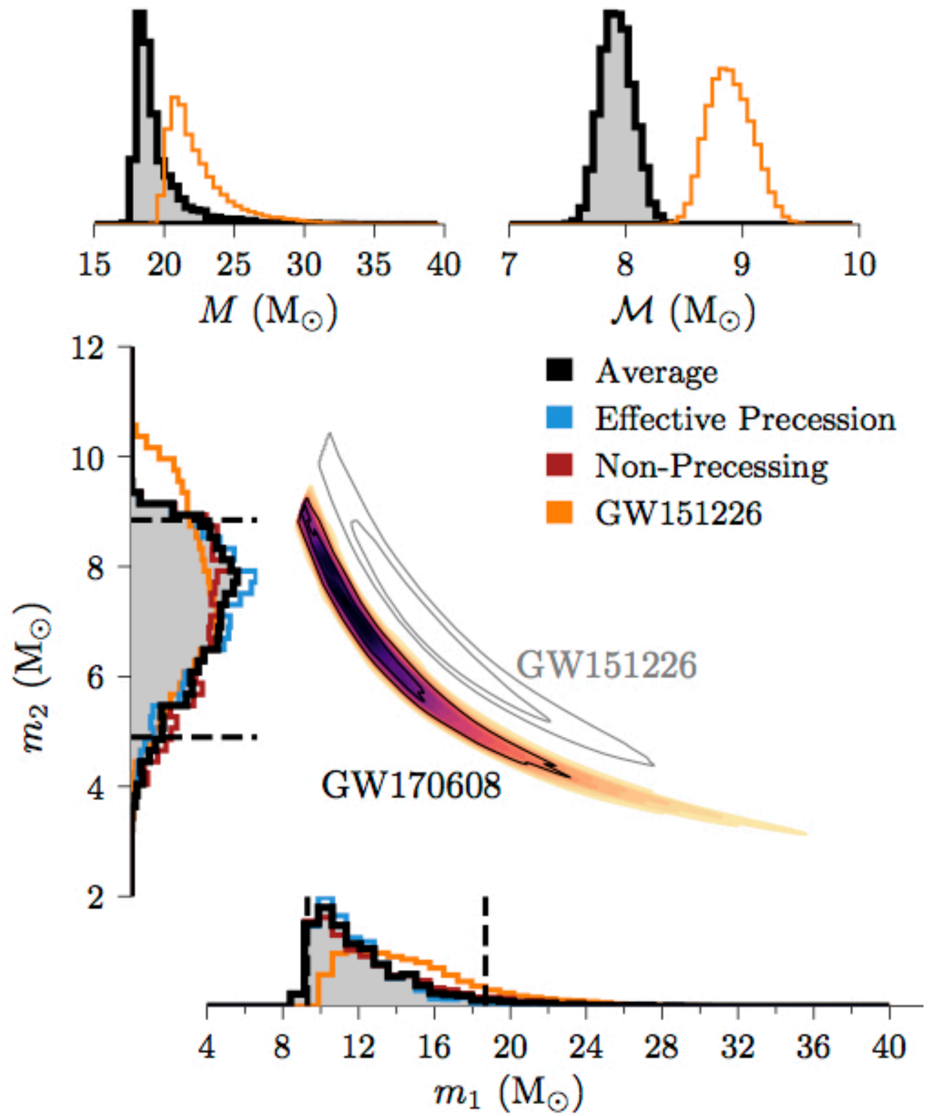
Extract information on masses, spins, energy radiated, position, distance, inclination, polarization. Population distribution may shed light on formation mechanisms

LVC reported on 6 BBH mergers

Fundamental physics, astrophysics, astronomy, and cosmology

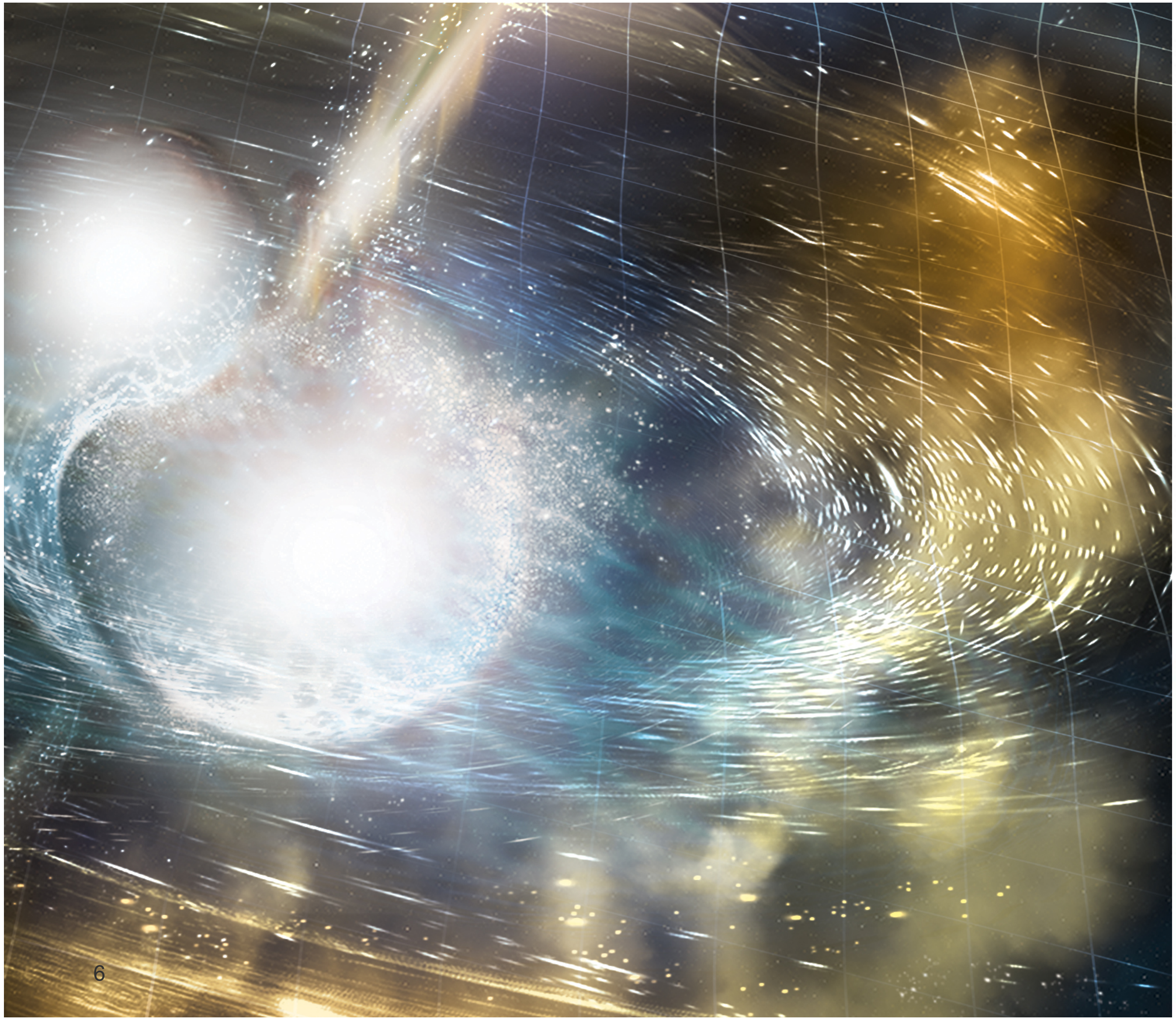
Testing GR, waveforms (with matter)

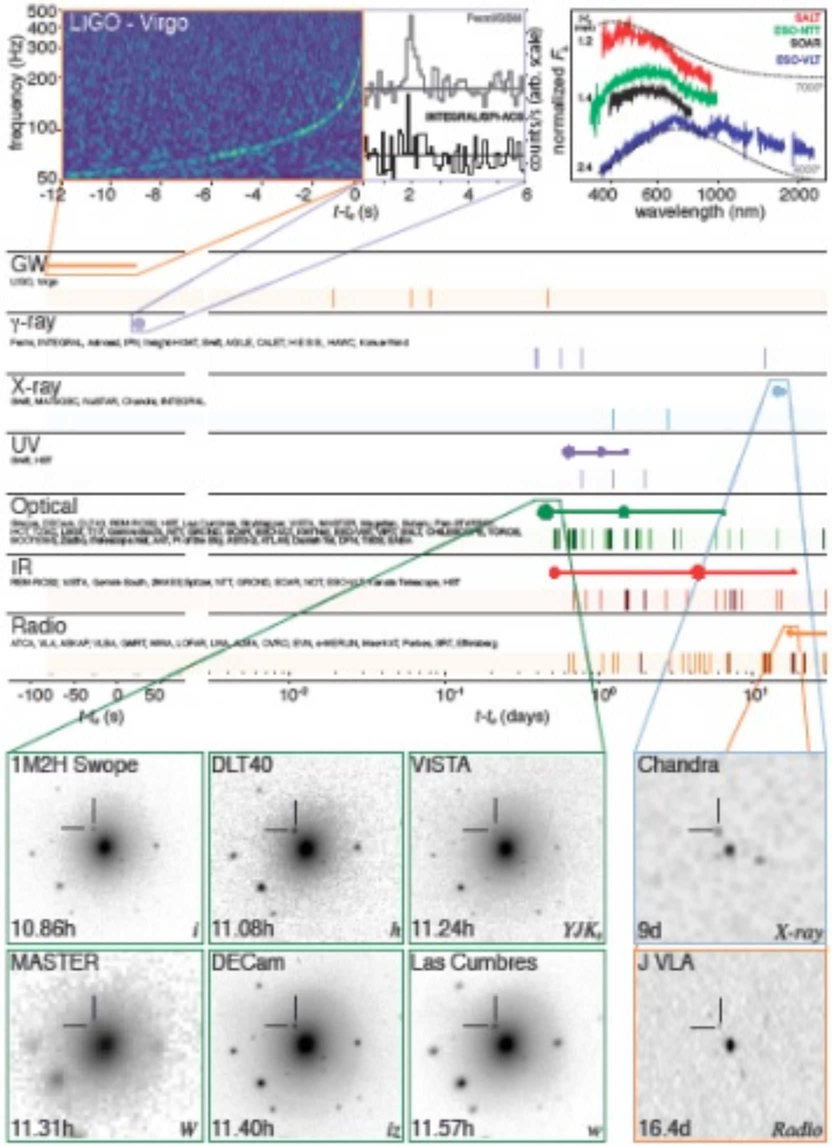




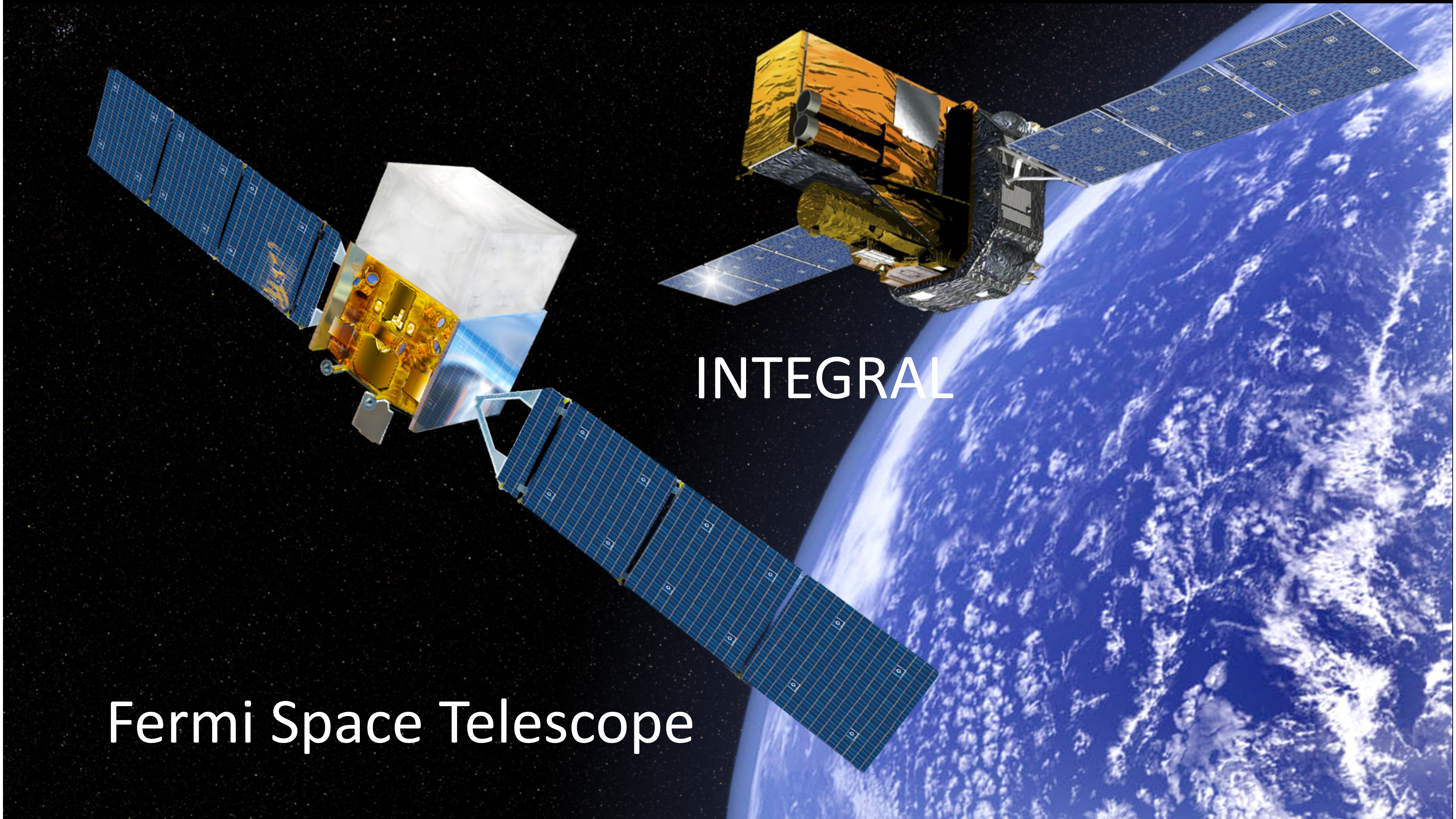
GW170817: start of multi-messenger astronomy with GW

Many compact merger sources emit, besides gravitational waves, also light, gamma- and X-rays, and UV, optical, IR, and radio waves, as well as neutrino's or other subatomic particles. Our three-detector global network allows identifying these counterparts





Gamma rays reached Earth 1.7 seconds after GW event



Looking into the heart of a dim nearby sGRB

Gravitational waves identified the progenitor of the sGRB and provided both space localization and distance of the source. This triggered the EM follow-up by astronomers for the kilonova

Scientific impact of gravitational wave science

Multi-messenger astronomy started: a broad community is relying of detection of gravitational waves

Fundamental physics

Access to dynamic strong field regime, new tests of General Relativity
Black hole science: inspiral, merger, ringdown, quasi-normal modes, echo's
Lorentz-invariance, equivalence principle, polarization, parity violation, axions

Astrophysics

First observation for binary neutron star merger, relation to sGRB
Evidence for a kilonova, explanation for creation of elements heavier than iron

Astronomy

Start of gravitational wave astronomy, population studies, formation of progenitors, remnant studies

Cosmology

Binary neutron stars can be used as standard “sirens”
Dark Matter and Dark Energy

Nuclear physics

Tidal interactions between neutron stars get imprinted on gravitational waves
Access to equation of state

LVC will be back with improved instruments to start the next observation run (O3) in H2 this year

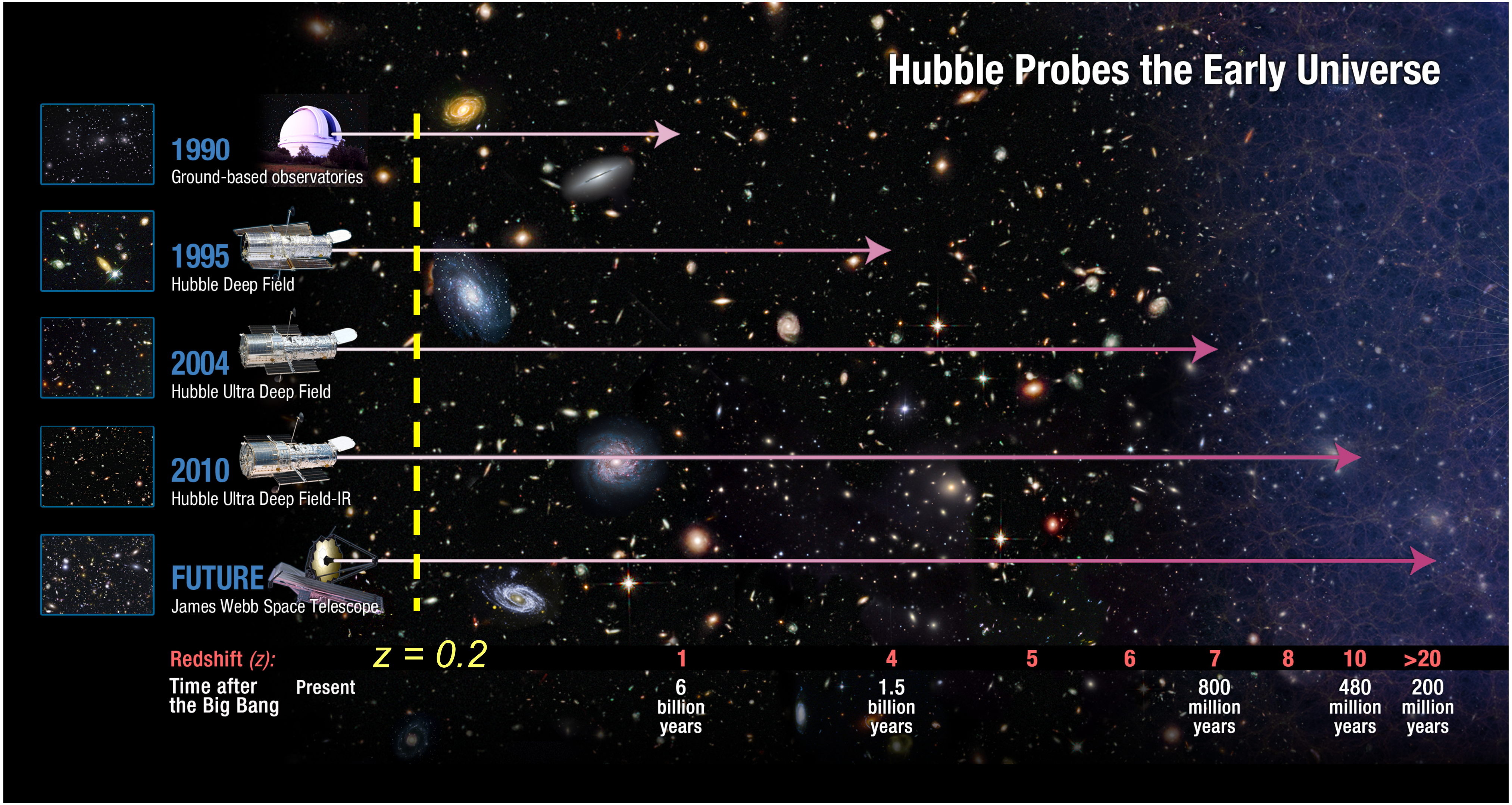
Advanced Virgo

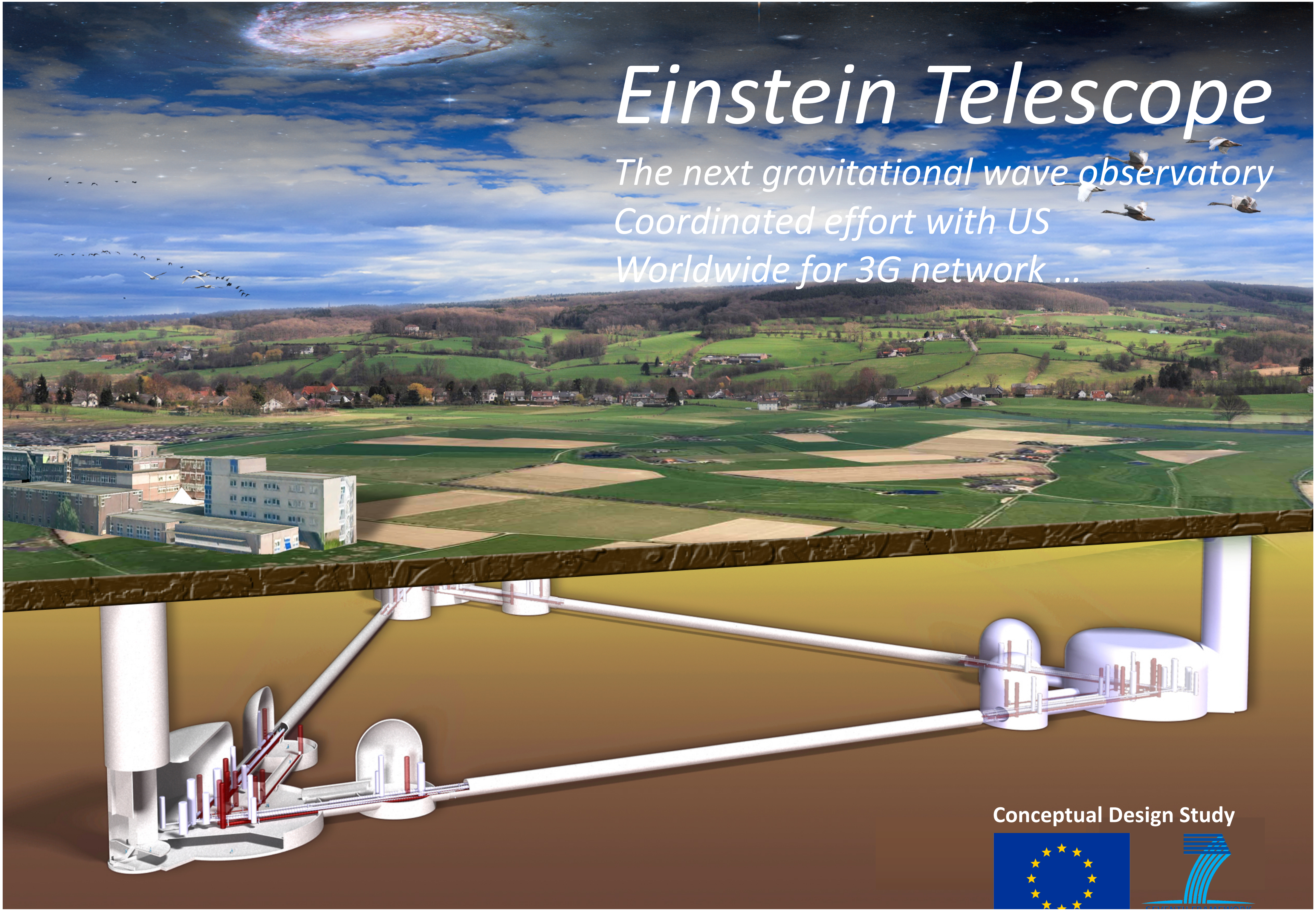
Einstein Telescope: observing all BBH mergers in Universe

This cannot be achieved with existing facilities and requires a new generation of GW observatories

We want to collect high statistics (*e.g.* millions of BBH events), high SNR, distributed over a large z-range ($z < 20$)

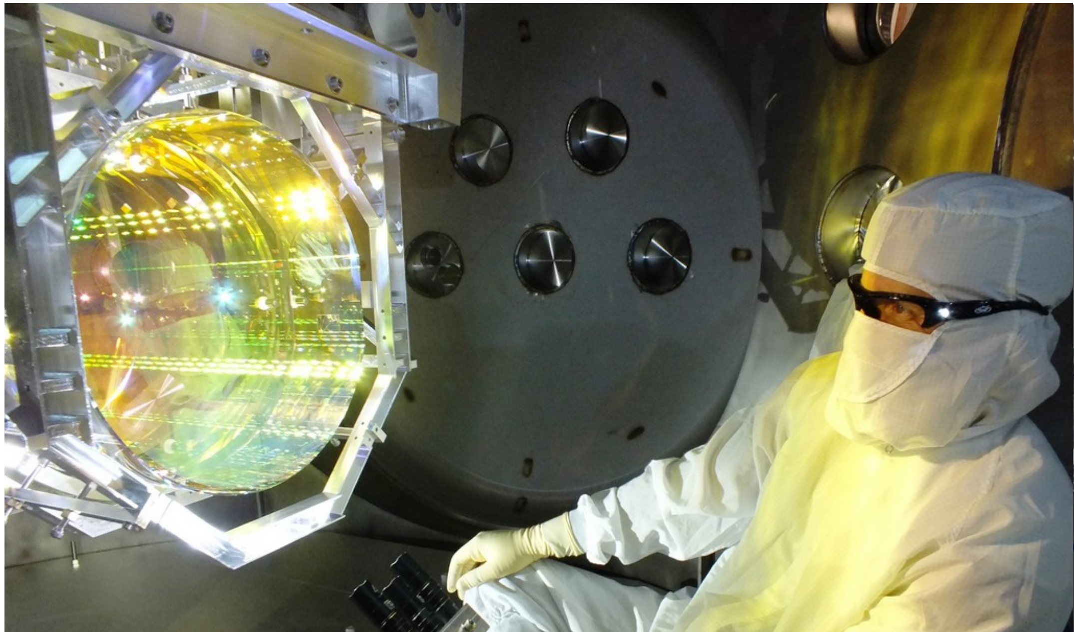
This allows sorting data versus redshift, mass distributions, *etc*. Early warning, IMBH, early Universe, CW, …

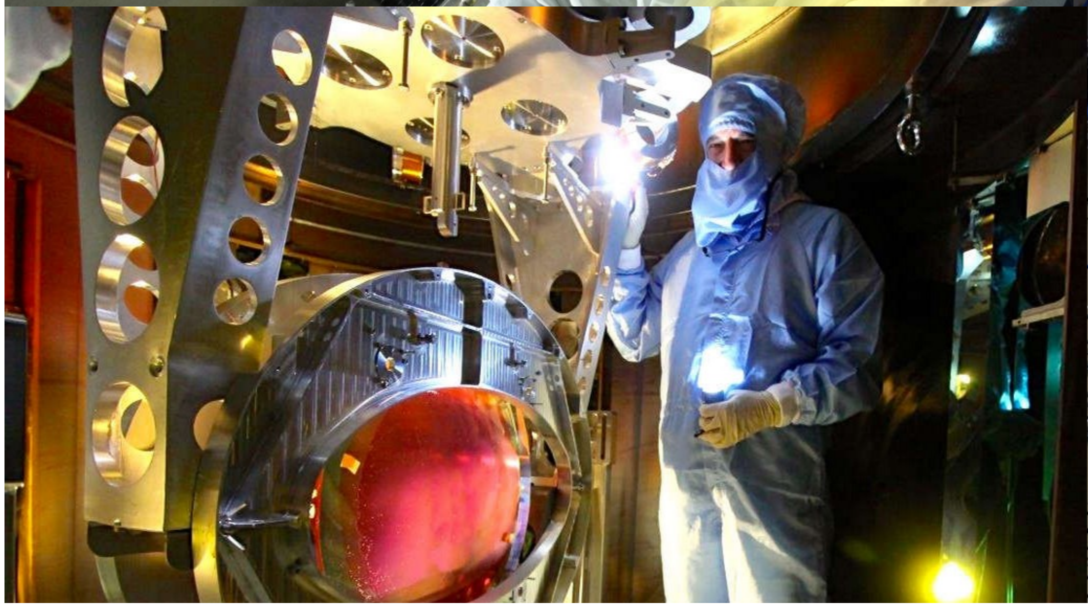



Einstein Telescope
The next gravitational wave observatory
Coordinated effort with US
Worldwide for 3G network …
Conceptual Design Study

Advanced optical systems

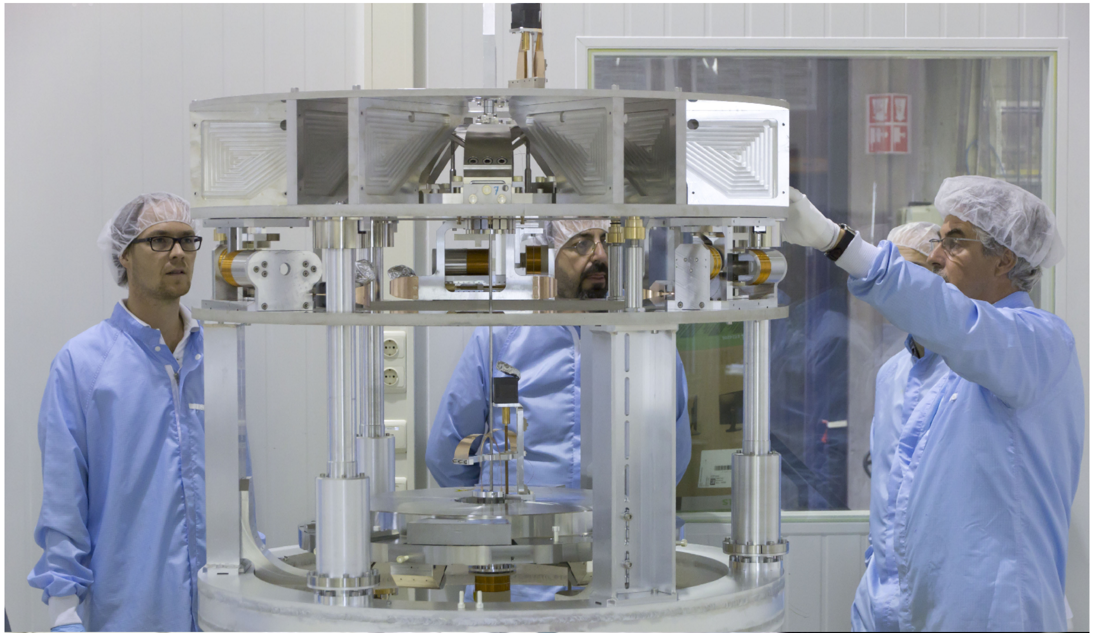
Mirrors as test masses, beamsplitters, suspended mode cleaners, …

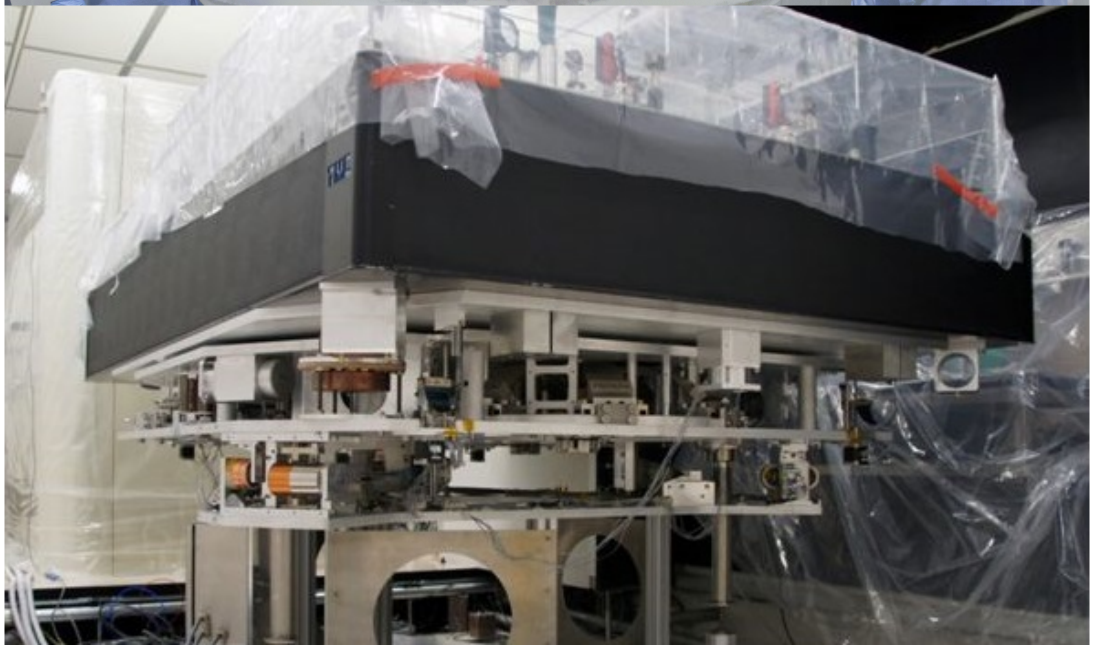




Vibration isolation systems

Optical systems for linear alignment, vibration isolation, PDs, QPDs, and phase camera's, etc.

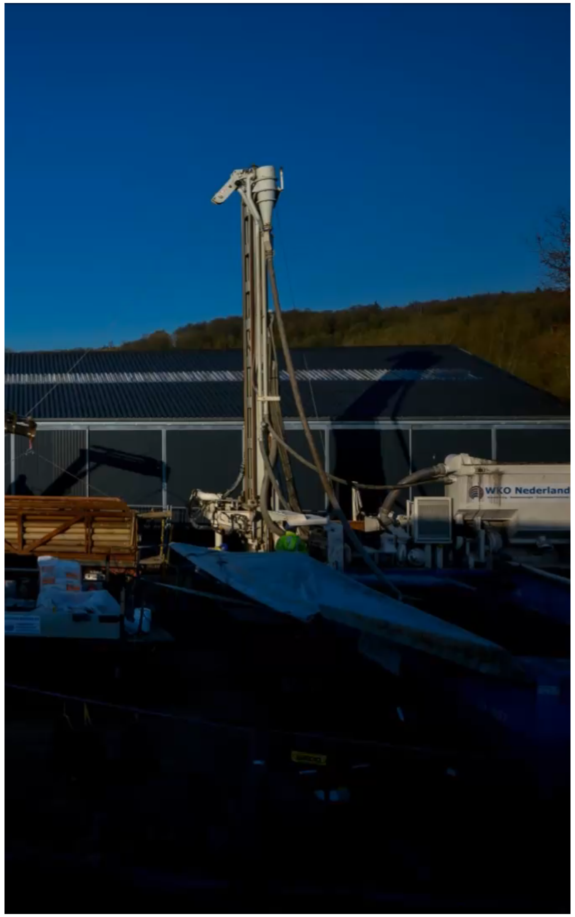




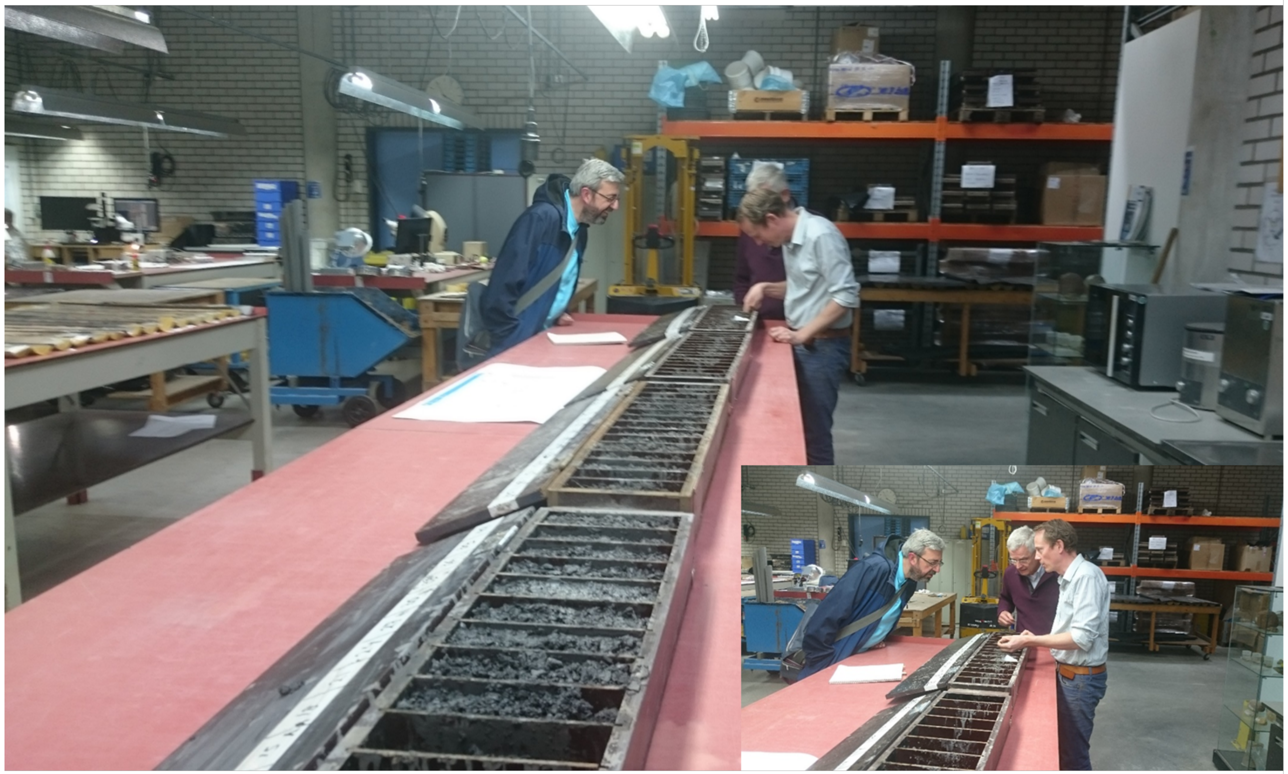
Geologists are actively involved in underground studies

We obtained soil samples up to a depth of 140 m. Picture: Geert-Jan Vis (TNO), Jan Lutgert (EBN), Alessandro Bertolini (Nikhef). Research on samples at CITG in TU-Delft

Antea borehole



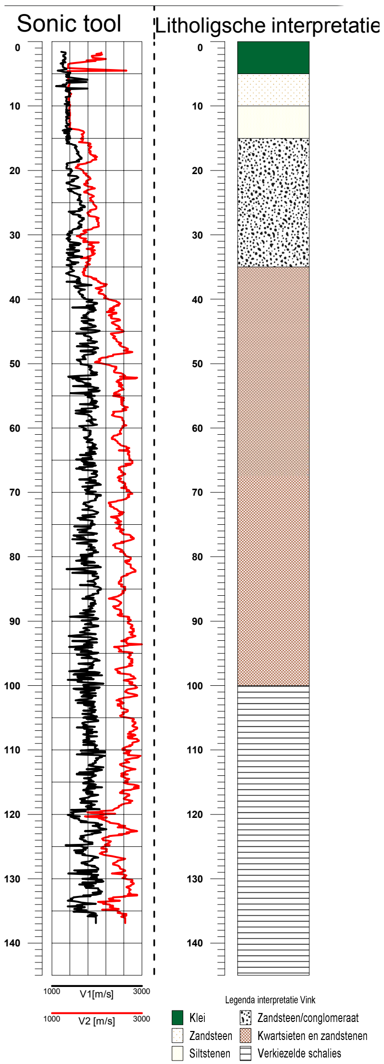
TNO and EBN



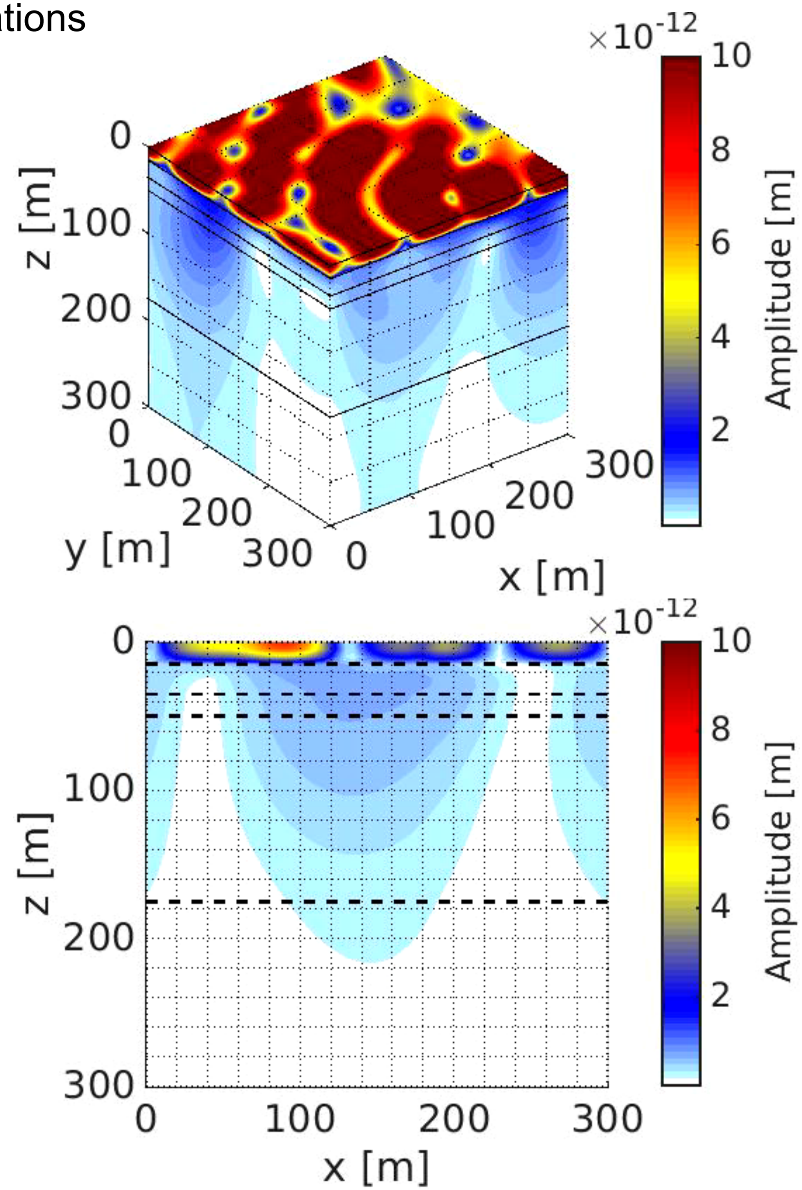
What is unique about the geology?

The geology of the Zuid-Limburg border area: hard rock with on top a layer of soft absorbing and damping soil. In addition the region is free of disturbing (man-made) seismic activities

Deltares research



Nikhef simulations



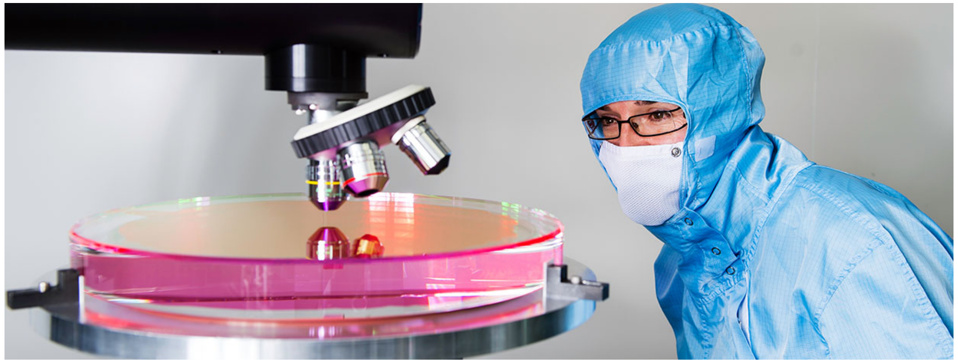
What is the added value of Einstein Telescope?

The arrival of ET stimulates national and regional innovation power, activity, employment and attractivity for top scientists

The facility poses extreme technical demands to equipment, that must be development specially for this application. The involvement and expertise of industry is essential

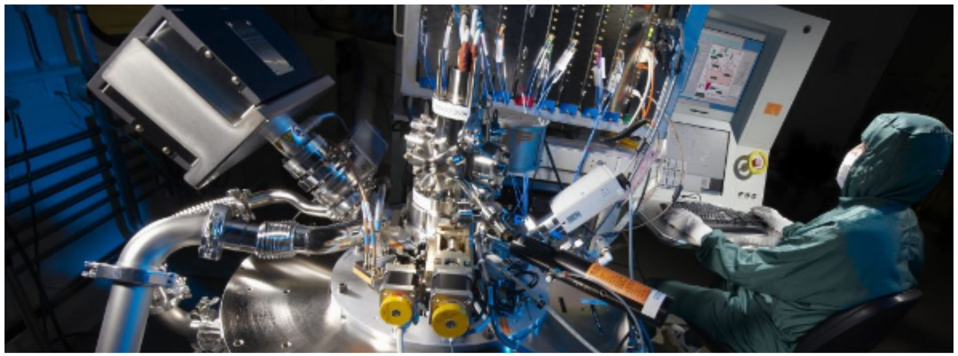
Measuring and attenuating vibrations: nano-technology, medical, defense

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



Vacuum technology: ET will be one of the biggest vacuum systems worldwide

Cryogenic systems: also applied in fusion and superconducting technology



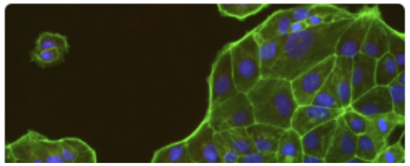
Examples of spin-off from gravitational wave research

Growing human bones using gravitational wave technology

12 September 2017

Technology originally developed to witness black holes colliding is now being used to grow human bone in a laboratory, which could revolutionise the treatment of bone injuries.

The research team used measurement technology, based on the sophisticated laser interferometer systems designed in the UK for gravitational wave detection, to turn stem cells into bone cells.



GEOPHYSICS

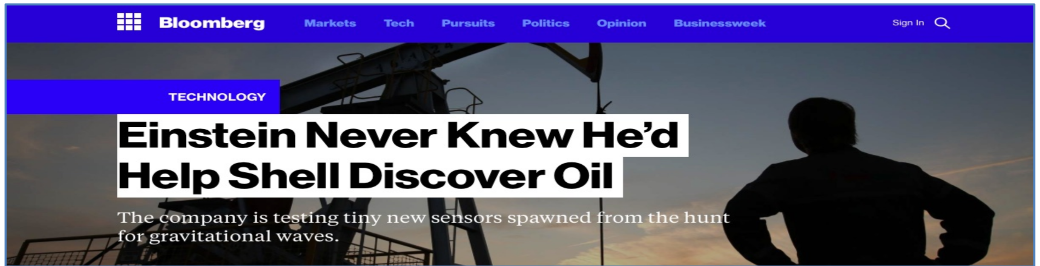
Observations and modeling of the elastogravity signals preceding direct seismic waves

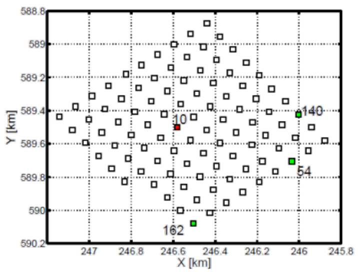
Martin Vallée,[1*] Jean Paul Ampuero,[2] Kévin Juhel,[1] Pascal Bernard,[1] Jean-Paul Montagner,[1] Matteo Barsuglia[3]

After an earthquake, the earliest deformation signals are not expected to be carried by the fastest (*P*) elastic waves but by the speed-of-light changes of the gravitational field. However, these perturbations are weak and, so far, th
enough to fully understand their origins and to use th
estimate of the earthquake magnitude. We show that
well observed with broadband seismometers at distance
from the source of the 2011, moment magnitude 9.1, Toh
model them by a new formalism, taking into account bo
gravity-induced motion. These prompt elastogravity s
time-scale magnitude determination for great earthqu

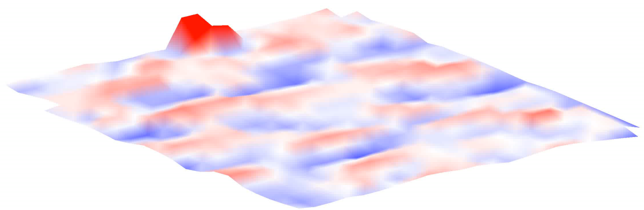
A

B





Earthquake monitoring



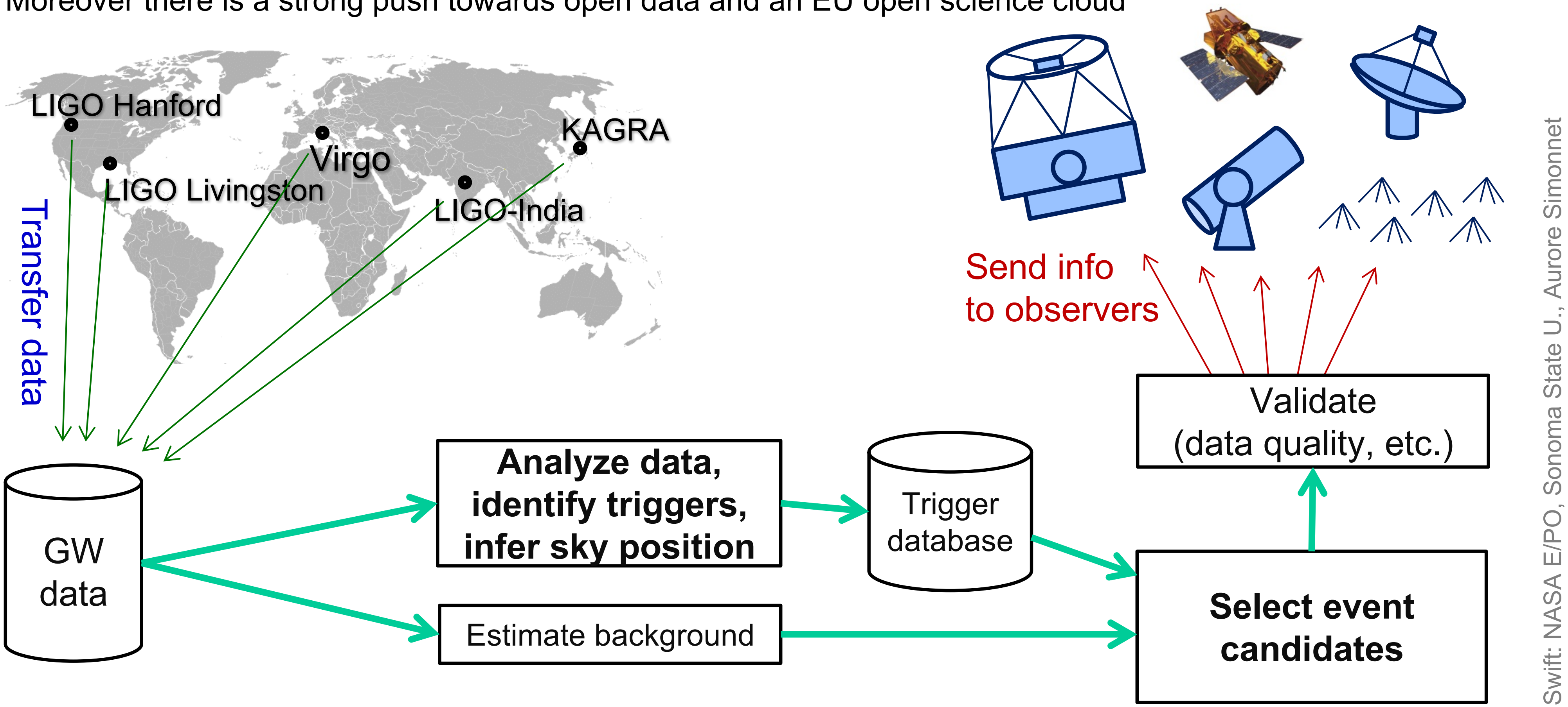
Resources should be dedicated to allow MMA computing

The LIGO-Virgo Collaboration has MOUs with 95 collaborations in astronomy and astro-particle physics. Multi-messenger astronomy requires rapid follow-up of interesting triggers and fast distribution of science data between partners distributed over the globe

Computing will become increasingly important as experiments mature

- GW event rate rapidly increases as sensitivity improves (note that GW-amplitude is measured; $\mathrm{Rate} \sim S_{GW}^{3}$)
- Also computing needs grow as templates get longer

Moreover there is a strong push towards open data and an EU open science cloud



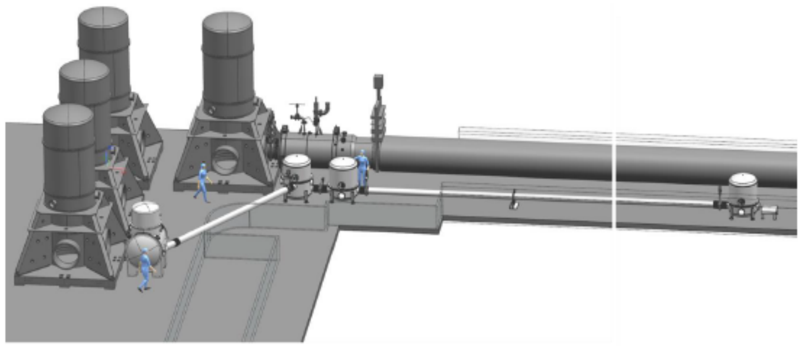
Roadmap from Virgo to Einstein Telescope

AdV+ as the next incremental step forward in sensitivity

AdV+ is the European plan to maximize Virgo's sensitivity within the constrains of the EGO site. It has the potential to increase Virgo's detection rate by up to an order of magnitude

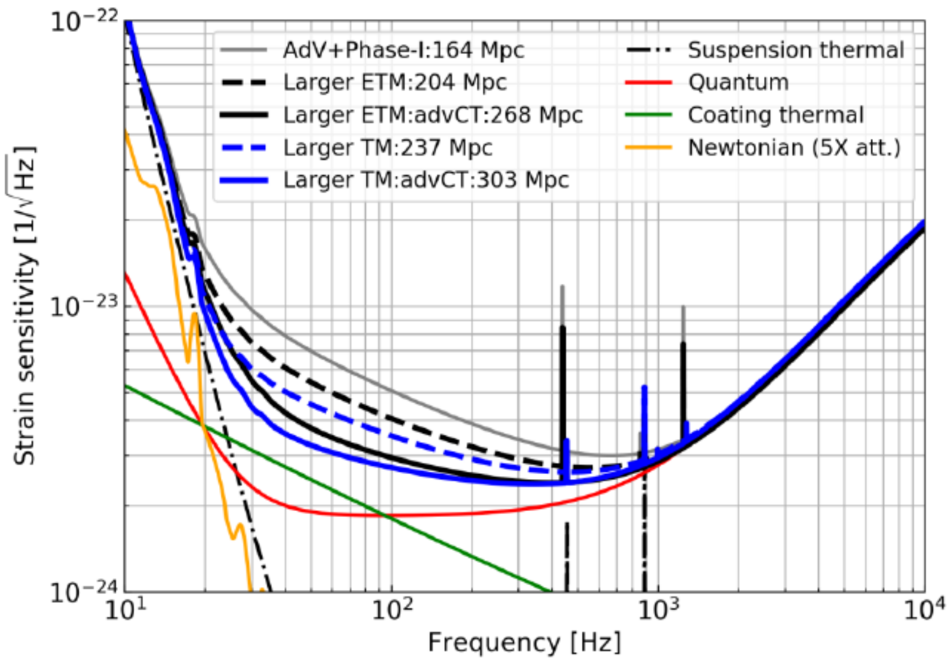
AdV+ features

- Maximize science
- Secure Virgo's scientific relevance
- Safeguard investments by scientists and funding agencies
- Implement new innovative technologies
- De-risk technologies needed for third generation observatories
- Attract new groups wanting to enter the field



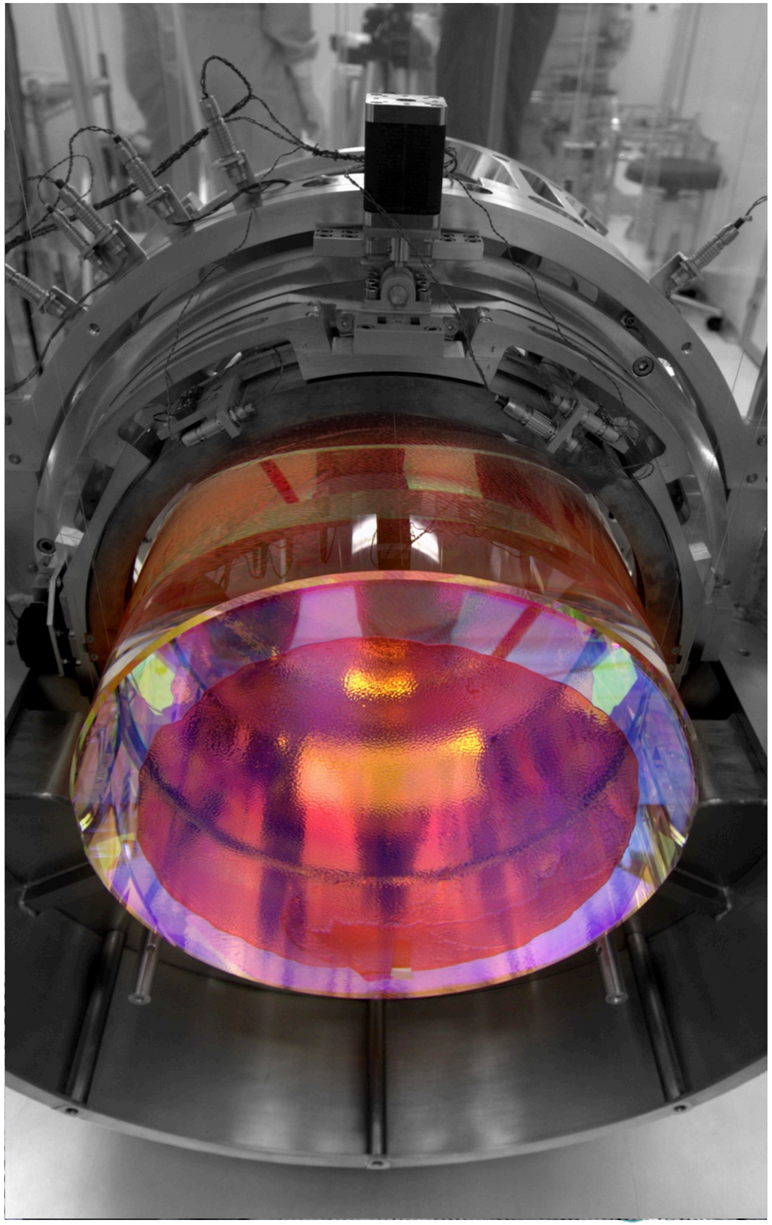
Upgrade activities

- Tuned signal recycling and HPL: 120 Mpc
- Frequency dependent squeezing: 150 Mpc
- Newtonian noise cancellation: 160 Mpc
- Larger mirrors (105 kg): 200-230 Mpc
- Improved coatings: 260-300 Mpc



AdV+ upgrade and extreme mirror technology

Laboratoire des Matériaux Avancés LMA at Lyon produced the coatings used on the main mirrors of the two working gravitational wave detectors: Advanced LIGO and Virgo. These coatings feature low losses, low absorption, and low scattering properties



Features

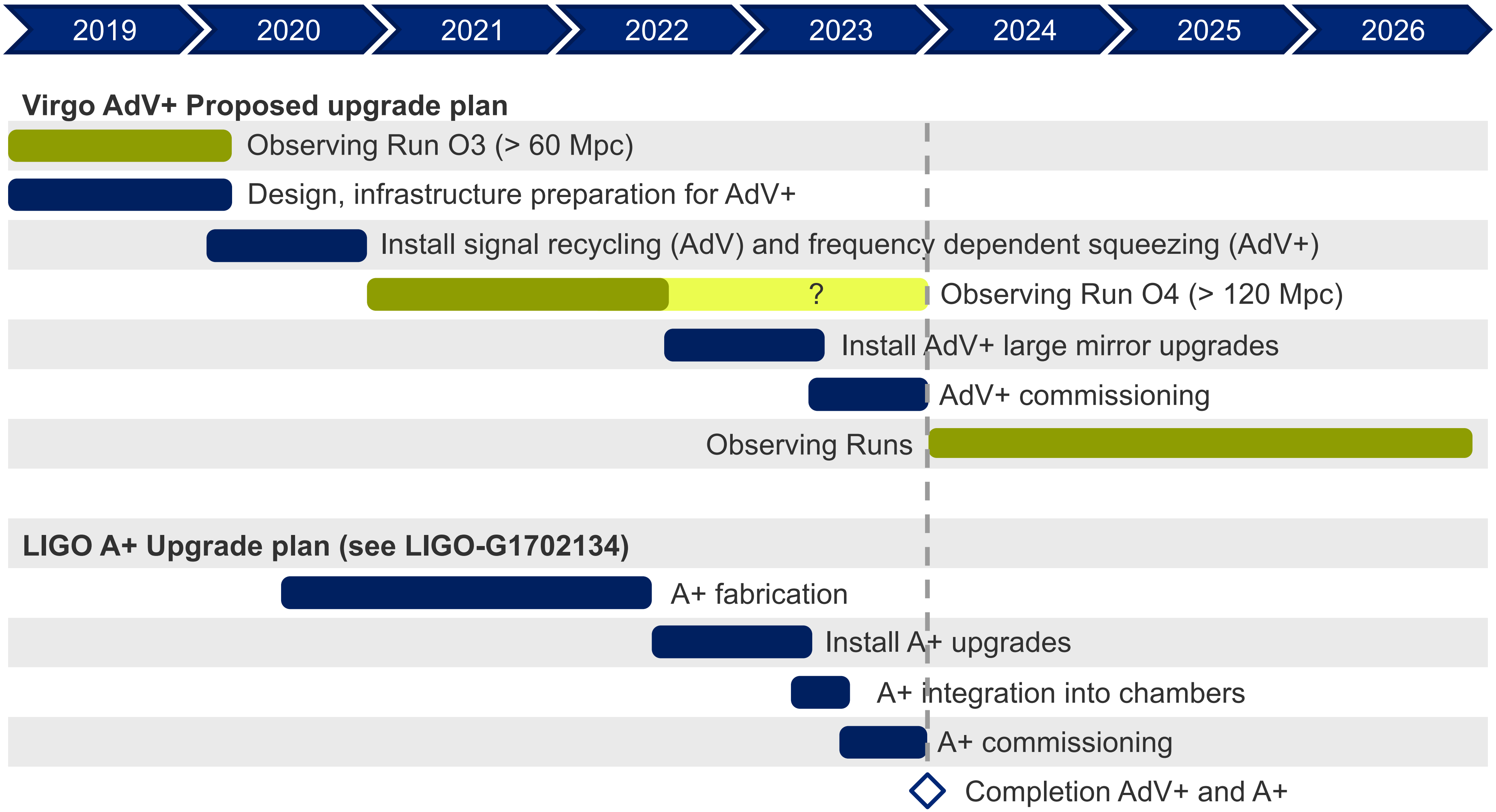
- Flatness < 0.5 nm rms over central 160 mm of mirrors by using ion beam polishing (robotic silica deposition was investigated)
- $Ti:Ta_2O_5$ and SiO_2 stacks with optical absorption about 0.3 ppm

Expand LMA capabilities for next generation

LMA is the only coating group known to be capable of scaling up

AdV+ to be carried out in parallel with LIGO's A+ upgrade

Five year plan for observational runs, commissioning and upgrades

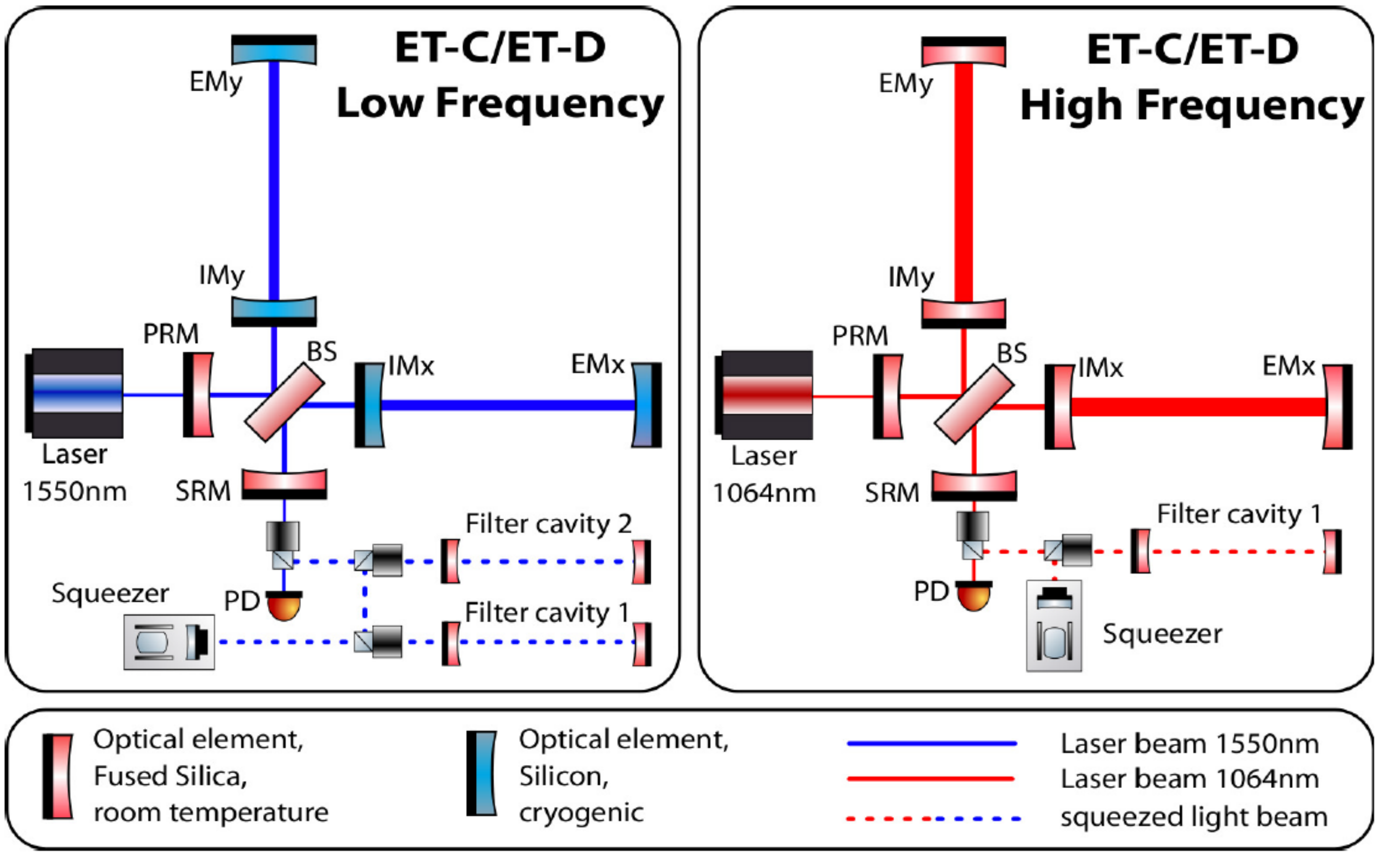


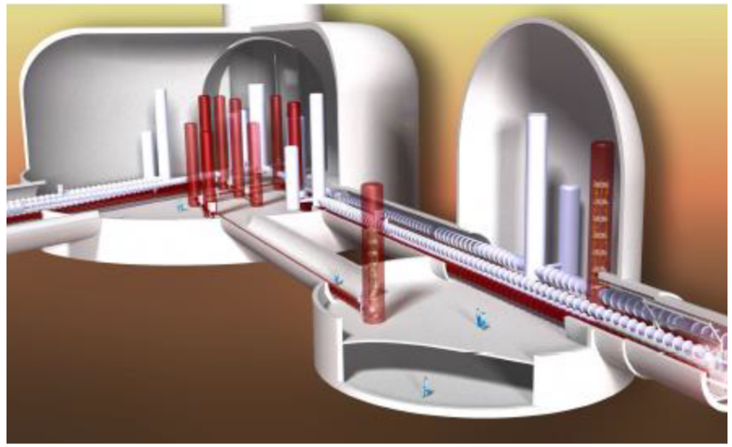
Note: duration of O4 has not been decided at this moment

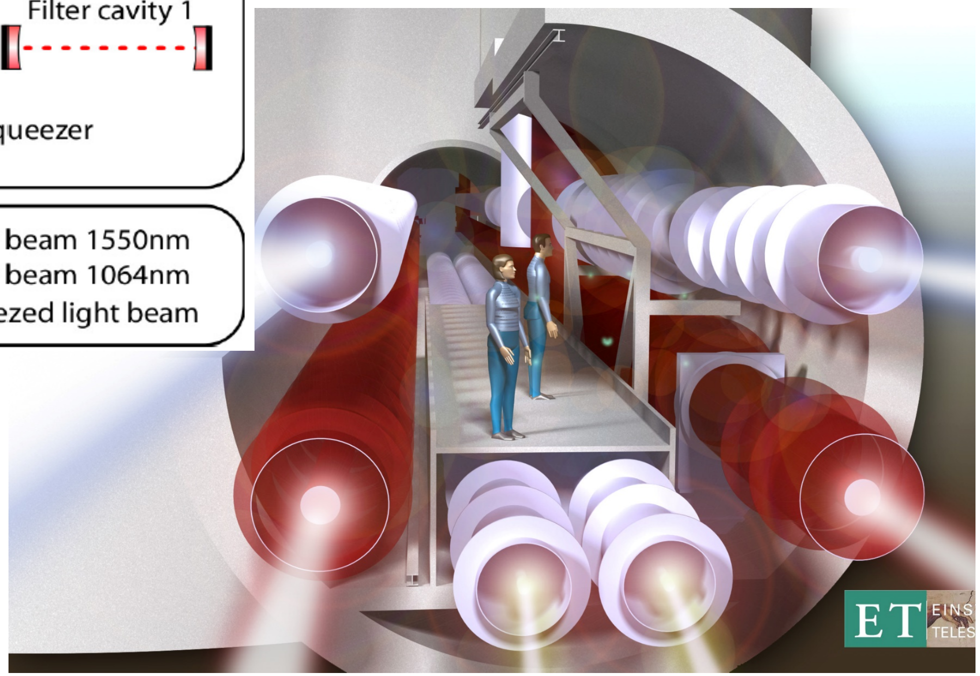
AdV+ is part of a strategy to go from 2nd generation to Einstein Telescope

Einstein Telescope requires significant R&D

Optical design with three detectors, each consisting of a low- and a high-frequency interferometer
This requires heavy cryogenic silicon test masses, coatings, controls, new stable lasers, LG33, …







Proposal: realize an ET test interferometer and develop and test core technologies

What is needed now?

A strategy to transition from 2nd generation Virgo to Einstein Telescope. This requires that industry, politics and science are acting in consort so that we together can investigate this unique chance on an iconic European project

How can scientists with support from politics and industry approach this?

- An innovative R&D program should be defined together with industry
- De-risk part of the ET technology in AdV+
- MOU with most important scientific parties should be established
- Develop a common strategy that will lead to an ESFRI request backed by various ministries (2019)
- A unique chance for Europe, but support from the ministries of various partner countries is of essential importance

European Strategy Forum on Research Infrastructures ESFRI

Worldwide support for gravitational wave research

LIGO and Virgo are operational. LIGO-India and KAGRA in Japan under construction. ESA launches LISA in 2034. Einstein Telescope CDR financed by EU, support by APPEC

Gravitational wave research

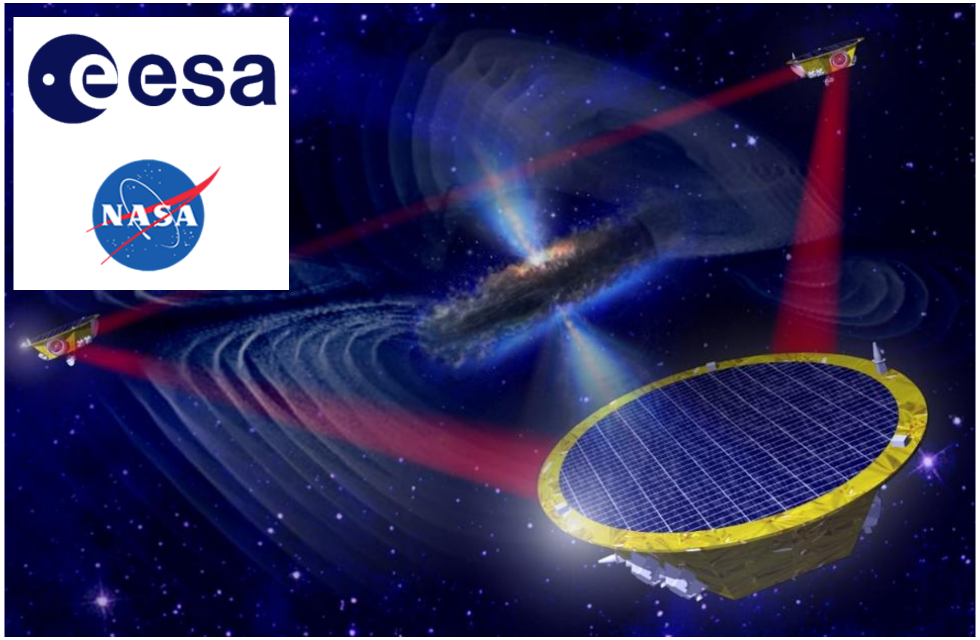
- LIGO and Virgo operational
- LIGO-India and KAGRA under construction
- ESA and NASA select LISA
- Pulsar Timing Arrays, such as EPTA and SKA
- Cosmic Microwave Background radiation

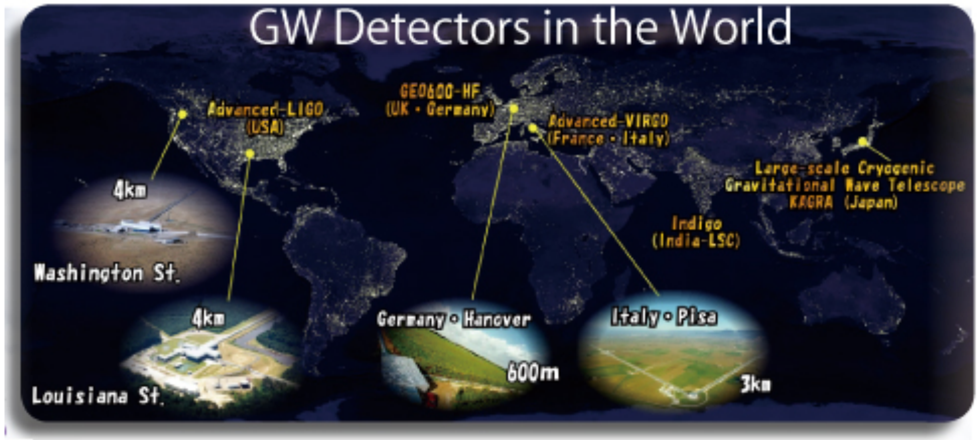
Einstein Telescope

- Design financed by EU in FP7
- APPEC gives GW a prominent place in the new Roadmap and especially the realization of ET

Next steps

- Collaborate Europe wide on all levels
- ESFRI Roadmap





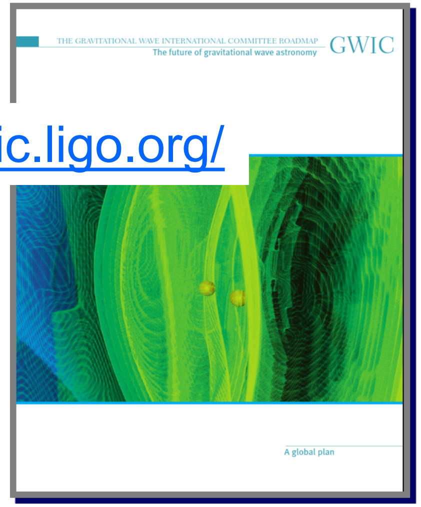
Gravitational Wave International Committee

GWIC seeks to facilitate international collaboration and cooperation in use of GW facilities

What is GWIC?

- Working Group (GW11) of the International Union of Pure and Applied Physics (IUPAP)
- Links to the International Astronomical Union (IAU) and the International Society for General Relativity and Gravitation (ISGRG)
- GWIC membership represents the world's active gravitational wave projects, as well as other relevant communities, covering gravitational wave frequencies from nanohertz to kilohertz

https://gwic.ligo.org/



GWIC strongly supports and is working to coordinate upgrades of future detectors

GWIC on Exploitation of LIGO and Virgo

- APPEC has a crucial role in providing support for European contributions to the global Advanced detector network

GWIC on 3G GW observatories

- APPEC has a critical role in supporting European scientists (via appropriate instruments) to participate in the 3G activities: global network science case studies, networking, R&D, etc
- APPEC could interface to GWAC to provide a collective perspective on European work in the global context

Gravitational Wave Agency Correspondents

GWAC's primary purpose is to enable international co-sponsoring activities in GW Astrophysics

GWAC is a GW "funding" agencies committee promoted by NSF, involving

- Australian Research Council (ARC)
- Canada Foundation for Innovation (CFI)
- Centre National de la Recherche Scientifique (CNRS)
- Consejo Nacional de Ciencia y Tecnología (CONACYT)
- Deutsche Forschungsgemeinschaft (DFG)
- Istituto Nazionale di Fisica Nucleare (INFN)
- National Aeronautics and Space Administration (NASA)
- Science & Technology Facilities Council (STFC)
- Netherlands Science Organization (NWO)

GWAC is a tool for the GW community. Type of activities

- Large scale: developing new GW observatories
- Medium scale: support of GW R&D of any kind (risk mitigation, characterization, DA, etc.)
- Small scale: training of junior scientists, investigator exchange programs, etc.

Slide info: from Pedro Maronetti, NSF
"Dawn 2" Meeting
Atlanta, GA – July, 2016

Soumagne TGV tunnel for HSL Liège - Aachen

The bored section is 5,940 metres (6,500 yd), extended by covered sections of respectively 177 and 388 m. Dozens of geological layers of differing hardness had to be tunnelled through, lime layers needing to be blasted through with dynamite. The tunnel reaches a depth of 127 m in some areas; it has an average ramp height of 1.7%, with a maximum of 2% at the entrance in Soumagne

Dimensions

Tunnel length	5 940 m
Area	69 m2

Quantities

Concrete volume	210 000 m3
Reinforced steel	10 000 t
Excavated material	670 000 m3
Water proofing	140 000 m3
Shotcrete	80 000 m3
Formwork	900 t
Explosives used	600 t

Cost of construction 144 000 000 Euro