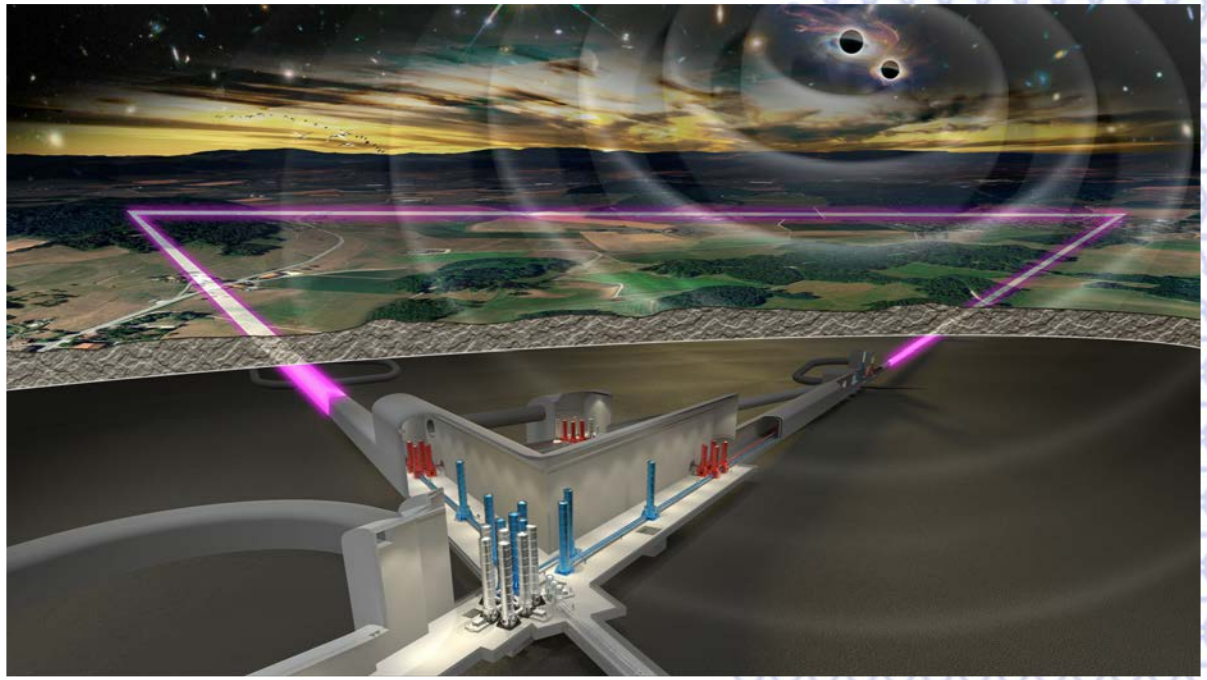


Einstein Telescope

Stefan Hild, University of Maastricht & Nikhef

for the ET-team (and with lots of input from Nikhef-GW-folk)

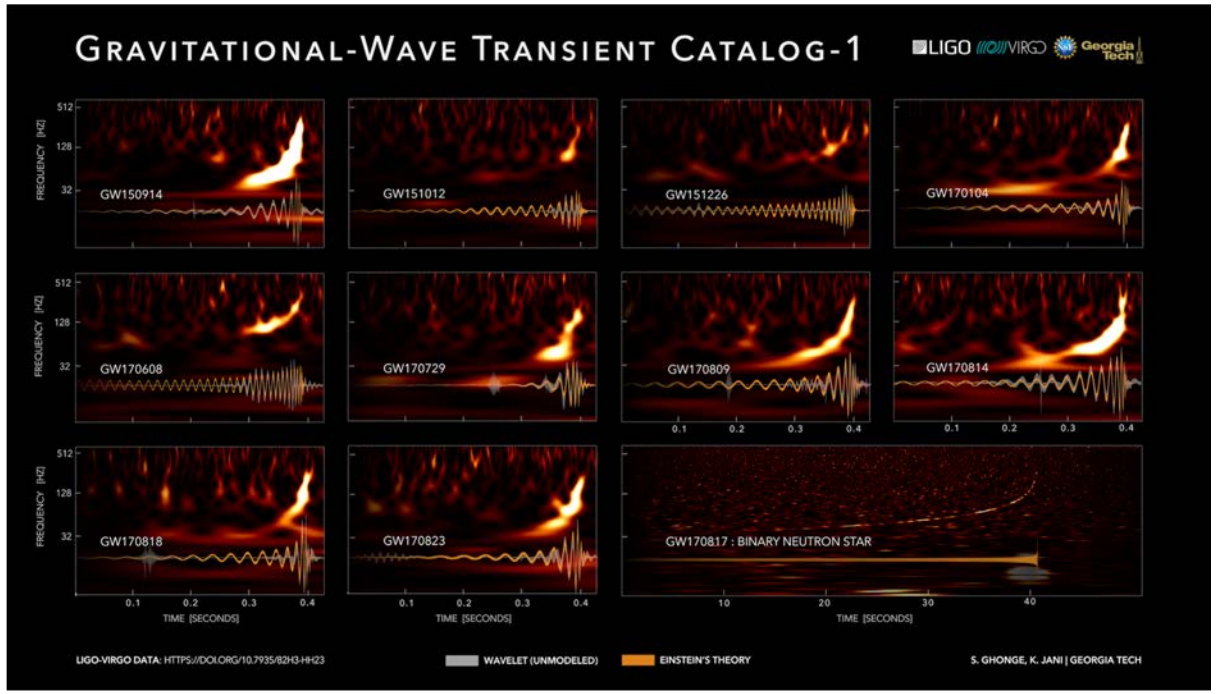
www.einsteintelescope.nl / www.etpathfinder.eu

Outline

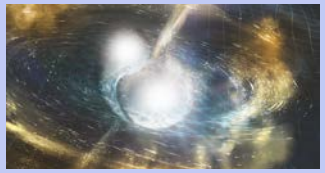
- Brief Overview of Einstein Telescope
- Current Status of the European Efforts
- Hosting ET in the Euregio Meuse Rhine?
- Synergies with other Nikhef research programmes

From a few seconds of signals …

… detected with LIGO and Virgo …

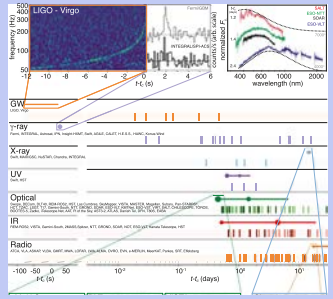


… we learned a lot!

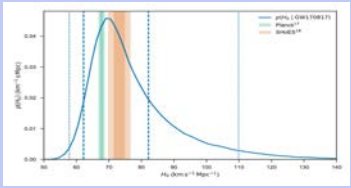


Confirmed BNS as origin for some GRBs

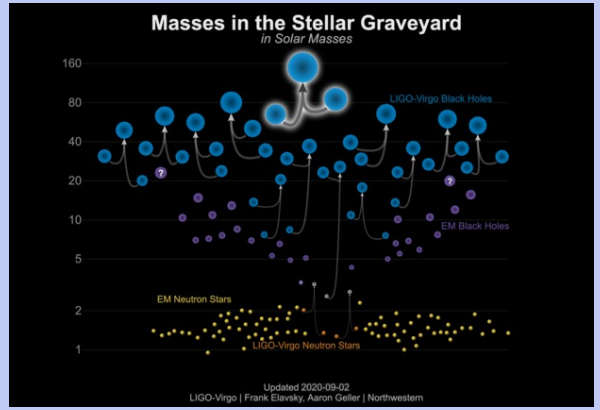
Ruled out some proposed EOS of neutron stars



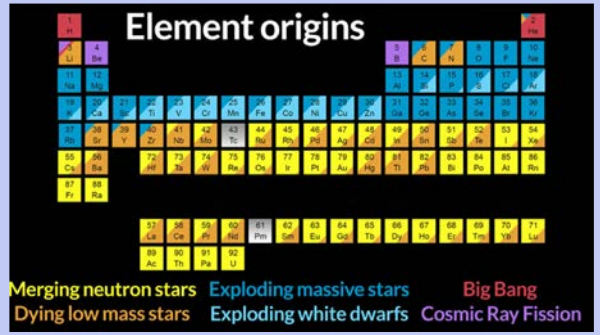
Start of GW multi-messenger astronomy



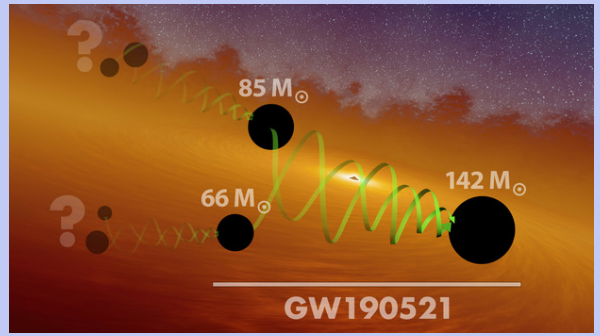
Cosmology independent of distance ladder



Found new class of heavy stellar mass BBH

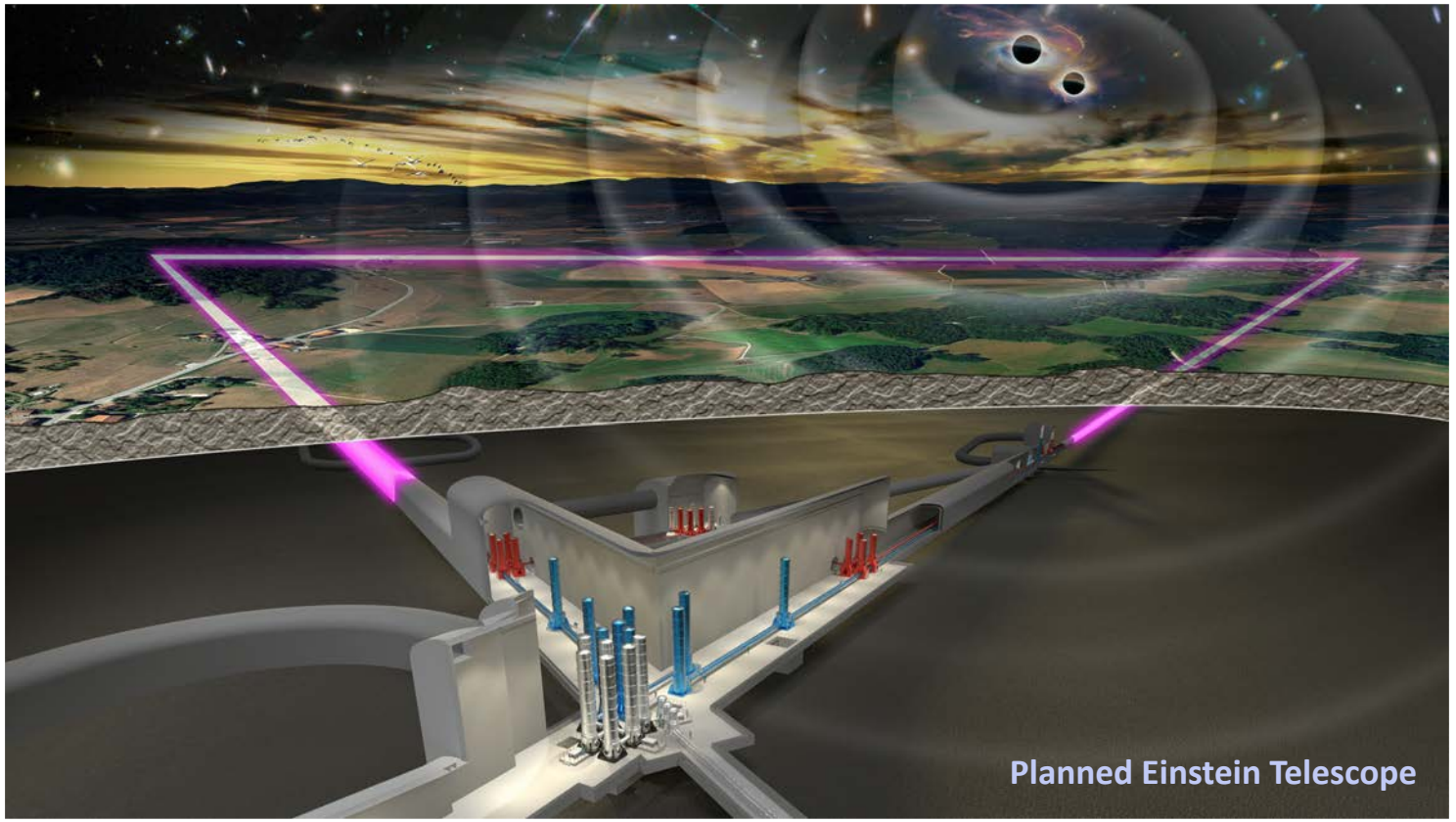


Confirmed Kilonova and R-process



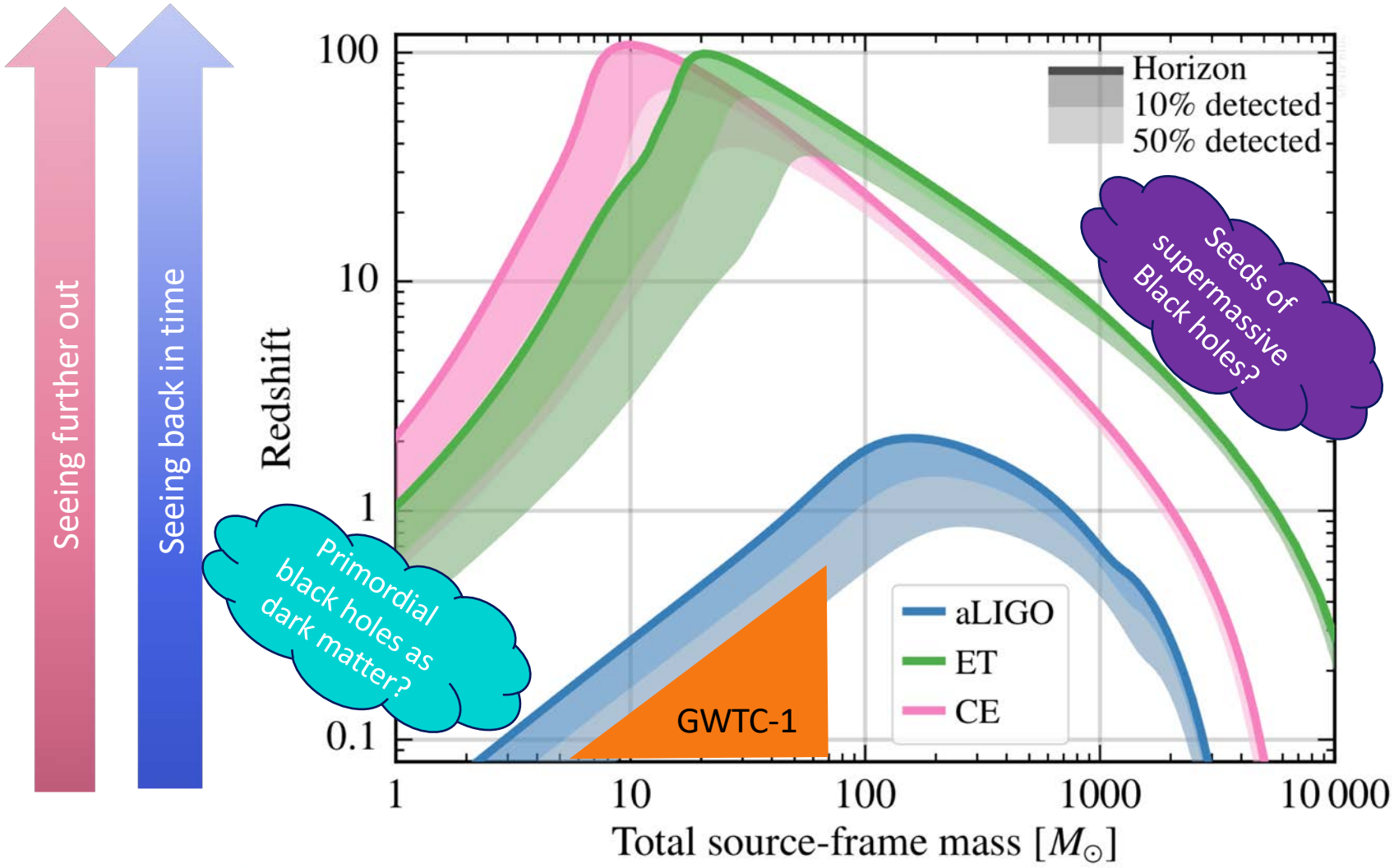
Proved existence of intermediate-mass black holes

From current detectors to ET



- Current detectors observe about one signal per week.
- ET will observe about 100.000 to 1.000.000 binary black holes mergers per year! And many other new sources => discovery space!

Reaching for the full cosmos!

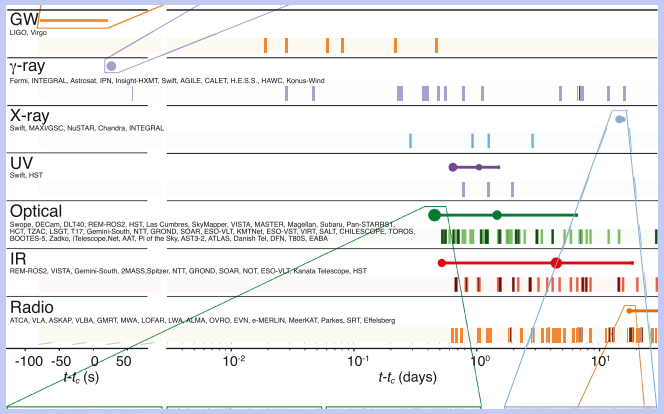


Binary Coalescences Overview:

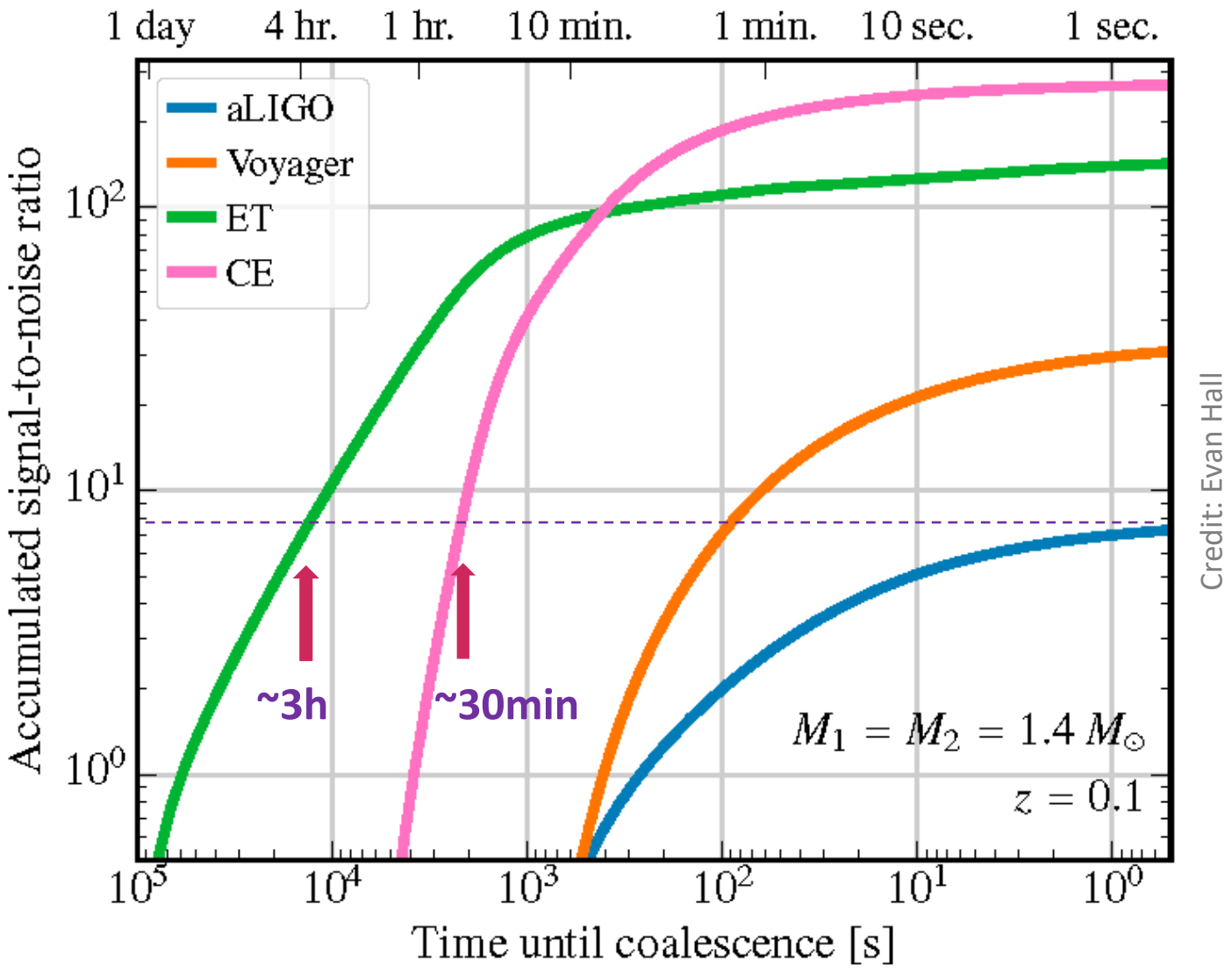
- Census of stellar and intermediate-mass BBH population over full Universe, 10^5-10^6 events per year;
- High SNR events will provide excellent precision to do accurate test of GR, nature of the BH, strong-field dynamics, black hole no-hair theorem etc;
- Extend the range of observed BBH masses towards >1,000M_{sol} and <1$M_{sol;}$
- Observe several 10,000 binary neutron star mergers per year.
- ET will determine NS EOS.

Seeing BNS with GWs before merger!

GW170817: Optical counterpart located ~6 hours after merger.



With ET we have a chance to observe the kilonova right from the beginning, observe fast radio emission and pin down the engine of short GRBs.

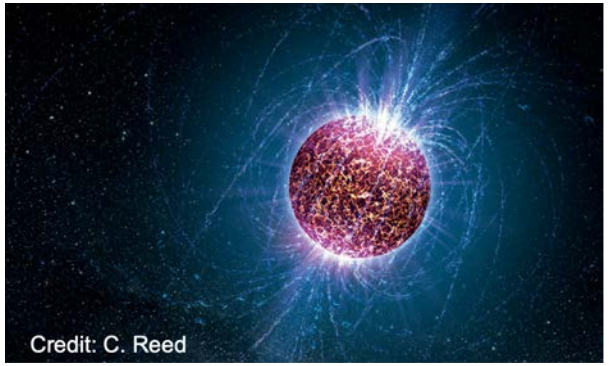


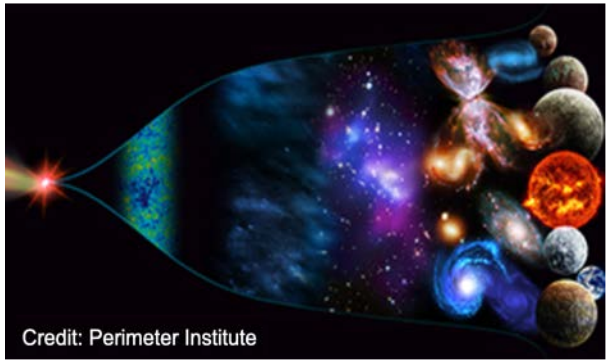
Credit: Evan Hall

[S.Hild, Vista meeting, 21.10.2020]

More Science!

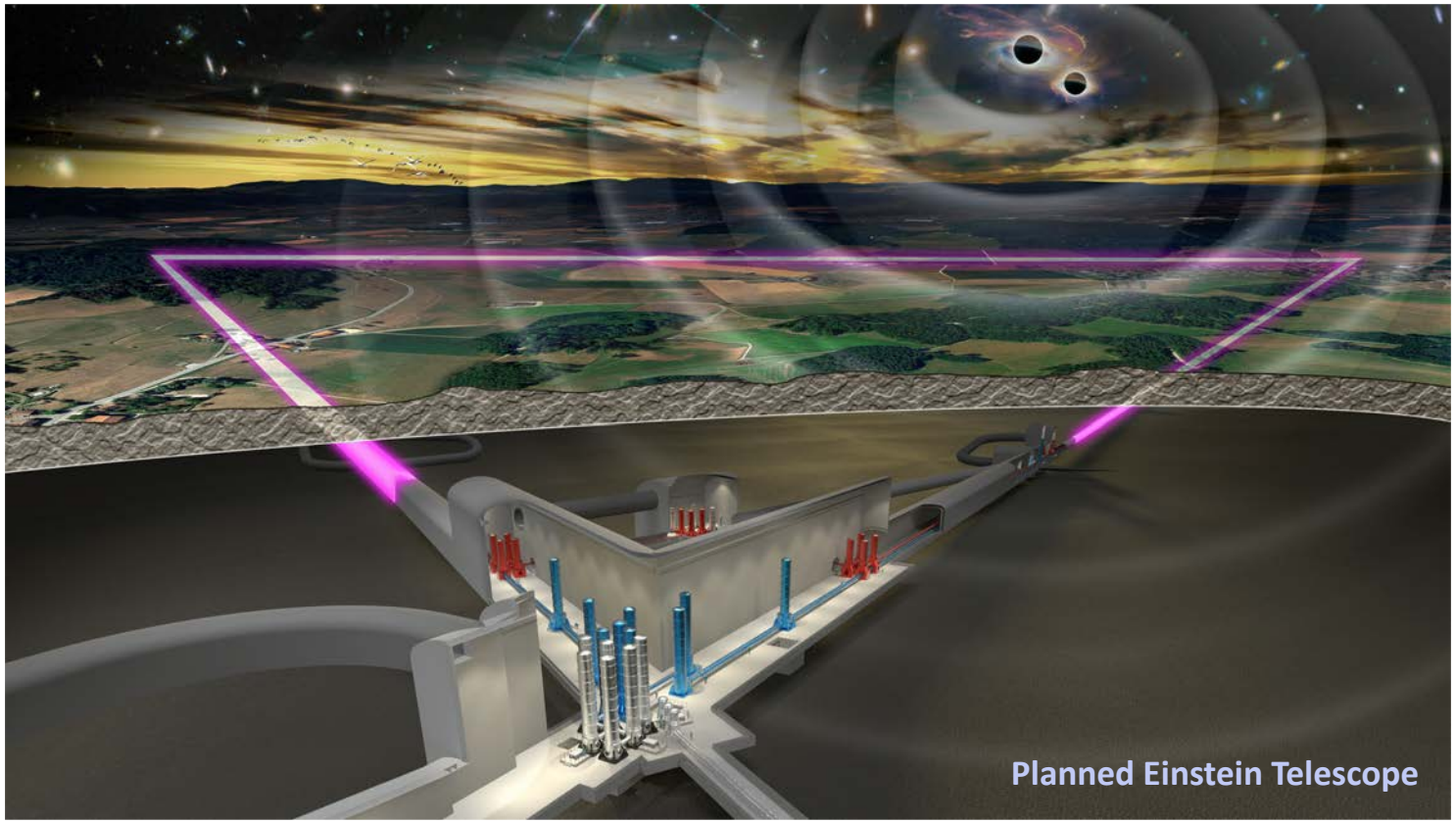
- Supernovae
- Isolated rotating neutron stars
- Testing of a variety of dark matter candidates
- Exploring the nature of dark energy
- Stochastic background of GWs, back to shortly after Big Bang
- What else might be out there what do not think/know about yet?





From current detectors to ET

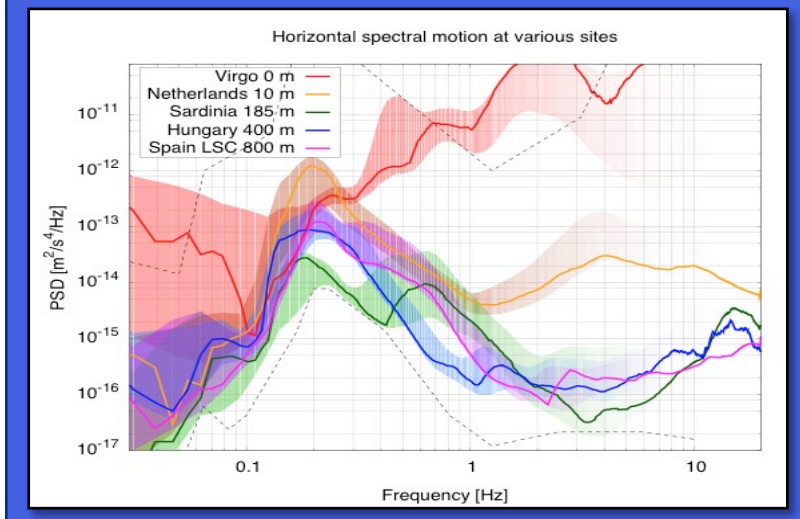
Current detectors started ~1990s



ET will be an infrastructure to provide observing power for half of the 21st century, i.e. from about 2035-2085!

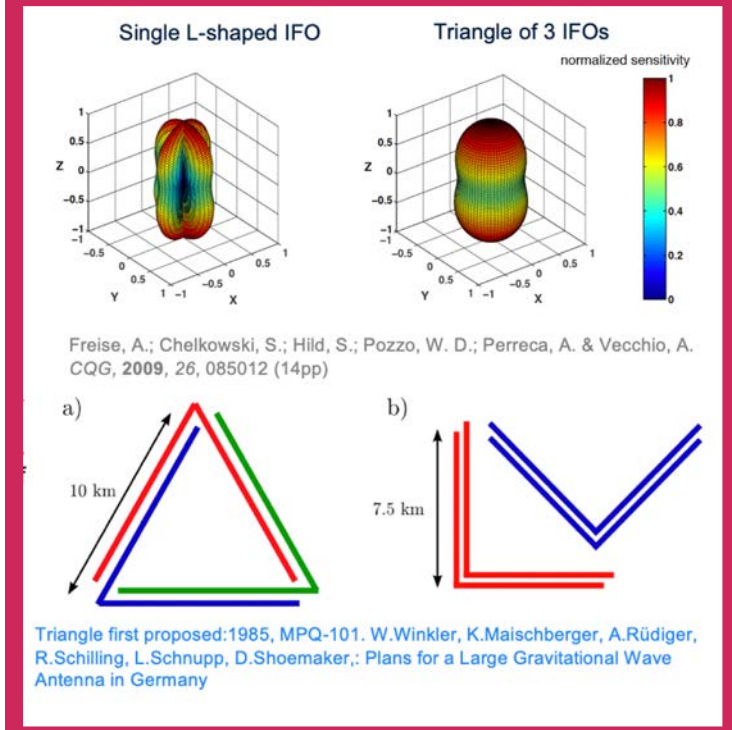
Why does ET look so different compared to current interferometers?

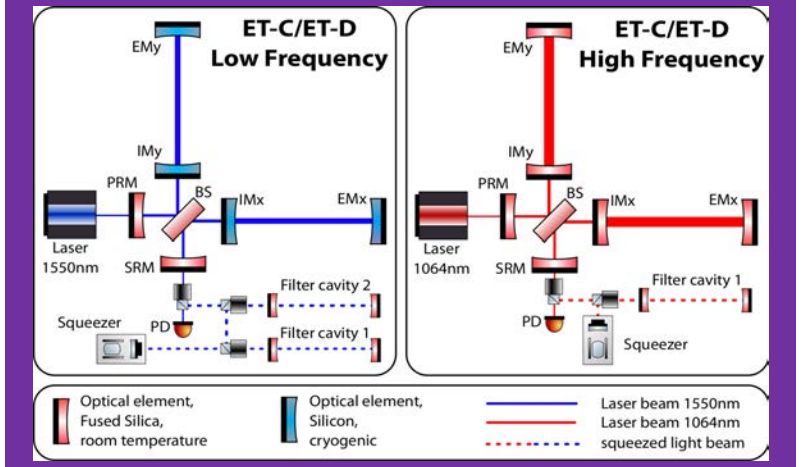
Key concepts of ET in a single slide



Underground location for Reduction of seismic and atmospheric GGN
+ long baseline

Triangular for full sky coverage and redundancy





Xylophone concept

Many new technologies, like for instance cryogenic silicon mirrors

Outline

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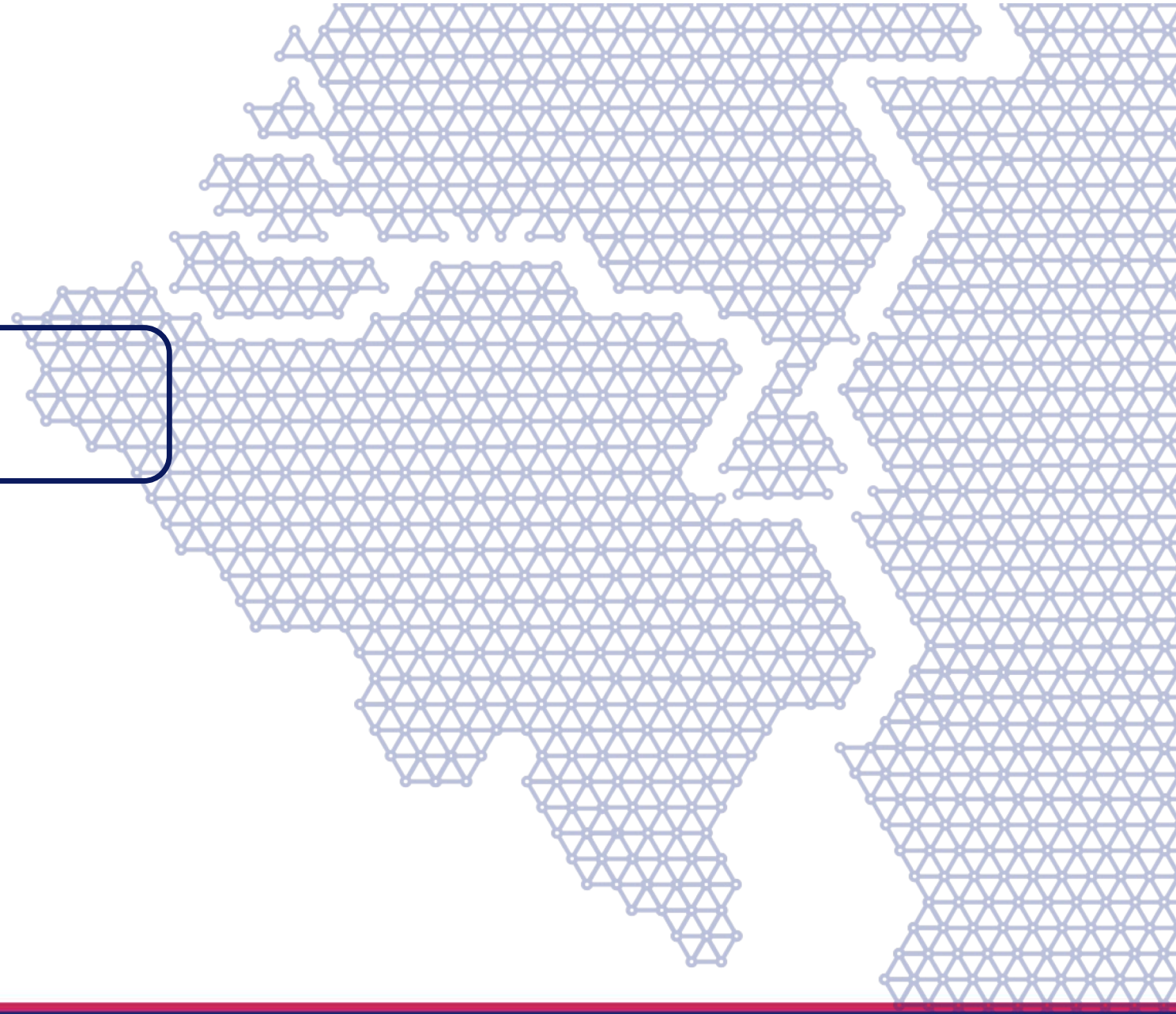
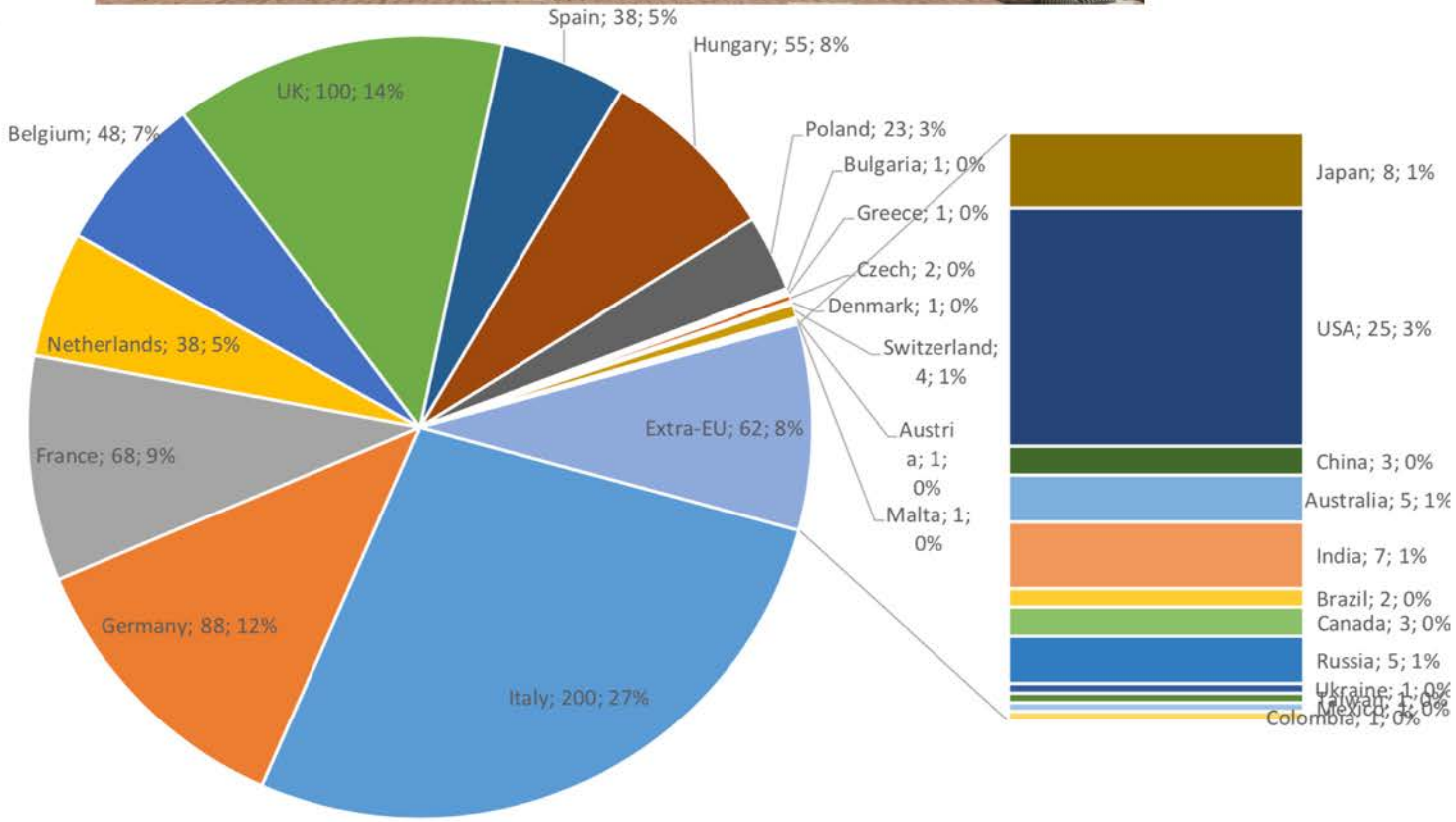


ET collaboration

- Launched the ET letter of intent @ the 9th ET symposium (April 2018)
- At the 10th ET symposium, April 2019, we collected more than 730 signatories

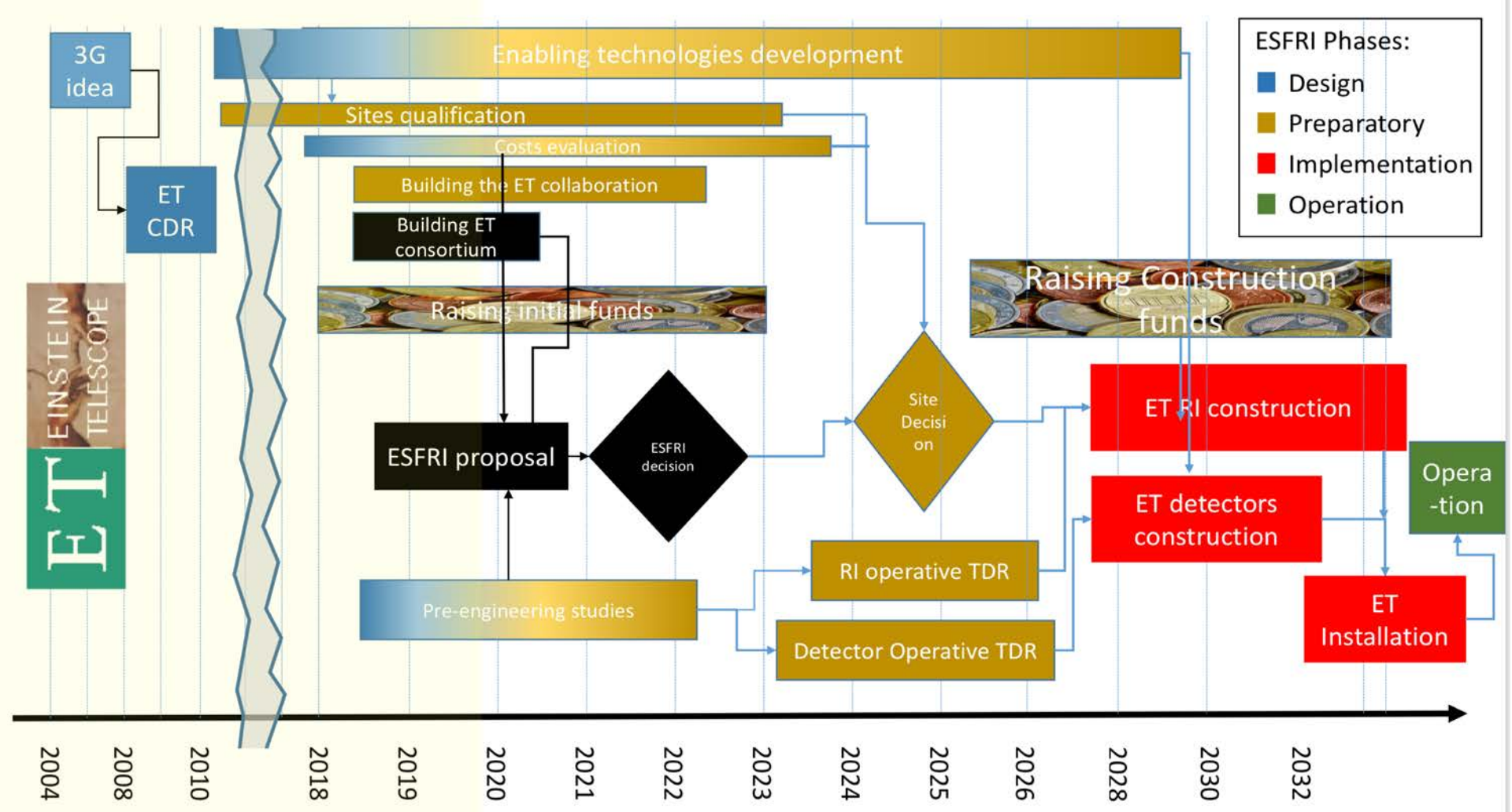


http://www.et-gw.eu/index.php/letter-of-intent

11th ET symposium will take place 30th Nov-3rd Dec 2020

https://indico.in2p3.fr/event/20576/overview

ET timeline



- Idea for ET like-observatory is from 2004
- CDR was finished in 2011
- Discovery of GWs in 2015/16 brought ET really to life

ESFRI application submitted

- ET is on Dutch National Roadmap for Large-Scale Scientific Infrastructure. ET is on European Astroparticle Roadmap.
- Next step is ESFRI roadmap. Application was submitted by governments of 5 EU countries last month.
- 2 candidate sites: Sardinia (IT) & Euregio Meuse Rhine (NL, BE, G).

SECTION 4: RESEARCH INFRASTRUCTURE CONSORTIUM

COORDINATOR

	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	Istituto Nazionale di Fisica Nucleare
1	INSTITUTION ADDRESS:	Piazza dei Caprettari 70, Roma
	REPRESENTATIVE:	Antonio Zoccoli
	EMAIL:	presidenza@presid.infn.it
	TELEPHONE:	+39 06 6840031
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	THE NETHERLANDS
	INSTITUTION NAME:	Nikhef
2	INSTITUTION ADDRESS:	Science Park 105, 1098 XG Amsterdam, the Netherlands
	REPRESENTATIVE:	Stan Bentvelsen
	EMAIL:	s.bentvelsen@nikhef.nl
	TELEPHONE:	+31 205925001

2 coordinators: INFN & Nikhef

ESFRI MoS

ESFRI Monitoring System

Strategy Report on Research Infrastructures

ROADMAP 2021

Proposal Questionnaire Part A: General Information

Submitted on 2020-09-05

PROPOSAL SUBMISSION THROUGH ESFRI MOS+

PROPOSAL COORDINATOR:
Michele Punturo

RI NAME:
Einstein Telescope

Netherlands provided strong support for ESFRI

Ministry of Education, Culture a
Science

>Return address P.O. Box 16375 2500 BJ The Hague The Netherlands

European Strategy Forum on Research Infrastructures
To Dr Jan Hrusak, Chair
ORBN 04/110
1049 Brussels
Belgium

Date 21 AUG. 2020
Subject Letter of Support for the Einstein Telescope (ET) as a project in the 2021 ESFRI Roadmap

Dear Dr Hrusak,

It is my pleasure to inform you that I fully support the proposal to include the Einstein Telescope for inclusion in the 2021 ESFRI Roadmap. My support for the project is seconded by the governing bodies of the Province of Limburg and the Euregion Meuse-Rhine (see letters attached).

with all six universities involved in physical sciences. The Einstein Telescope has been part of the National Roadmap for Large-scale Scientific Infrastructures of the Netherlands since 2018. In 2019, I joined the region, the relevant institutes and universities, and the Belgian government in investing in ETpathfinder, an R&D laboratory dedicated to developing innovative technological solutions for the Einstein Telescope.

Before the construction phase, a selection procedure should be drawn up by the countries likely to invest in the Einstein Telescope. This calls for a transparent bidding process with clear terms of reference for evaluating the proposals. Ideally, the countries involved should agree an interim governing mechanism for making decisions such as site selection, made up of ministerial and scientific delegates from the respective countries. Site selection should be finalized in 2025 so as not to delay the start of operations in 2035.

The Euroregion site necessitates collaboration between the Netherlands, Belgium and Germany. Joint investments and preparations are already under way for geological surveys and socioeconomic impact reports. Nikhef and the Province of Limburg, in close conjunction with parties in Belgium and Germany, are assessing the suitability of the region's geology. To strengthen their commitment, the countries' scientific institutes and universities have signed a Memorandum of Understanding formalizing their cooperation on gravitational waves research and the development of the Einstein Telescope (see attachment).

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Formal recognition as an ESFRI project will go a long way towards consolidating the scientific, technological and political efforts needed to deliver this European flagship. I am convinced that the Einstein Telescope meets all of the criteria for a highly competitive ESFRI Roadmap project, serving the best interests of Europe's gravitational wave research community.

Yours sincerely,

Ingrid van Engelshoven
Minister of Education, Culture and Science

From the ET-costbook and socio-economic studies

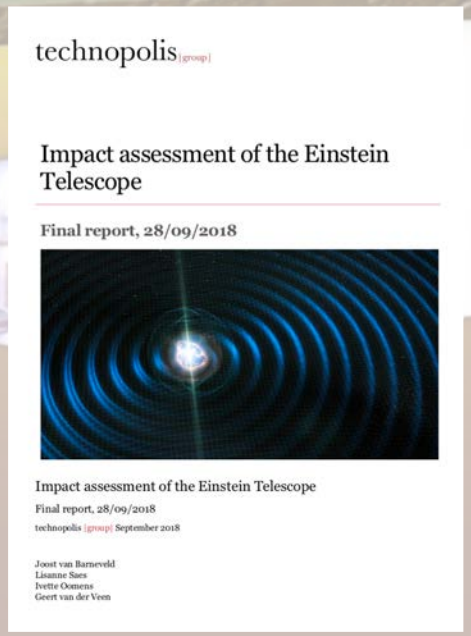
Site infrastructure	ca 900
Vacuum	ca 550
Seismic isolation	ca 50
Cryogenics	ca 50
Optics	ca 125
Design and Prepaprtion	ca 200
Total	ca 1900

Estimated budget in Mega-Euro (excl Personnel)

Note: Largest cost items have big overlap with CERN, i.e. underground and civil construction, vacuum systems, cryogenics etc. Also note there is an exciting MOU between CERN, INFN and Nikhef covering those items.

1 Euro invested in ET generates **3.6 Euro of Total Output*** or between **1.4 and 1.55 Euro of Value Added****. **Estimated overall employment effect of about 34000 py during construction**.

*TO measures the increase of the volume of economic activity induced by the project.
**VA measures the new value generated by the project, i.e. its contribution to the GDP, net of the duplication effects due to the production of intermediate goods and services along the supply chain.


technopolis |group|

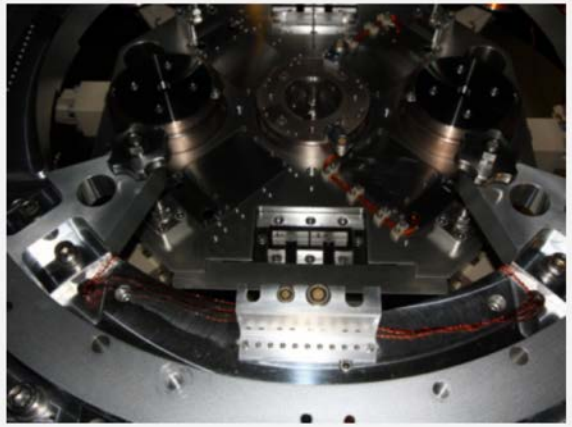
Impact assessment of the Einstein Telescope

Final report, 28/09/2018

Impact assessment of the Einstein Telescope
Final report, 28/09/2018
technopolis |group| September 2018

Joost van Barneveld
Lisanne Saes
Ivette Oomens
Geert van der Veen

Fostering Economic Impact



18 June 2020

Webinars on technical challenges of the Einstein Telescope for industry

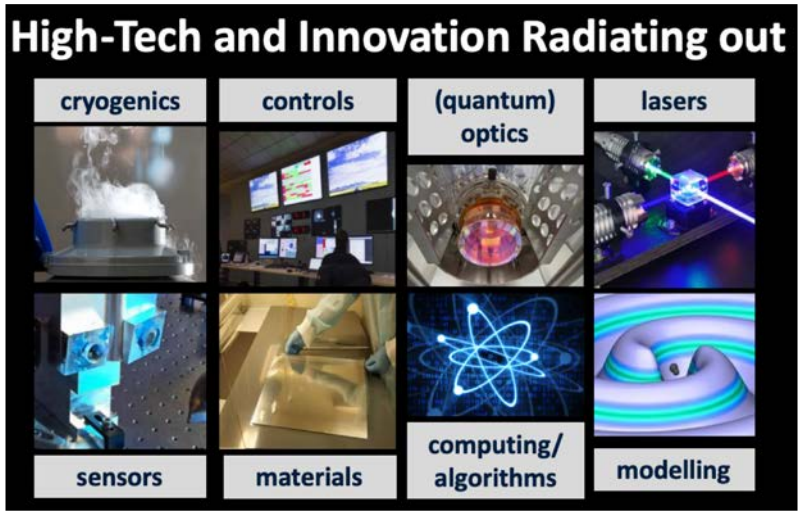
On 1 and 15 July, webinars will take place to discuss the technical challenges of the Einstein Telescope with interested companies. The Einstein Telescope comes with unique technical challenges that...

→ Read more

Einstein Telescope / NL / BE / D /

Einstein Telescope opportunities: orders, co-development, spin-offs

Prof Stefan Hild, University of Maastricht + Nikhef
Email: Stefan.Hild@maastrichtuniversity.nl
www.etpathfinder.eu / www.einsteintelescope.nl



Interreg Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

Nikhef

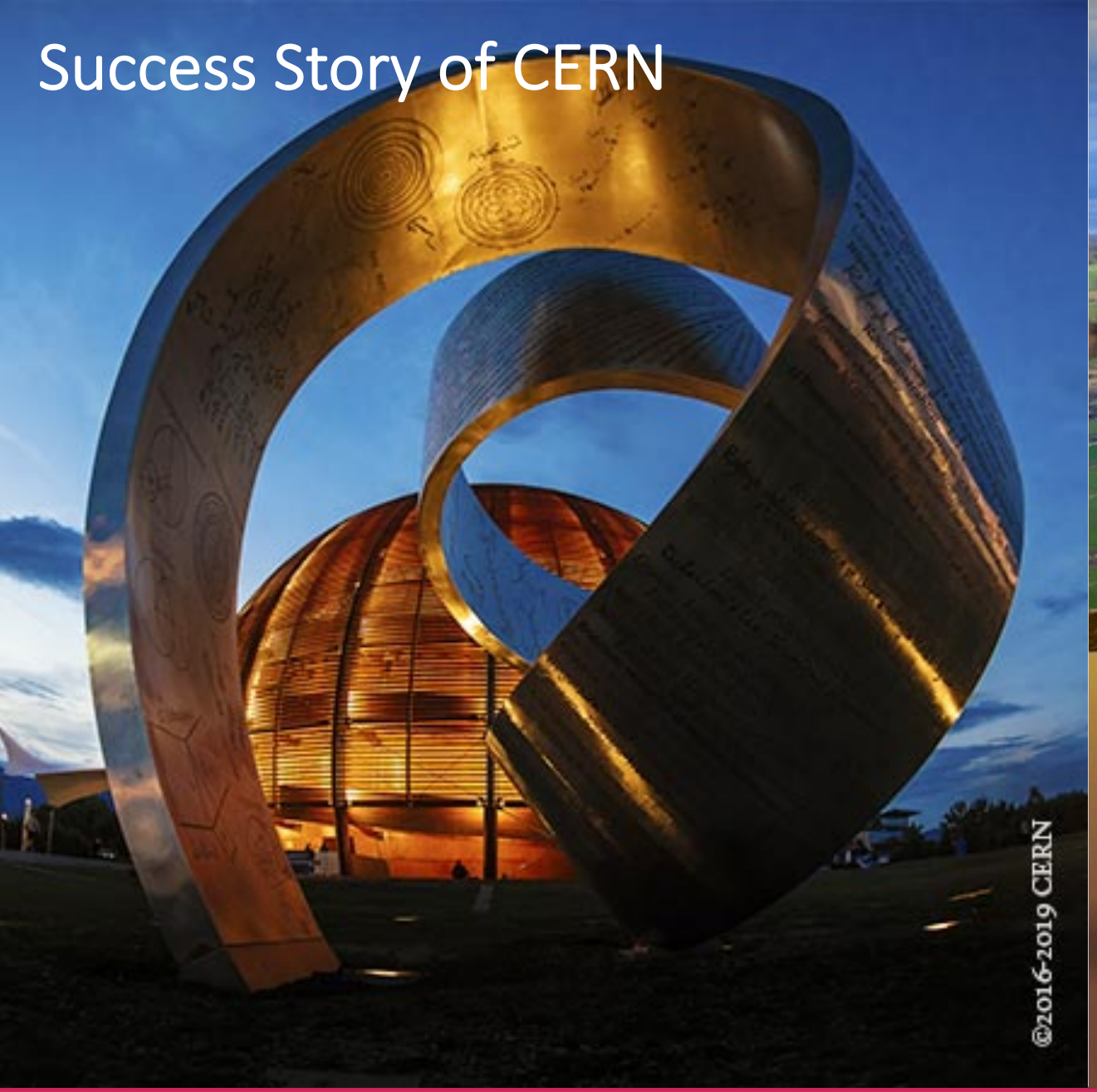
iLO-net

Holland High Tech
Global Challenges, Smart Solutions

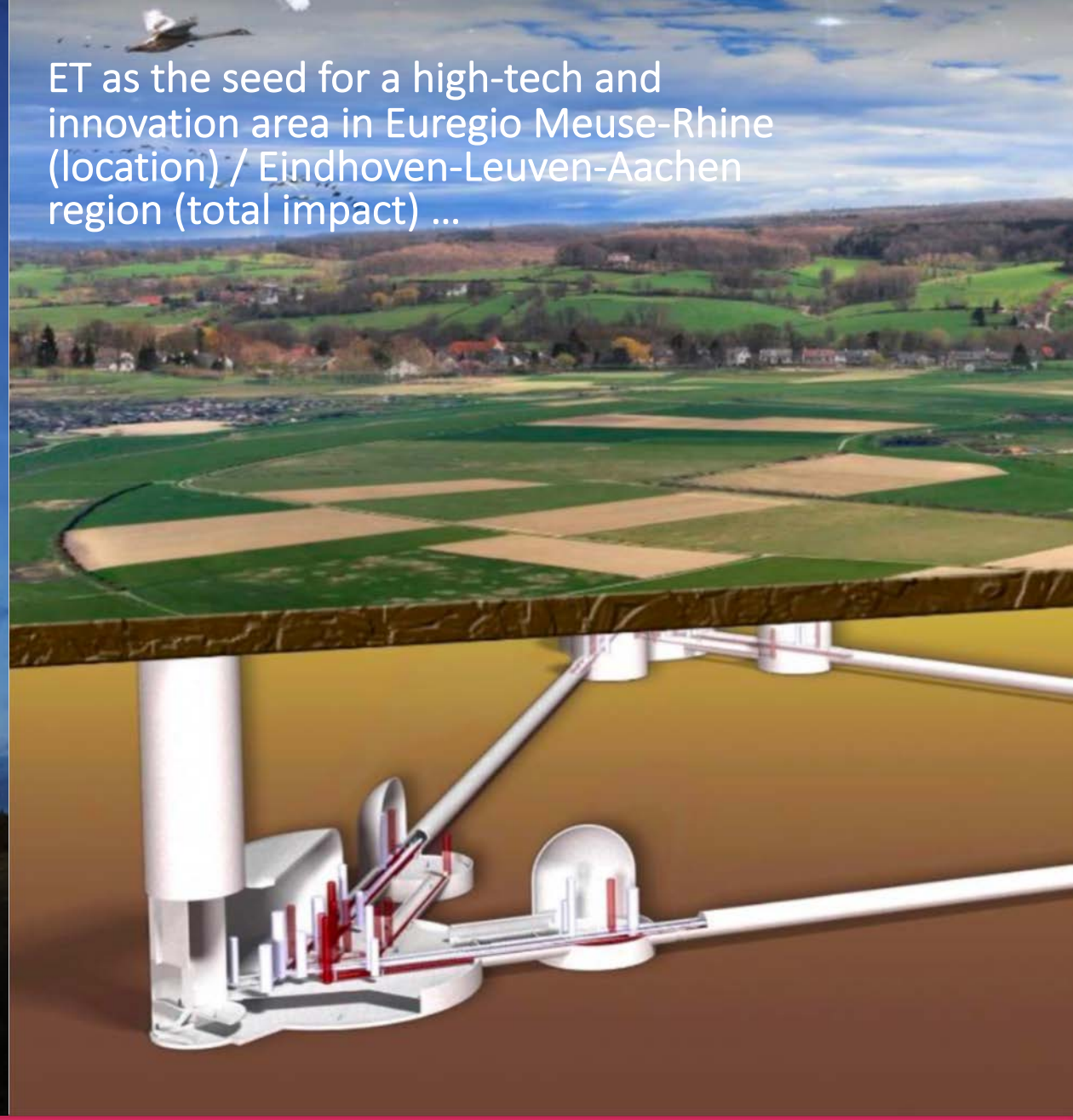
Holland.

LIOF

Success Story of CERN



ET as the seed for a high-tech and innovation area in Euregio Meuse-Rhine (location) / Eindhoven-Leuven-Aachen region (total impact) …



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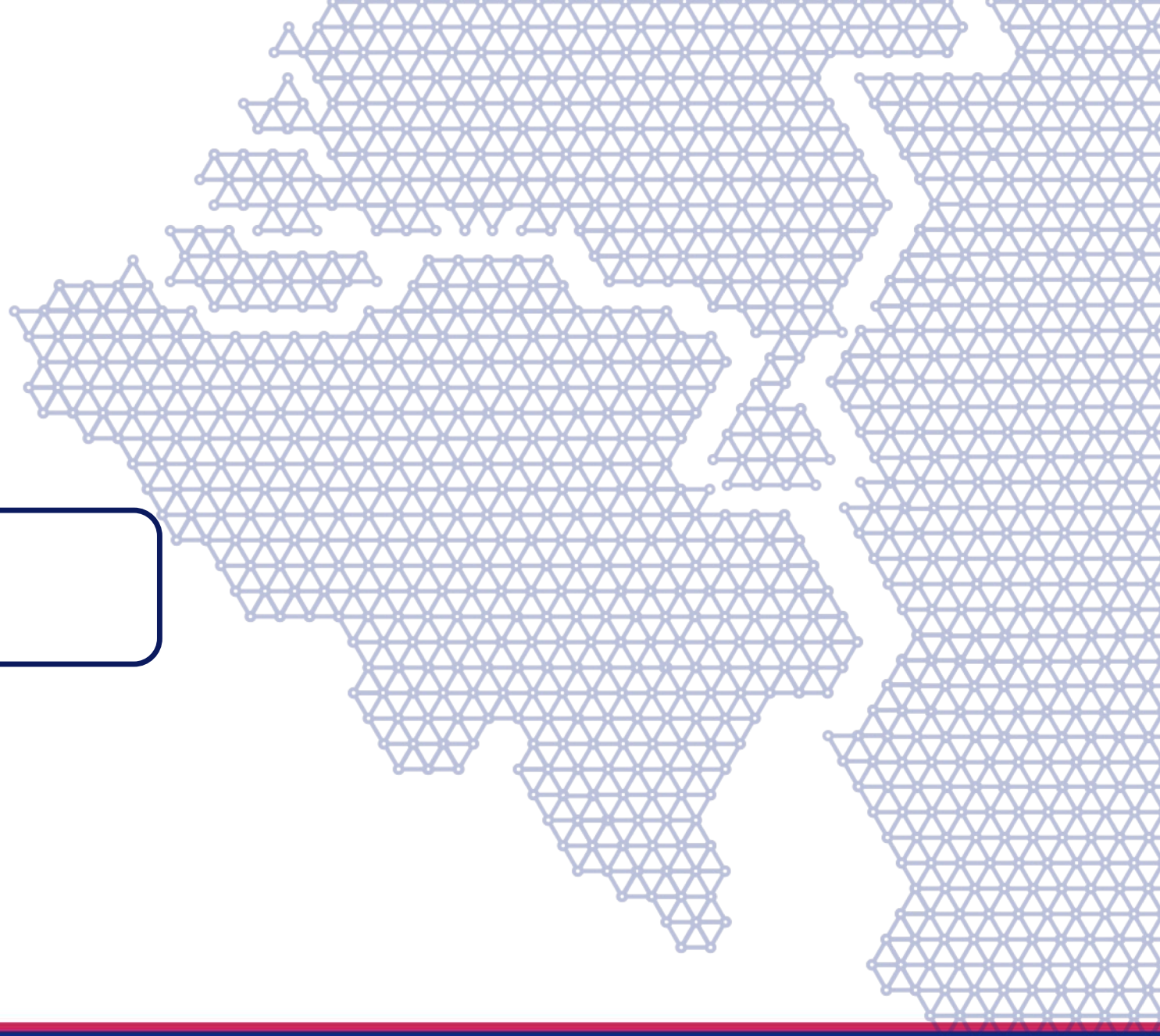
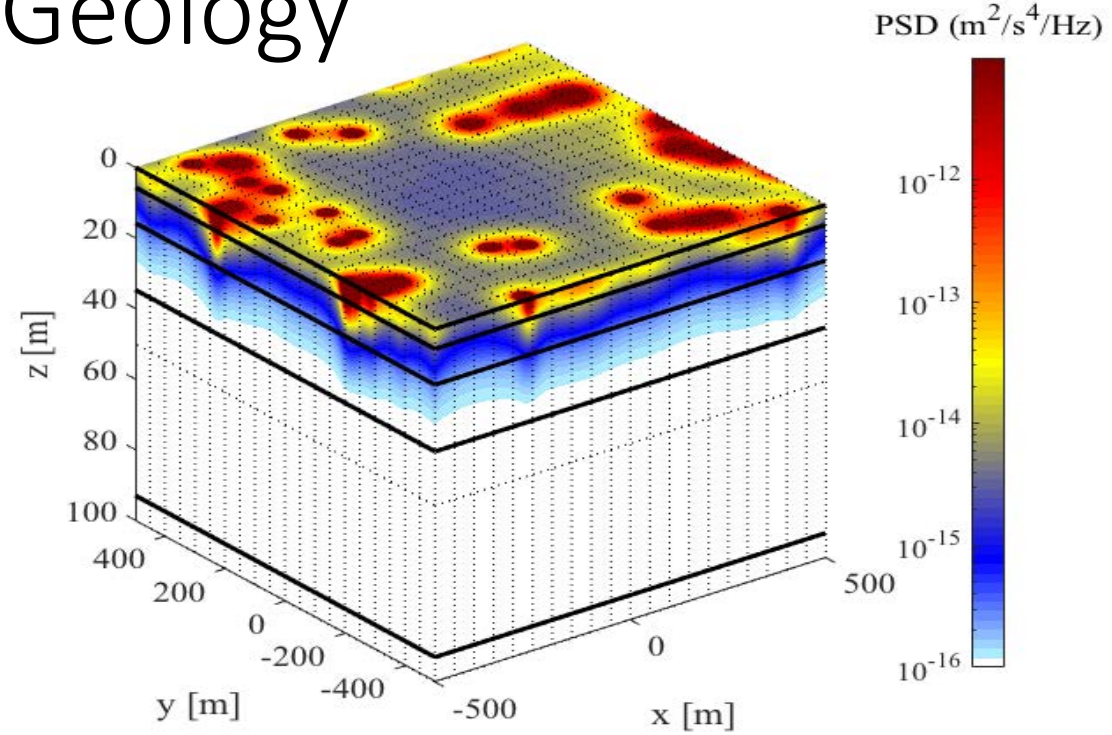
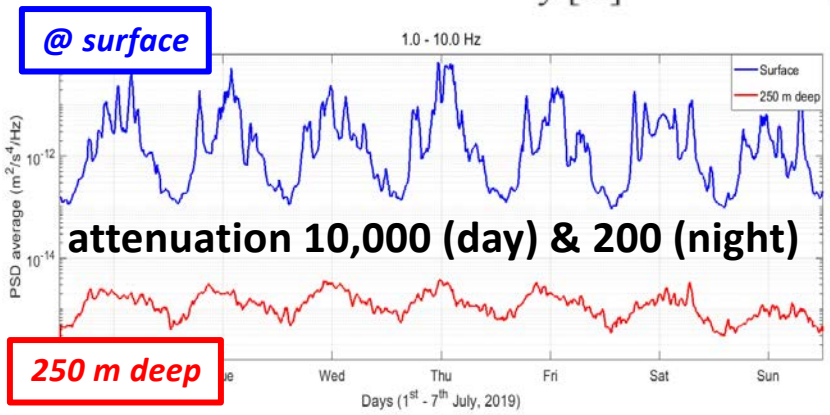


Suitable Geology





13 September 2019

First results of seismic studies of the Belgian-Dutch-German site for Einstein Telescope

Soumen Koley[1], Maria Bader[1], Alessandro Bertolini[1], Jo van den Brand[1,2], Henk Jan Bulten[1,3], Stefan Hild[1,2], Frank Linde[1,4], Bas Swinkels[1], Bjorn Vink[5]

1. Nikhef, National Institute for Subatomic Physics, Amsterdam, The Netherlands
2. Maastricht University, Maastricht, The Netherlands
3. VU University Amsterdam, Amsterdam, The Netherlands
4. University of Amsterdam, Amsterdam, The Netherlands
5. Antea Group, Maastricht, The Netherlands

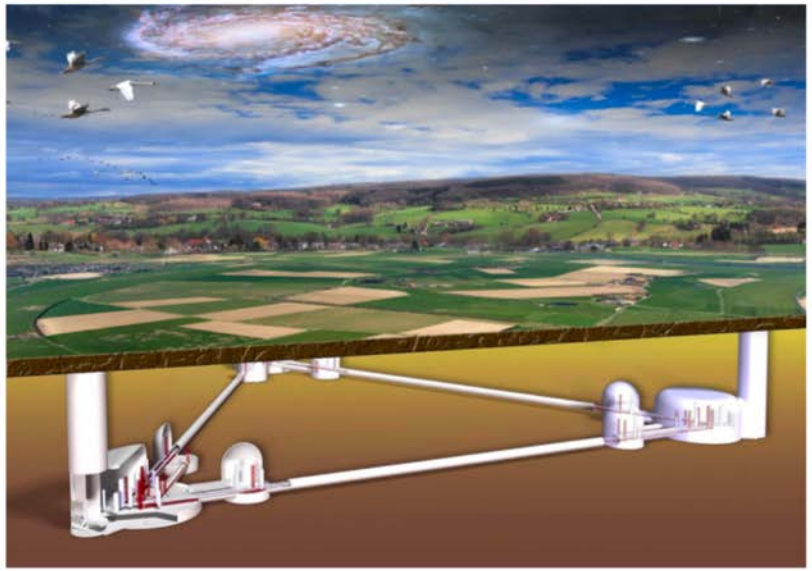
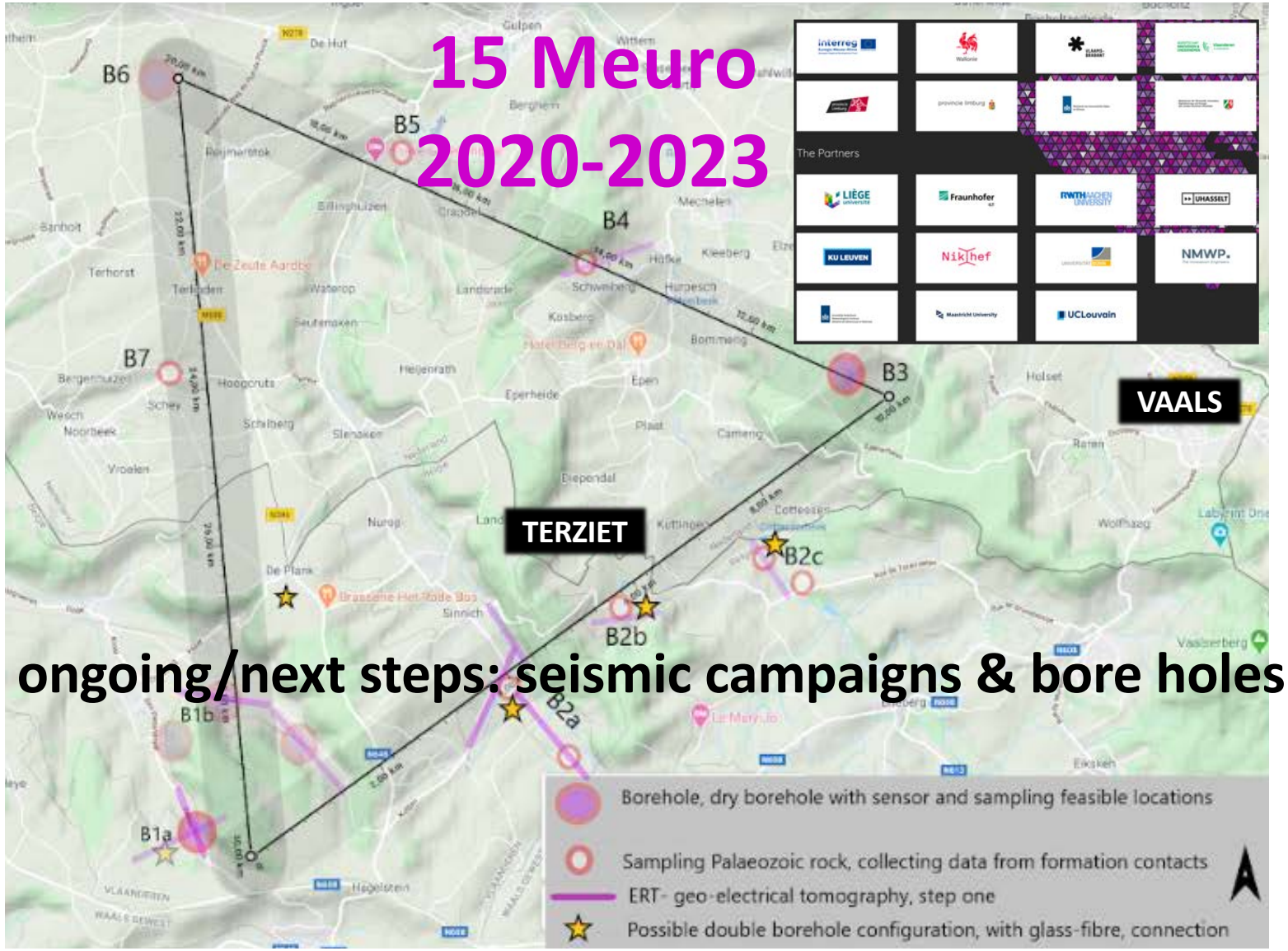


Figure 1: Artist impression of the Einstein Telescope gravitational wave observatory situated at a depth of 200-300 meters in the Euregio Meuse-Rhine landscape. The triangular topology with 10 kilometers long arms allows for the installation of multiple so-called laser interferometers. Each of which can detect ripples in the fabric of space-time – the unique signature of a gravitational wave – as minute relative movements of the mirrors hanging at the bottom of the red and white towers indicated in the illustration at the corners of the triangle.

E-TEST


Interreg
Euregio Meuse-Rhine
E-TEST
EUROPEAN UNION
European Regional Development Fund
E-TEST
The Einstein Telescope will open a new window on the Universe through the observation of gravitational waves. Its infrastructure will be buried 300 meter below the surface to reduce human-, wind- and ground-induced vibrations and movements. The Interreg project E-TEST is a very important step of the Einstein Telescope, as it will be a proof of concept, both on the prototype side and on the geological side. E-TEST will build a prototype – a large suspended mirror at cryogenic temperature (10 Kelvin) – to validate the telescope's technology. E-TEST will also run an underground study to map and model the geology of the Euregio Meuse-Rhine. This will allow to define the optimal design and location of the future Einstein Telescope. This project is a major scientific breakthrough but will also have a significant economic impact on SMEs in the Euregio Meuse-Rhine.
www.interregemr.eu
At Interreg Euregio Meuse-Rhine, we fund projects where partners work together across borders. In 2014-2020, we invest EUR 96 million from the European Regional Development Fund in our region.
We are a collaboration between 13 regions from Belgium, Germany and The Netherlands. Together, we develop shared solutions to common challenges. This gives Interreg its own, distinct spirit of cooperation: across regions and across borders.
Wallonie
provincie limburg
VLAAMS-BRABANT


15 Meuro
2020-2023
The Partners
LIÈGE
Fraunhofer
RWTH AACHEN UNIVERSITY
UHASSELT
KU LEUVEN
Nikhef
NMWP.
Maastricht University
UCLouvain
VAALS
TERZIET
B1a
B1b
B2a
B2b
B2c
B3
B4
B5
B6
B7
ongoing/next steps: seismic campaigns & bore holes
Borehole, dry borehole with sensor and sampling feasible locations
Sampling Palaeozoic rock, collecting data from formation contacts
ERT- geo-electrical tomography, step one
Possible double borehole configuration, with glass-fibre, connection

Many Interested partners across Netherlands, Belgium and Germany

ETpathfinder – testbed for future GW technologies

- Technology development for Einstein Telescope. **Independent of ET siting decision.**
- ETpathfinder has multi-decade timeline.
- About 20 institutions contributing from NL,B,G,FR,UK
- 15Meuro capital investment
- New Technologies: Silicon optics, cryogenics, new laser wavelength, quantum noise reduction techniques etc

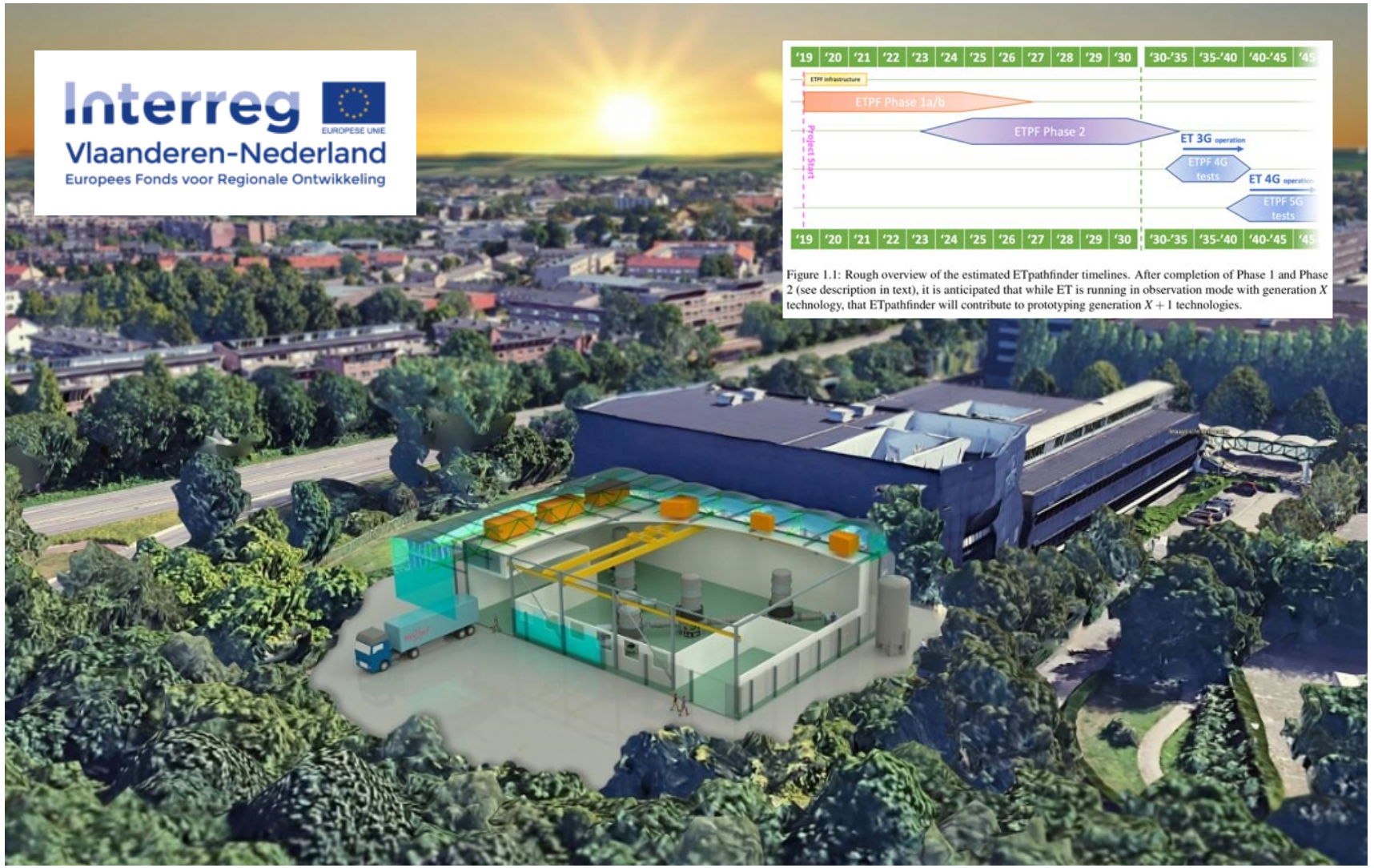


Figure 1.1: Rough overview of the estimated ETpathfinder timelines. After completion of Phase 1 and Phase 2 (see description in text), it is anticipated that while ET is running in observation mode with generation X technology, that ETpathfinder will contribute to prototyping generation $X+1$ technologies.

From ETpathfinder Advisory Board (STAC) report

- […] Overall, the ETPF-STAC was very impressed with the vision for the facility, the technical capability of the leader and team, and the scope of the effort. It will be transformative for the field to have a facility and a research program covering the foreseen capabilities of the installation, and it can become a very natural center for technical innovation and scientific breakthroughs in precision measurement, interferometry, cryogeny for gravitational-wave detectors, and for the formation of a next generation of gravitational-wave scientists (to handle the next generation of gravitational-wave detectors). The growth of the team (and of the institutions interested in participating) is an exciting development and speaks to the timeliness and centrality of this infrastructure. […]
- The ETPF-STAC is very excited to be part of the establishment and exploitation of this unique facility and this dynamic team.

Support on German side is increasing

The Federal Ministry of Education and Research supports the development of the Einstein Telescope

For the next generation of gravitational-wave detectors on Earth: Laser development and squeezed-light research in Hannover

JULY 24, 2020

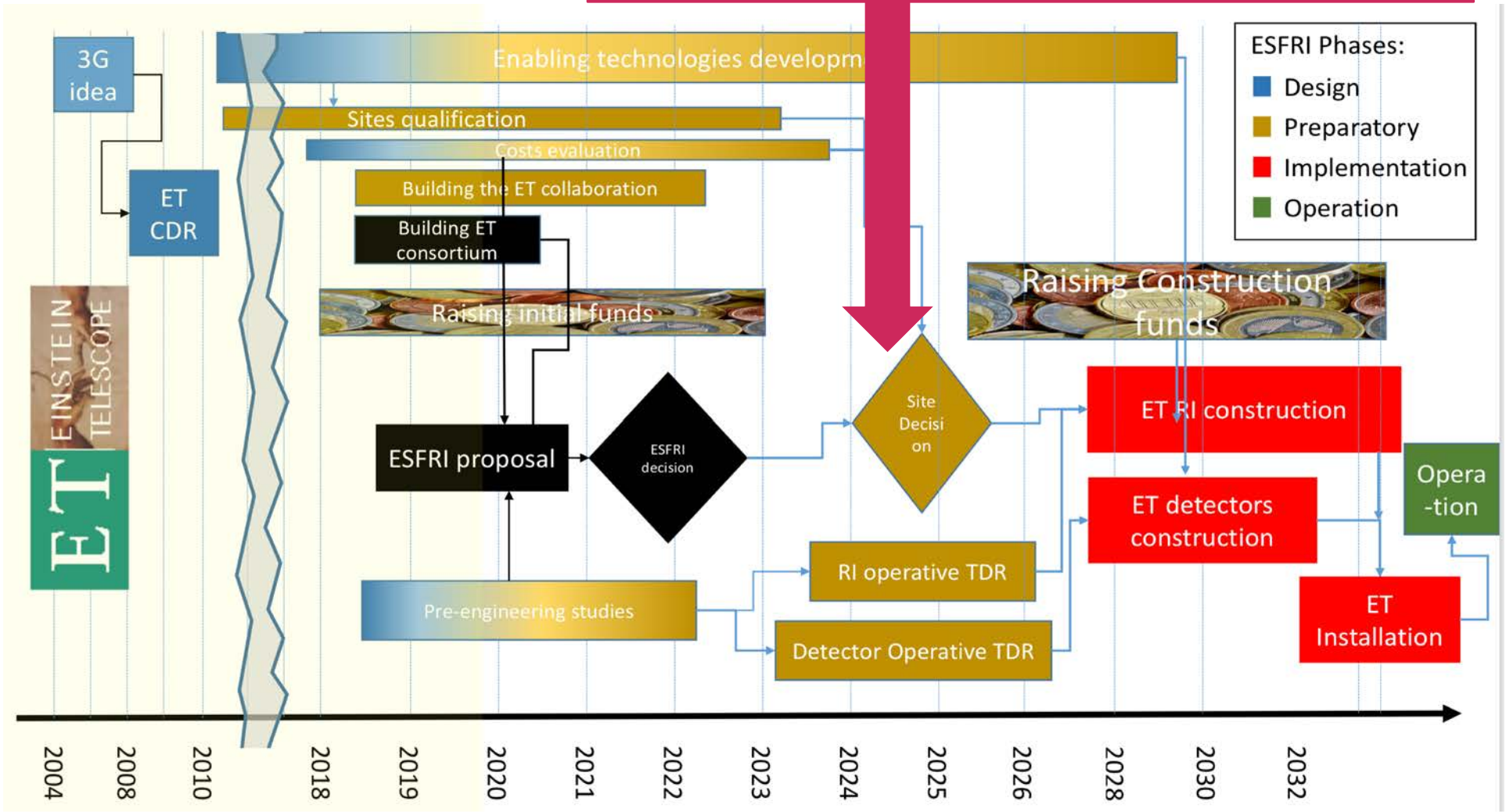
Fourteen German universities and non-university research institutions will receive a total of approximately 2 million Euros from the Federal Ministry of Education and Research (BMBF). This funding enables physicists and geophysicists to conduct research on various technological aspects of the Einstein telescope. These include, for example, seismic measurements and the development of crystalline fibers for suspending the mirrors.

At the Institute for Gravitational Physics of Leibniz Universität Hannover, in close cooperation with the Max Planck Institute for Gravitational Physics and the QuantumFrontiers Cluster of Excellence, a laser source for the Einstein Telescope Pathfinder – a prototype of the observatory – is to be developed and tested in Hannover and installed in the prototype in Maastricht. In addition, the participating researchers will investigate questions concerning the generation of squeezed light and the use of this technology in 3rd generation gravitational wave detectors. The BMBF funds will be used to finance an additional doctoral student position in Hannover.

Read more on about this in a news item on ↗ einsteintelescope.nl.

ET timeline

By 2024 the governments of host countries (N/B/G) need to have decided whether to support or not.



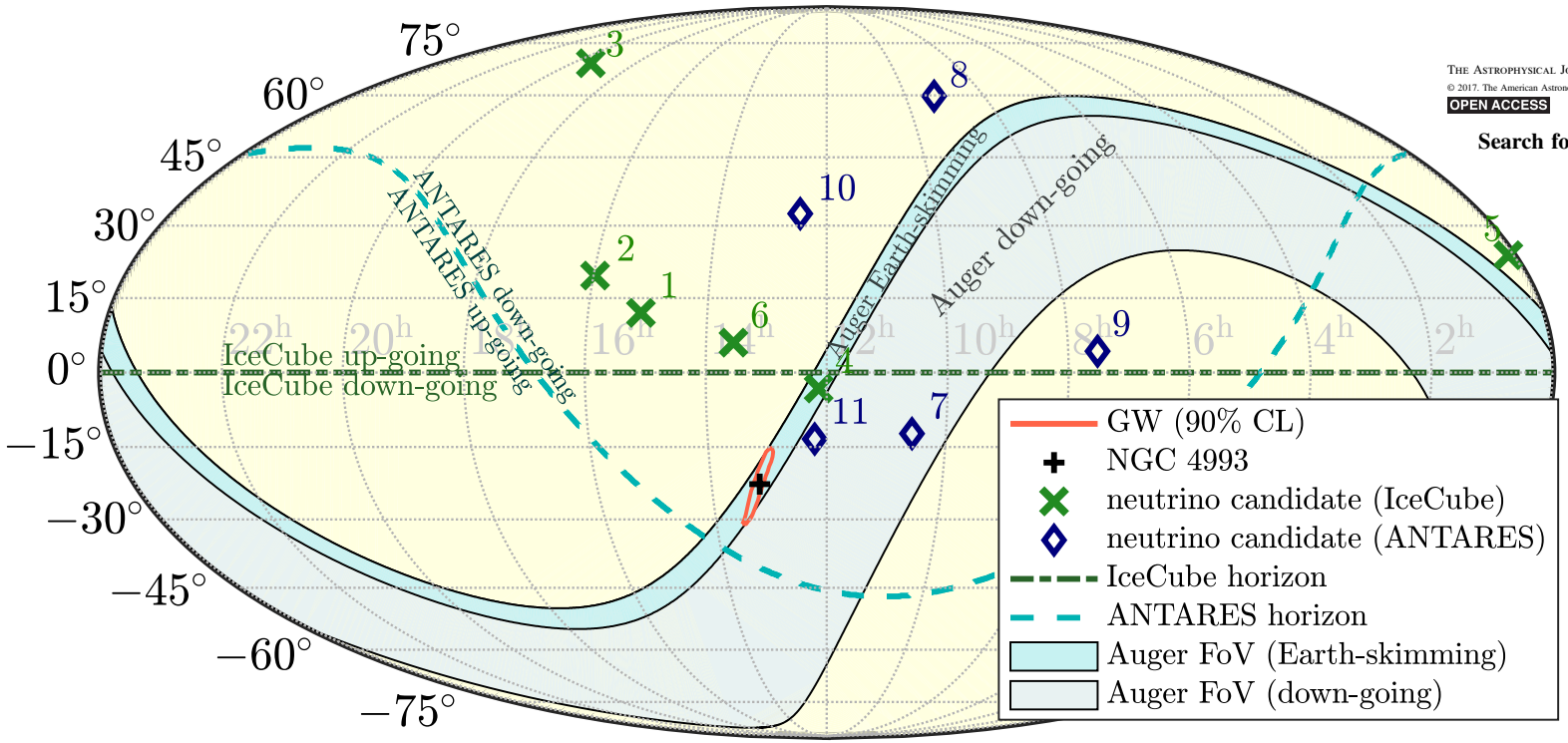
- Idea for ET like-observatory is from 2004
- CDR was finished in 2011
- Discovery of GWs in 2015/16 brought ET really to life

Outline

- Brief Overview of Einstein Telescope
- Current Status of the European Efforts
- Hosting ET in the Euregio Meuse Rhine?
- Synergies with other Nikhef research programmes

GW + ANTARES/KM3Net + Pierre Auger

- Multi-messenger investigations of binary neutron star merger GW170817.
- Nikhef Scientist from all three programmes on one paper.



The Astrophysical Journal Letters, 850:L35 (18pp), 2017 December 1 https://doi.org/10.3847/2041-8213/aa9aed

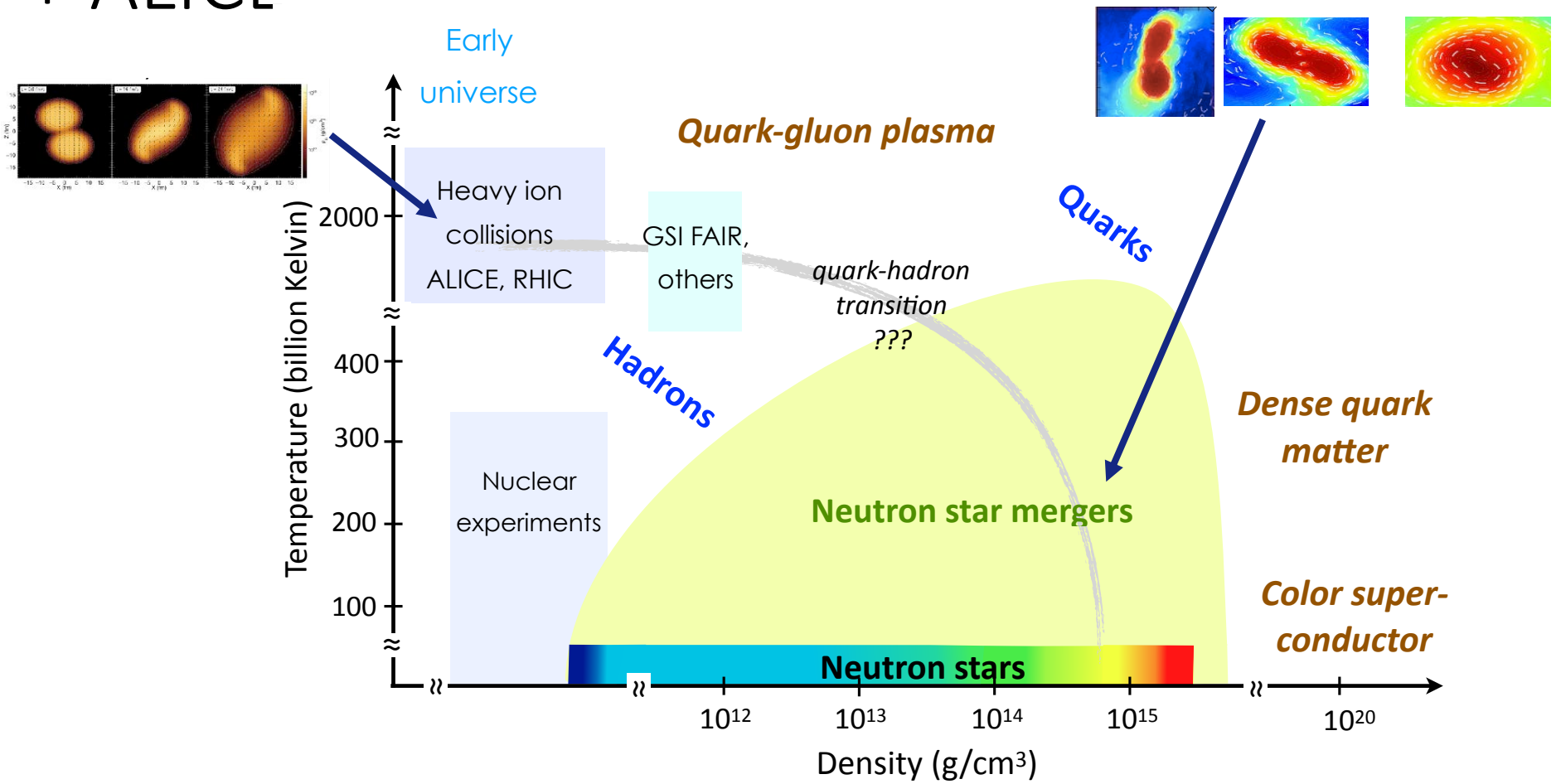
OPEN ACCESS

Search for High-energy Neutrinos from Binary Neutron Star Merger GW170817 with ANTARES, IceCube, and the Pierre Auger Observatory

ANTARES Collaboration, IceCube Collaboration, The Pierre Auger Collaboration, and LIGO Scientific Collaboration and Virgo Collaboration
(See the end matter for the full list of authors.)

Received 2017 October 15; revised 2017 November 9; accepted 2017 November 10; published 2017 November 29

GW + ALICE



E.g. recent PhD thesis connecting the two:

Govert Nijs, *Holography in quark-gluon plasma and neutron stars* (UU, 2020)

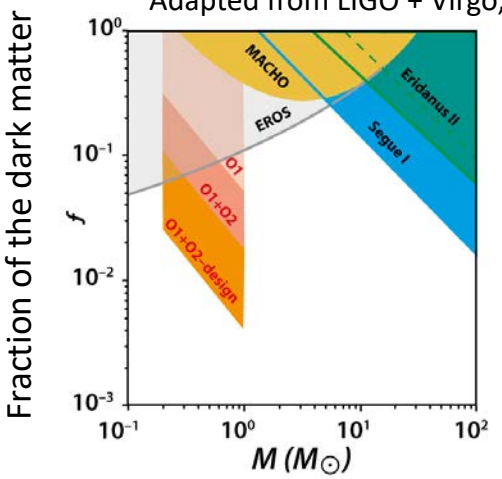
Complementary dark matter searches & beyond Standard Model physics

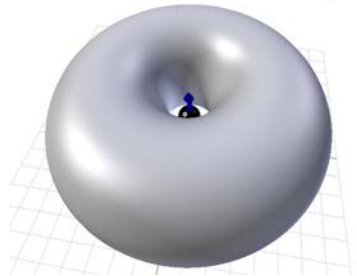
- Sub-solar mass black holes as (contributors to) dark matter?

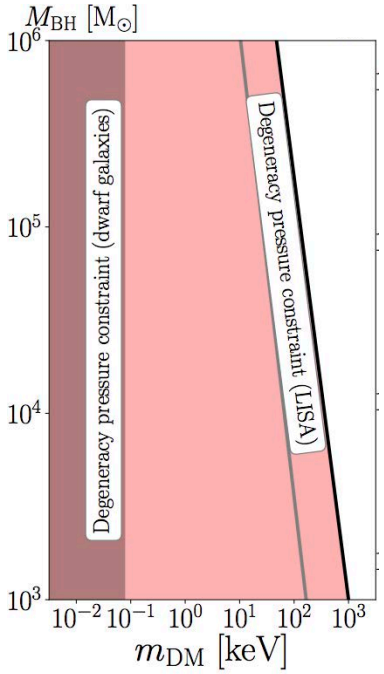
- Fermionic dark matter accumulations ("spikes") around black holes (ET and LISA):
  - Effect on binary orbital motion, imprint on GW signal
  - Probing particle masses $1\,\mathrm{keV} \lesssim m_{\mathrm{DM}} \lesssim 1\,\mathrm{MeV}$

- Condensates of ultralight bosons around rotating black holes (ET and LISA):
  - $10^{-19}\,\mathrm{eV} \lesssim m_{\mathrm{boson}} \lesssim 10^{-12}\,\mathrm{eV}$
  - Recent PhD thesis:
    - Horng Sheng Chia,
    - *Probing particle physics with gravitational waves* (UvA ,2020)

Adapted from LIGO + Virgo, 2019



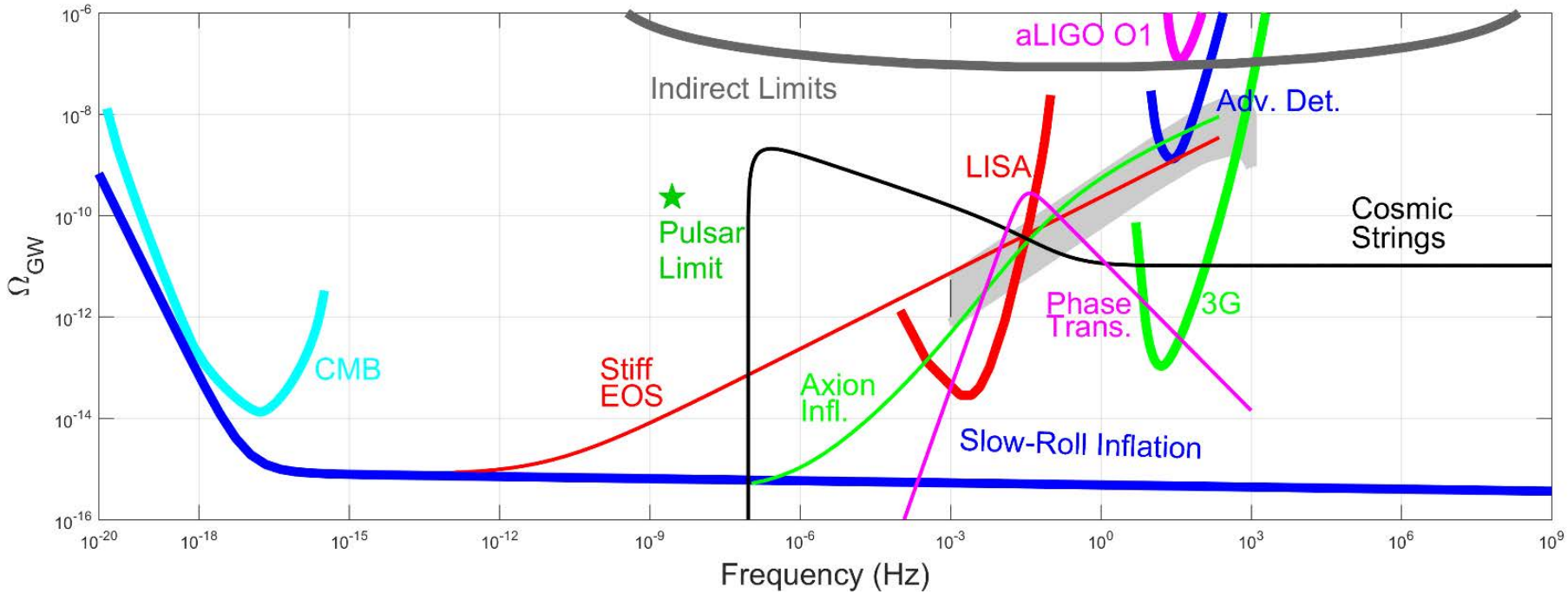




Hannuksela+, 2019

Primordial Gravitational Waves

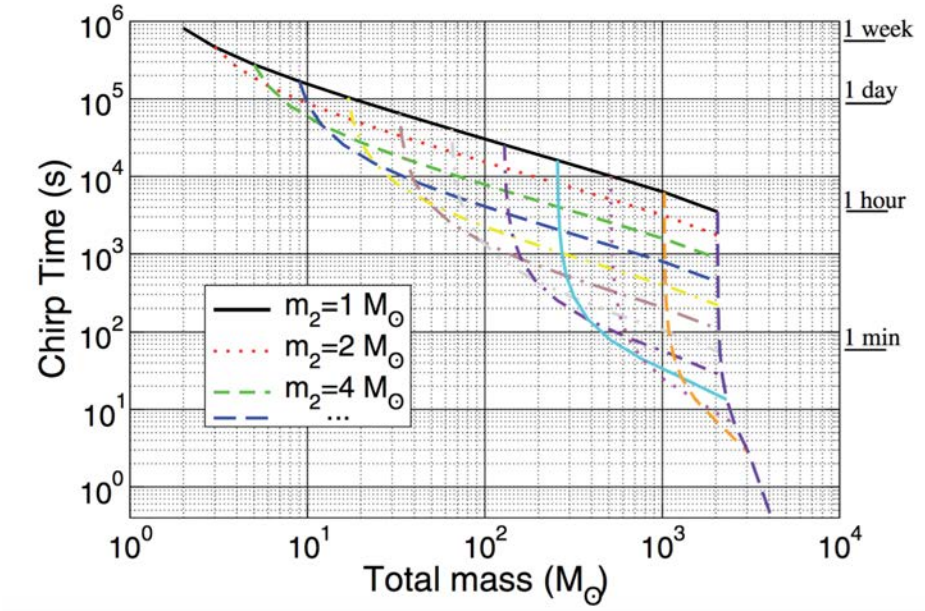
- Range of scenarios for primordial gravitational waves originating from immediately after Big Bang:
  - Phase transitions
  - Axion inflation
  - Resonant pre-heating
  - Cosmic strings
  - …



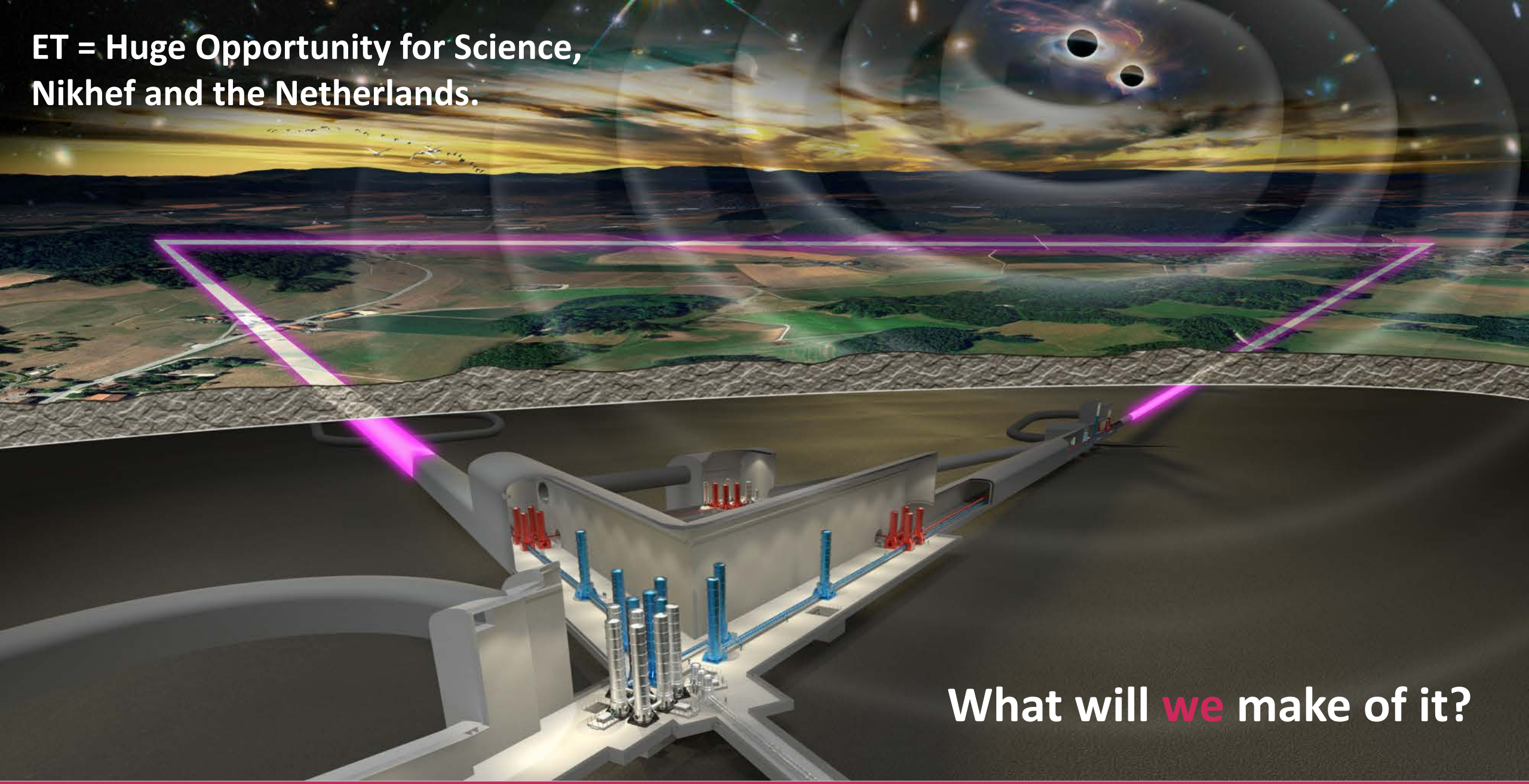
HPC for ET?

Compact Binary Coalescences

- Predicted to dominate ET observation band
  - Event ~ every 6 seconds (assuming uniform in space)
- Transients in current detectors will be in ET's band for hours/days.
  - Detector motion can no longer be neglected for signals longer than 1 day
    - Greater computational costs, $N \propto f_s^{-11/3}$
    - Development of new algorithms
  - Signals will overlap, causing confusion noise.
    - Can current algorithms extract overlapping signals buried in Gaussian noise?
    - Can parameter estimation be performed without significant degradation?



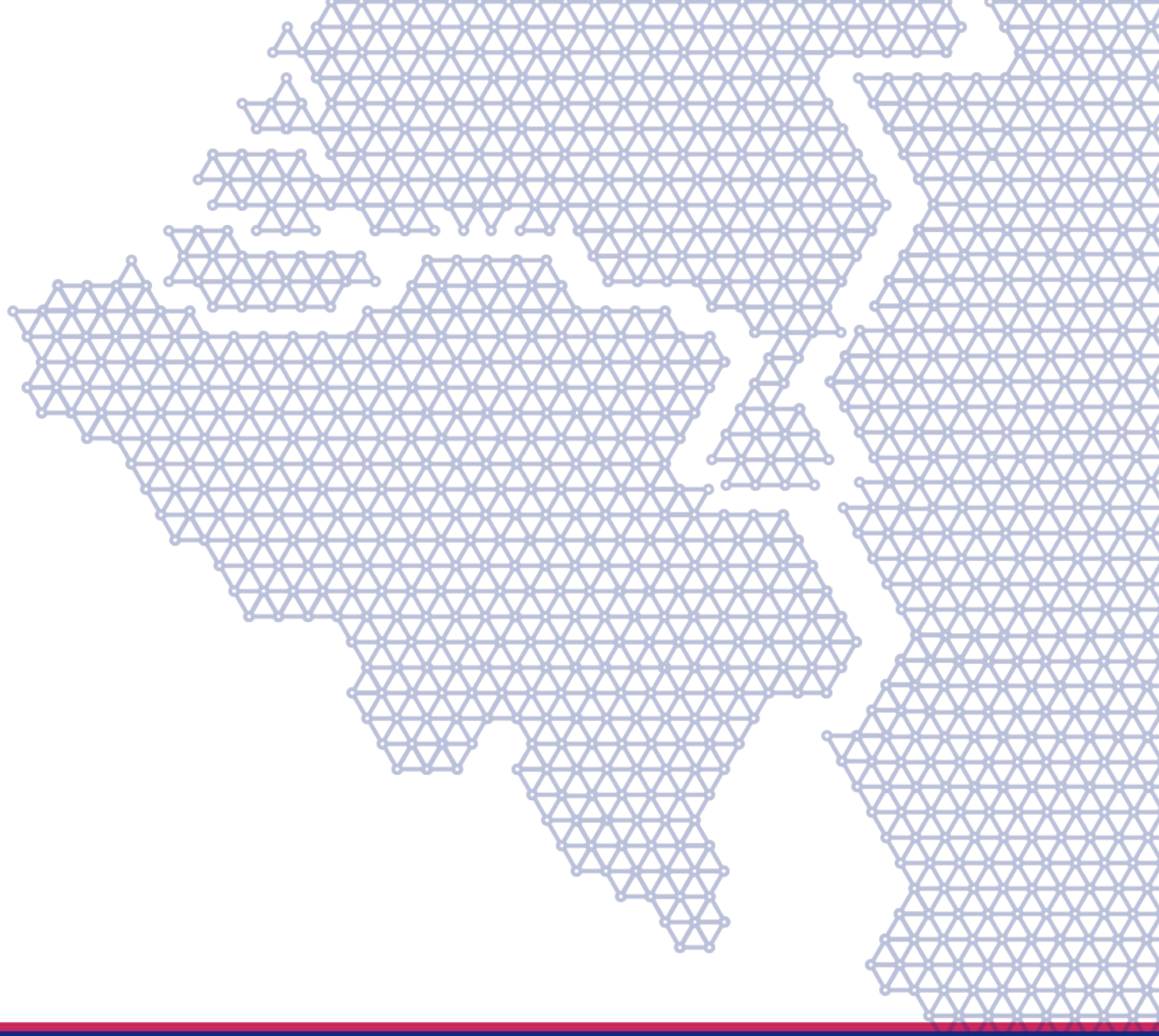
ET = Huge Opportunity for Science, Nikhef and the Netherlands.



What will we make of it?

Thank you for your attention.

Questions?



EXTRA SLIDES