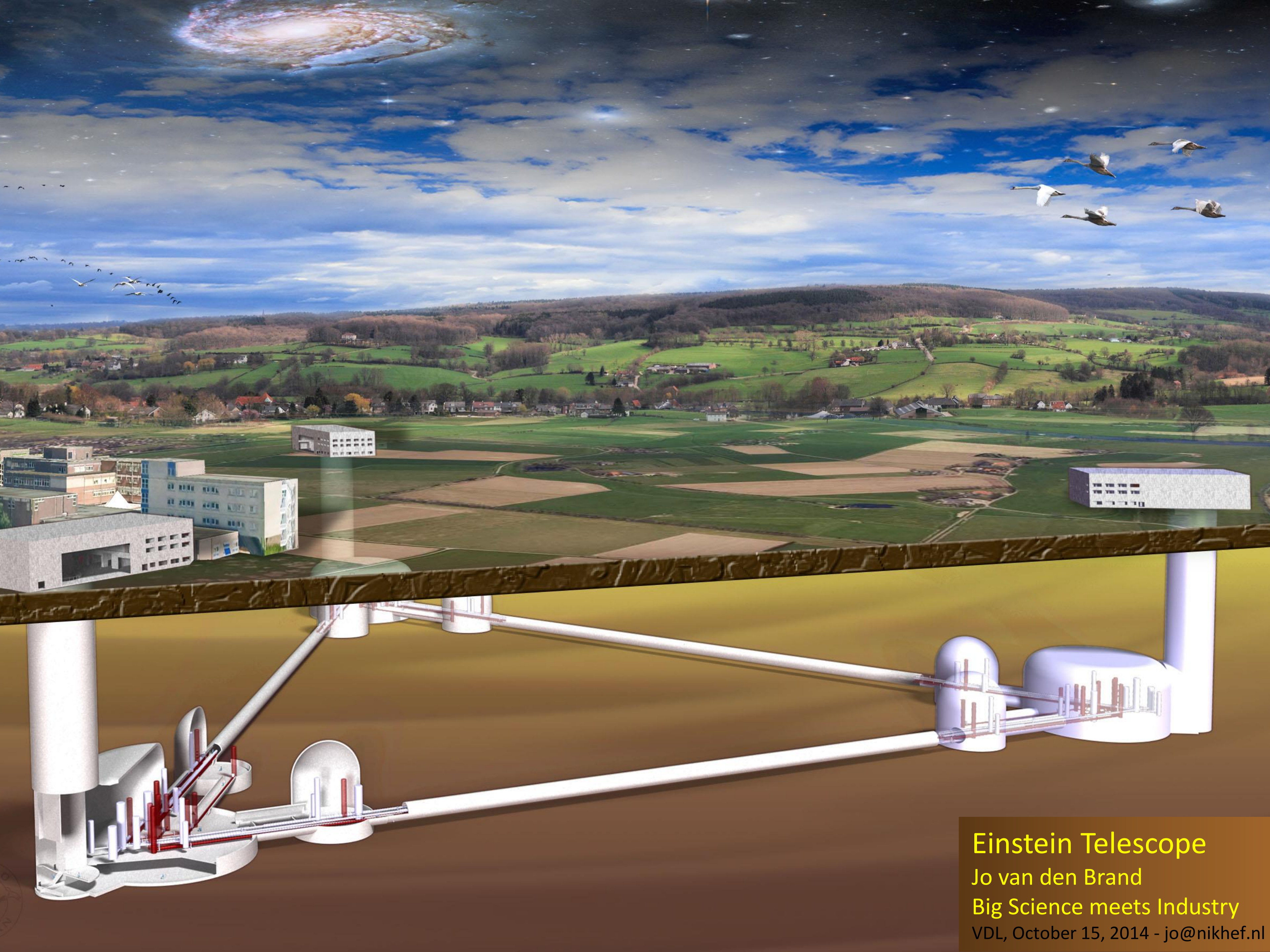


Einstein Telescope

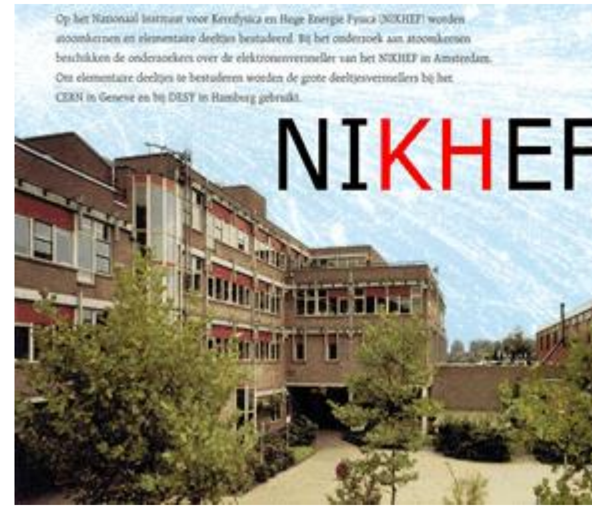
Jo van den Brand

Big Science meets Industry

VDL, October 15, 2014 - jo@nikhef.nl

Outline

- Science case
- Technology case
- International context
- Next steps



NIKHEF

Katholieke Universiteit Nijmegen

vrije Universiteit amsterdam

FOM

Universiteit Utrecht

Universiteit van Amsterdam

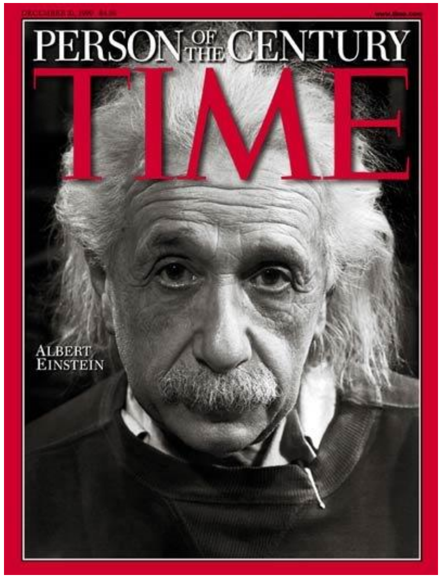
Scientific motivation

Einstein gravity :

$$G_{\alpha\beta} = 8\pi T_{\alpha\beta}$$

Gravity as a geometry

Space and time are physical objects



- Gravitation

  Least understood interaction

  Large world-wide intellectual activity

  - Theoretical: ART + QM, Cosmology
  - Experimental: Interferometers on Earth and in space

- Gravitational waves

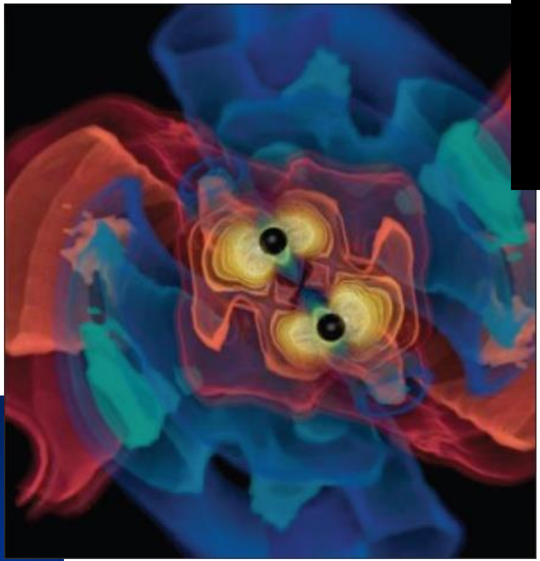
  Dynamical part of gravitation, all space is filled with GW

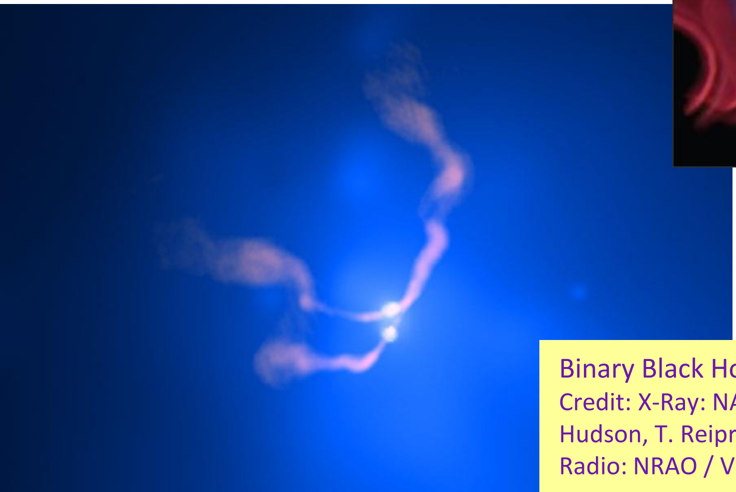
  Ideal information carrier, almost no scattering or attenuation

  The entire universe has been transparent for GWs, all the way back to the Big Bang

Compact Binary Mergers

- Binary neutrons stars
- Binary black holes
- Neutron star – black hole binaries





Binary Black Hole in 3C 75
Credit: X-Ray: NASA / CXC / D. Hudson, T. Reiprich et al. (AIfA); Radio: NRAO / VLA/ NRL

- Knowledge of the waveforms through numerical relativity

GW exist: PSR B1913+16

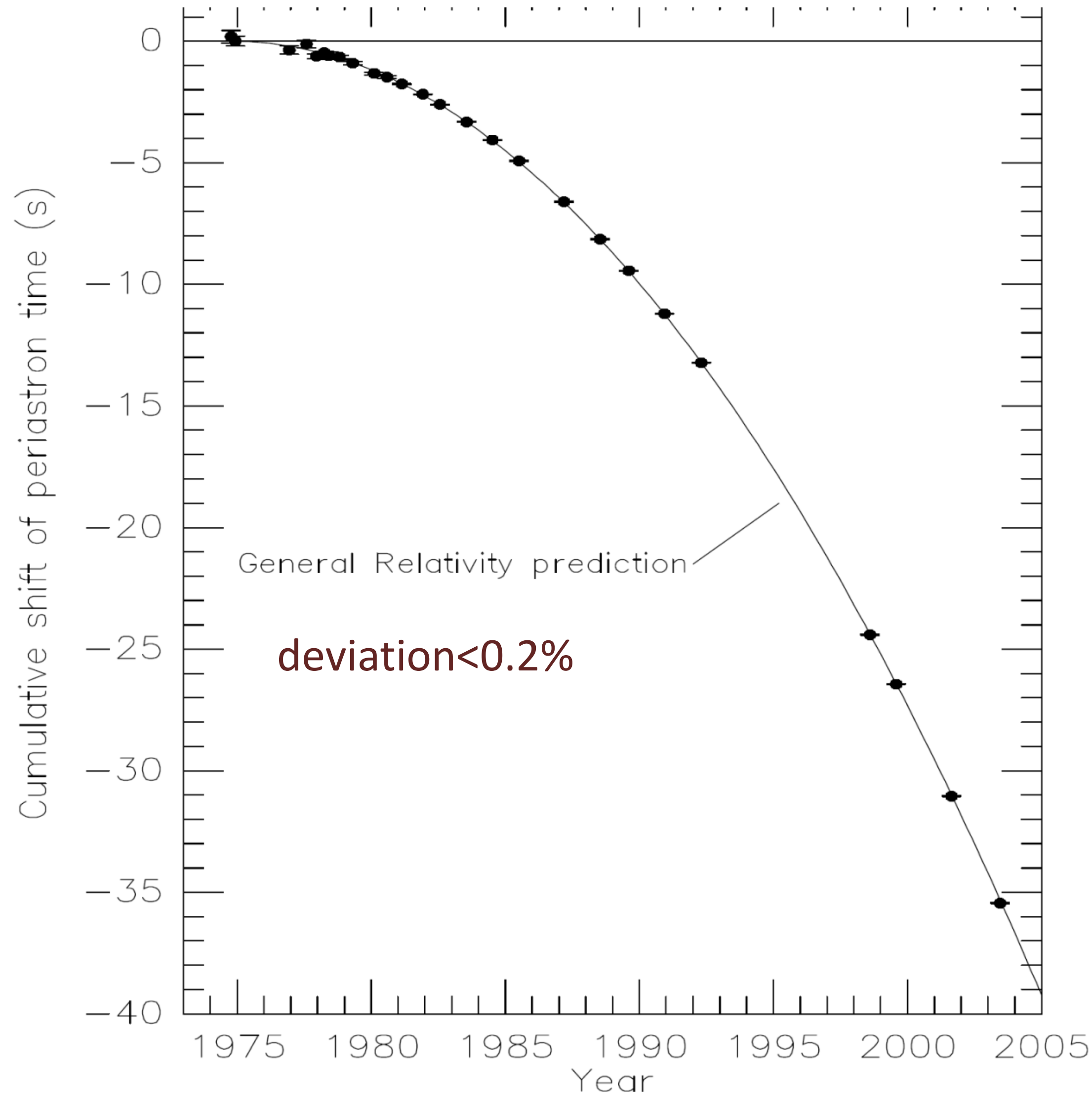
Russell A. Hulse
Joseph H. Taylor, Jr.
In 1974 discovery of pulsar in a binairy system

Period ~ 8h

GW emission shortens period

Indirect detection GWs

Nobel prize 1993



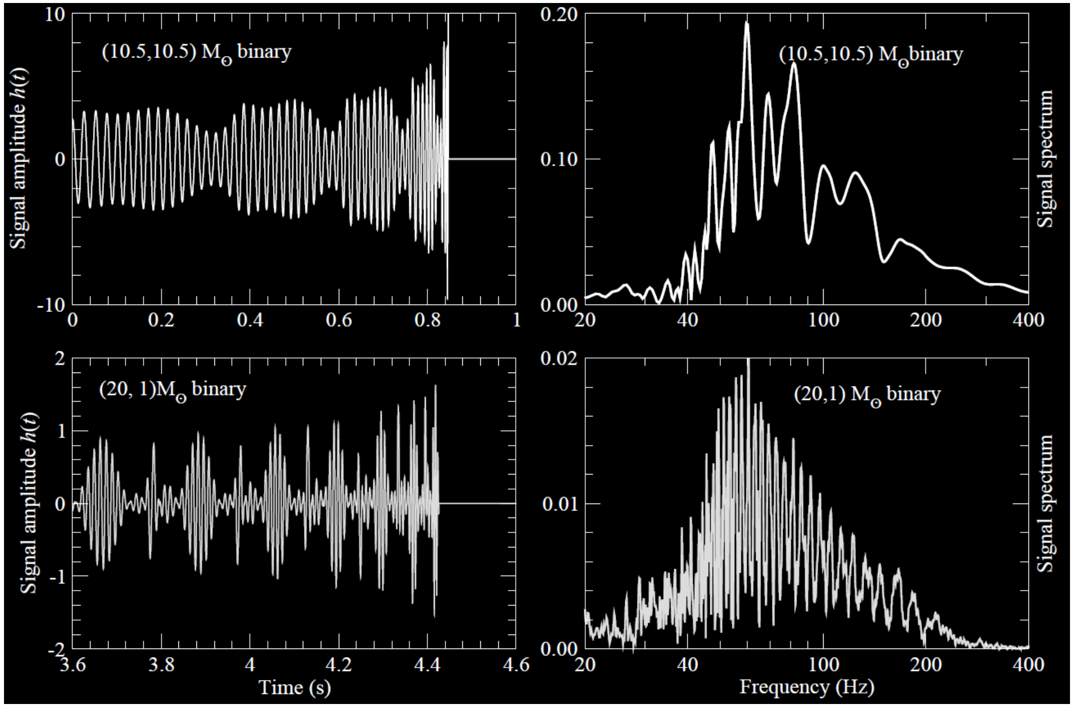
deviation<0.2%

Waveforms BBH and NS-BH binary

- Signal modulation
  - Amplitude and frequency
  - Due to spin-orbit precession of the orbital plane
- Gravitational waves
  - Merger phase dominates
  - Direct insight into dynamics of spacetime at extreme curvatures
  - Unambiguous evidence for existance of black holes

$h = \Delta L/L \approx 10^{-22}$

Time domain Frequency domain



$$\Delta L = 1\mu m \rightarrow L = (10^{-6} m)/(10^{-22}) = 10^{16} m = 1\ ly$$

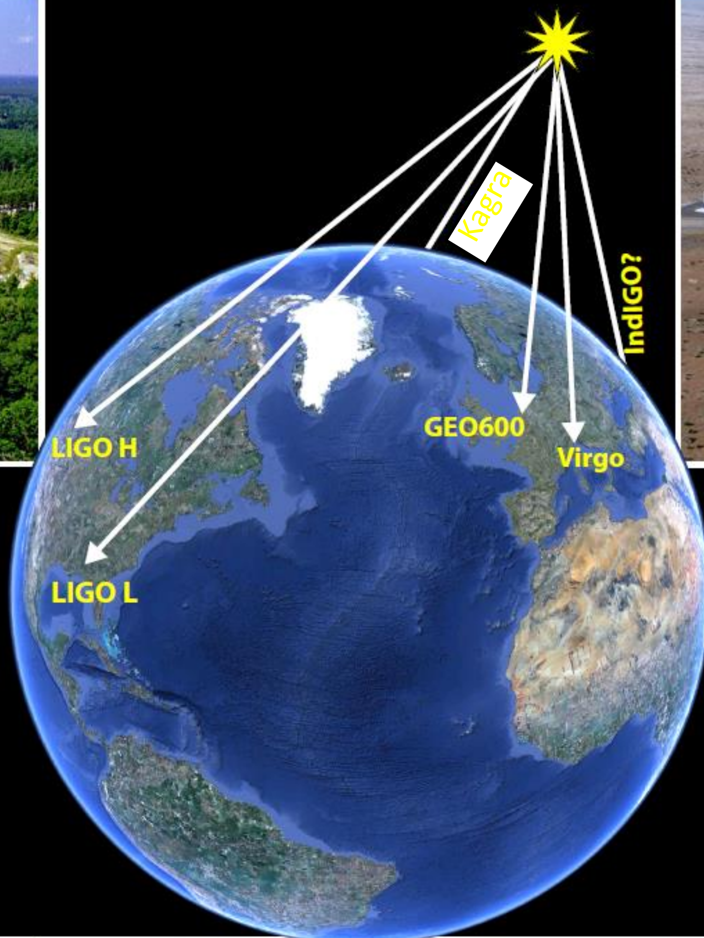
$$\Delta L = 10^{-18} m \rightarrow L = (10^{-18} m)/(10^{-22}) = 10^{4} m = 10\ km$$

Interferometer as GW detector

- Principle: measure distances between two free test masses
  - Michelson interferometer
  - Test masses = interferometer mirrors
  - Sensitivity: $h = \Delta L/L$
    - Need long interferometer arms
    - For Virgo $L = 3$ km

Virgo: CNRS+INFN
(ESPCI-Paris, INFN-Firenze/Urbino, INFN-Napoli, INFN-Perugia, INFN-Pisa, INFN-Roma,LAL-Orsay, LAPP-Annecy, LMA-Lyon, OCA-Nice)
+ Nikhef joined in 2007

Last science run ended on September 4, 2011

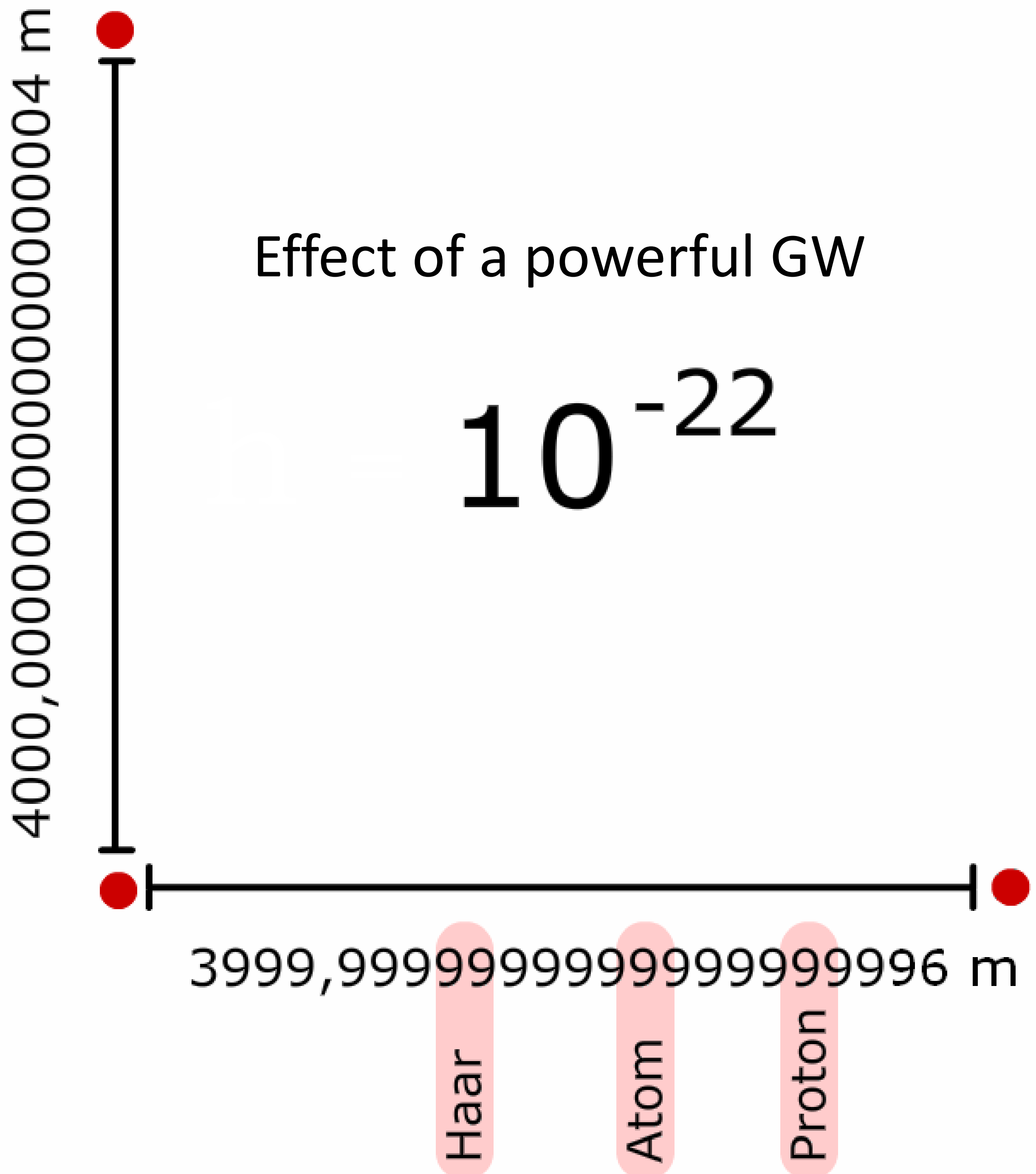


Advanced LIGO and Virgo
First common run in 2016

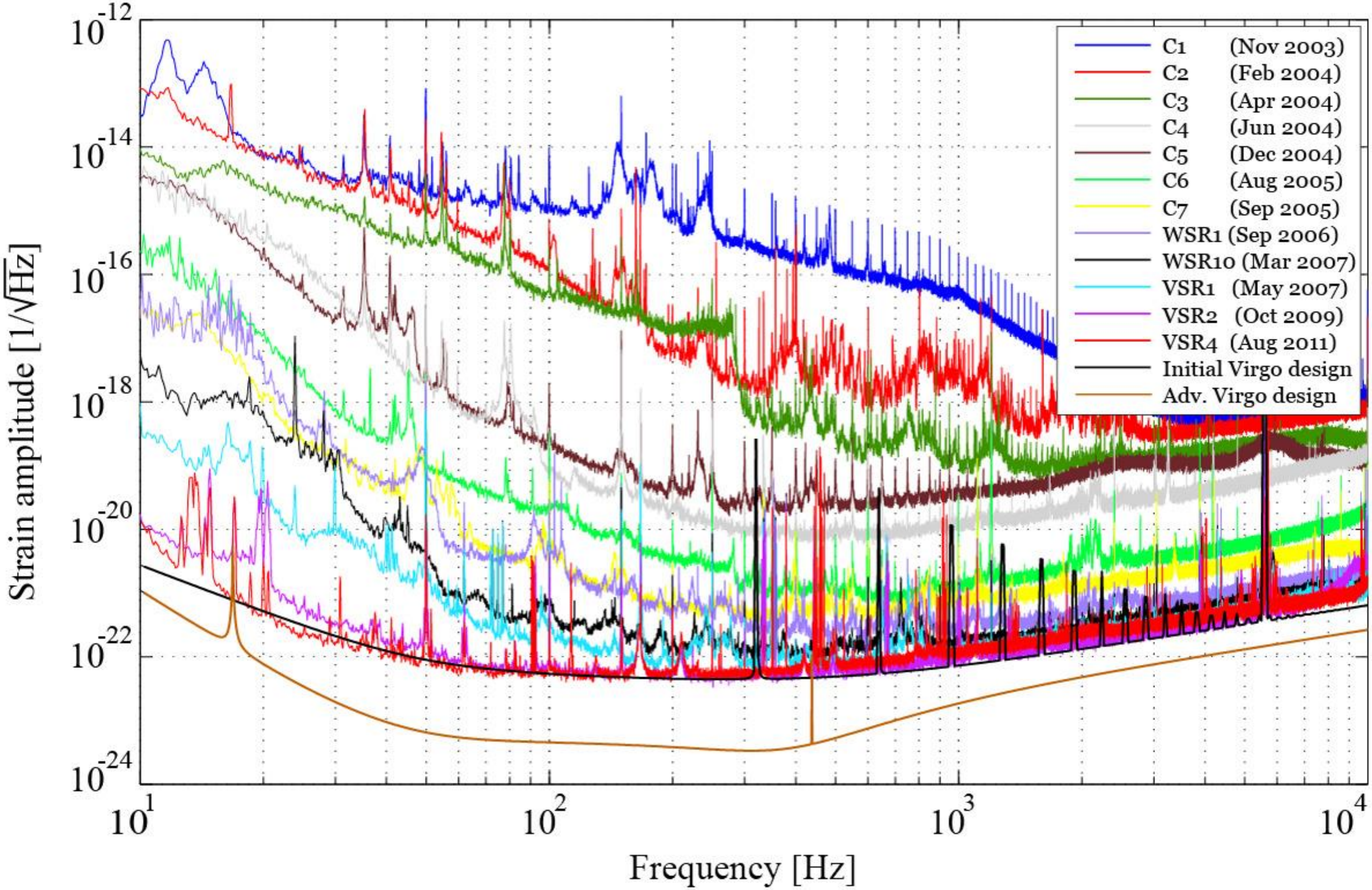
Kagra joins 2020
LIGO India?

Effect of a powerful GW

$$h = 10^{-22}$$



Evolution of sensitivity

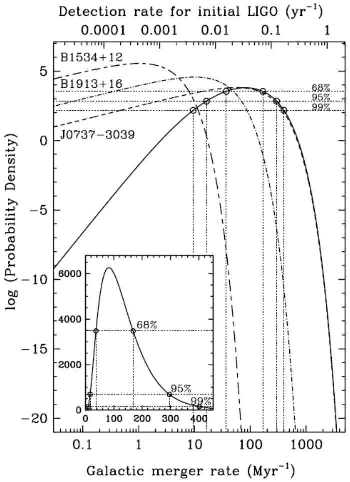


Direct discovery of GW

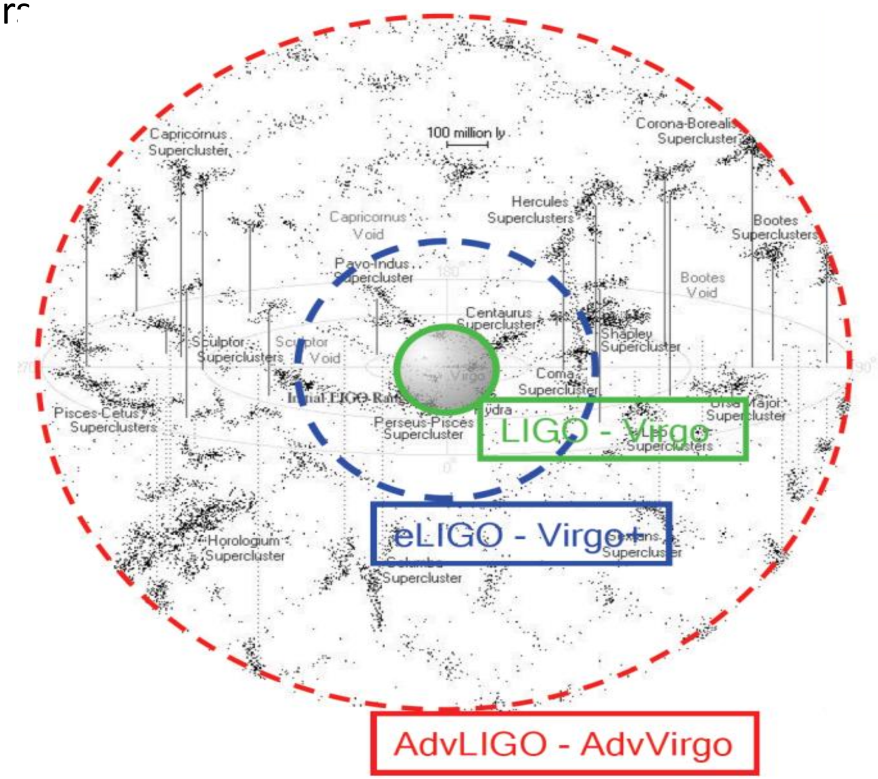
- Advanced Virgo
  - Improve sensitivity by factor 10
  - From Virgo cluster to Local supercluster
  - This yields a factor 1000 increase in event rate!
- Probable sources
  - Binary black hole coalescence
  - Binary neutron star mergers, supernovae, pulsars
- BNS Rates: (most likely and 95% interval)
  - Initial Virgo (30Mpc)
    - **1/100yr (1/500 - 1/25 yr)**
  - Advanced detectors (350Mpc)
    - **40/yr (8 - 160/yr)**

Kalogera *et al.*; astro-ph/0312101

- BBH more difficult to predict



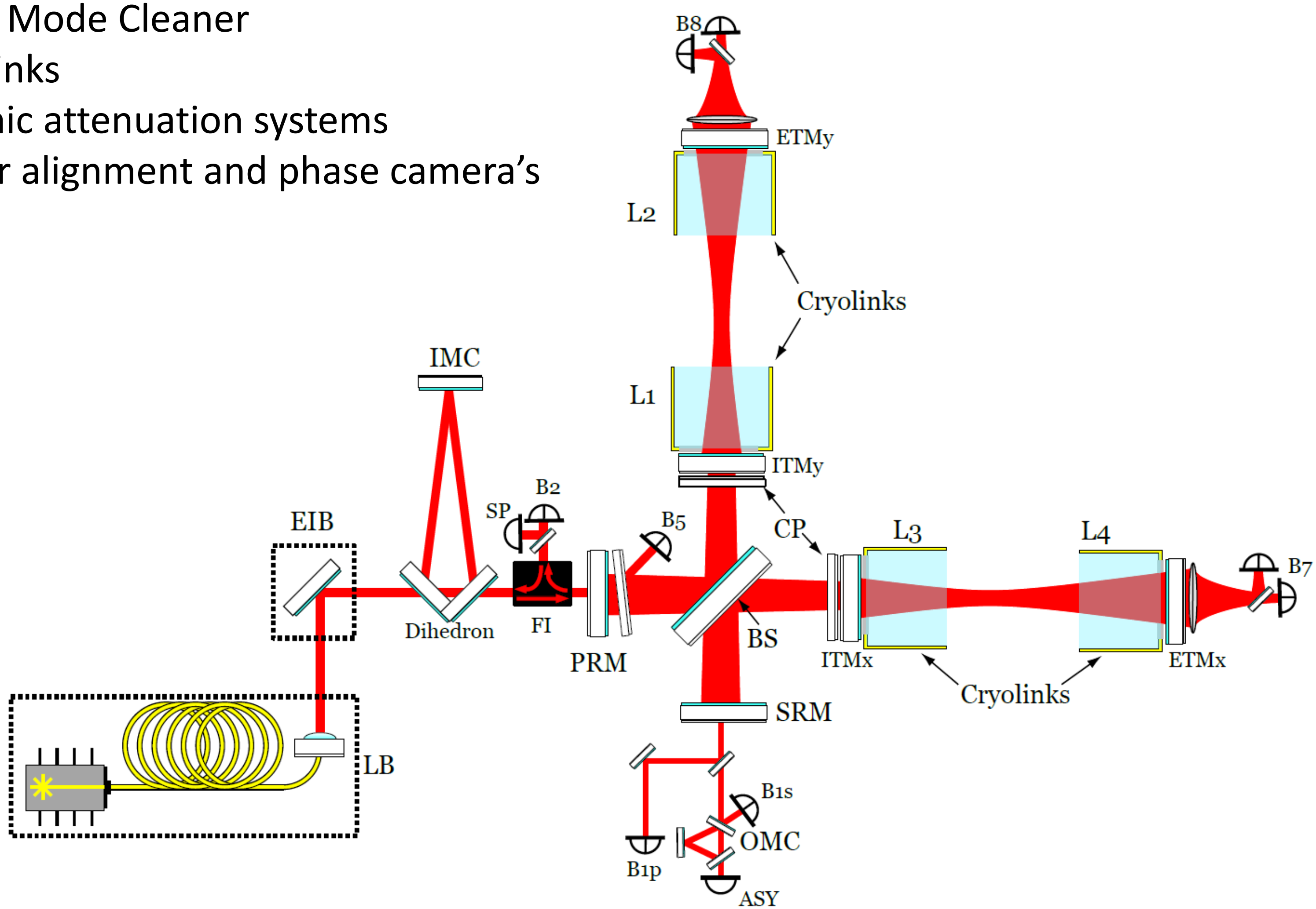
Astronomy: we know sources exist



NL contributions

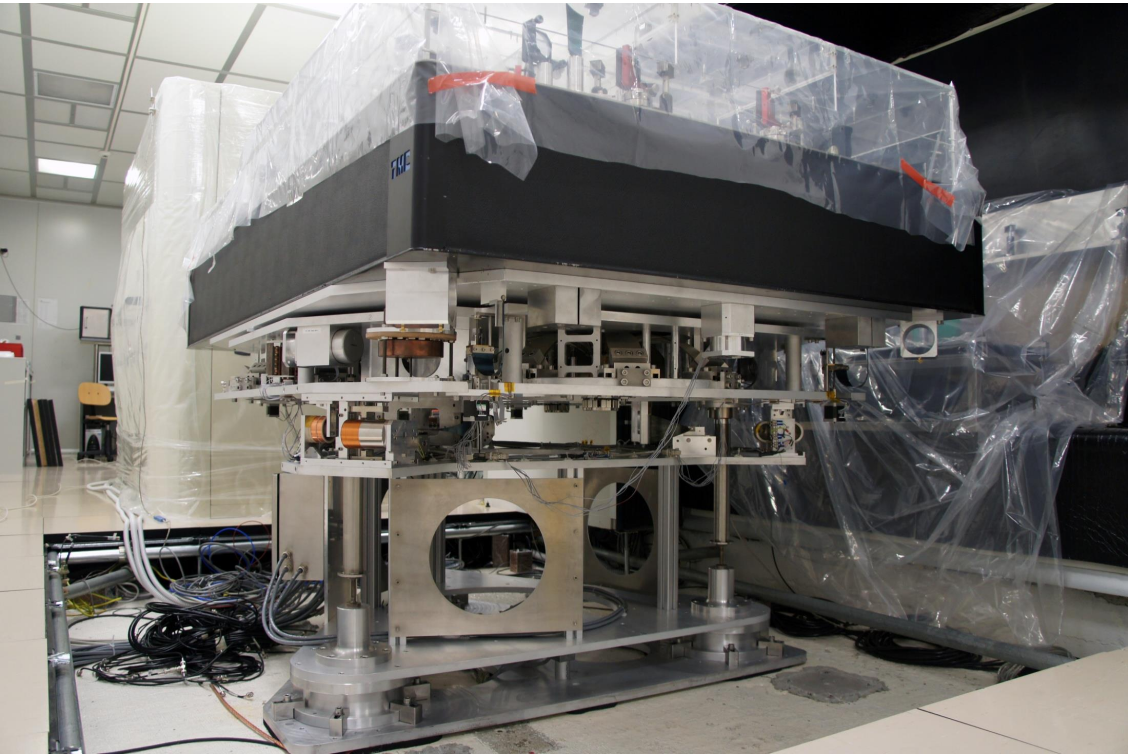
Nikhef

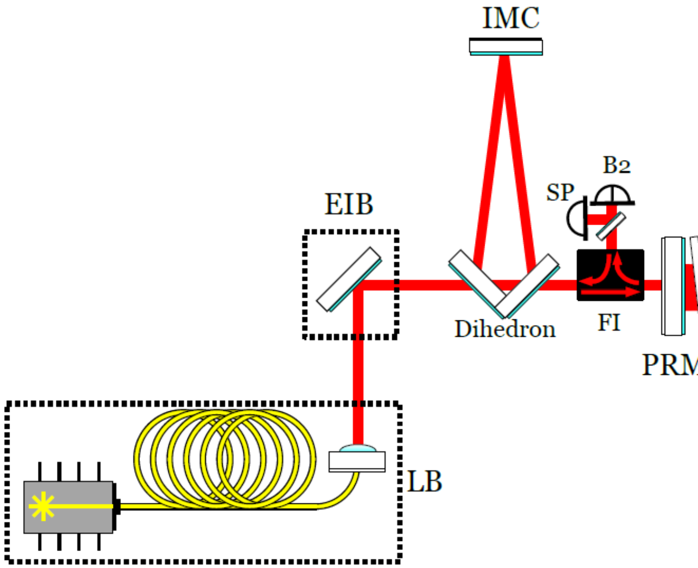
- Input Mode Cleaner
- Cryolinks
- Seismic attenuation systems
- Linear alignment and phase camera's



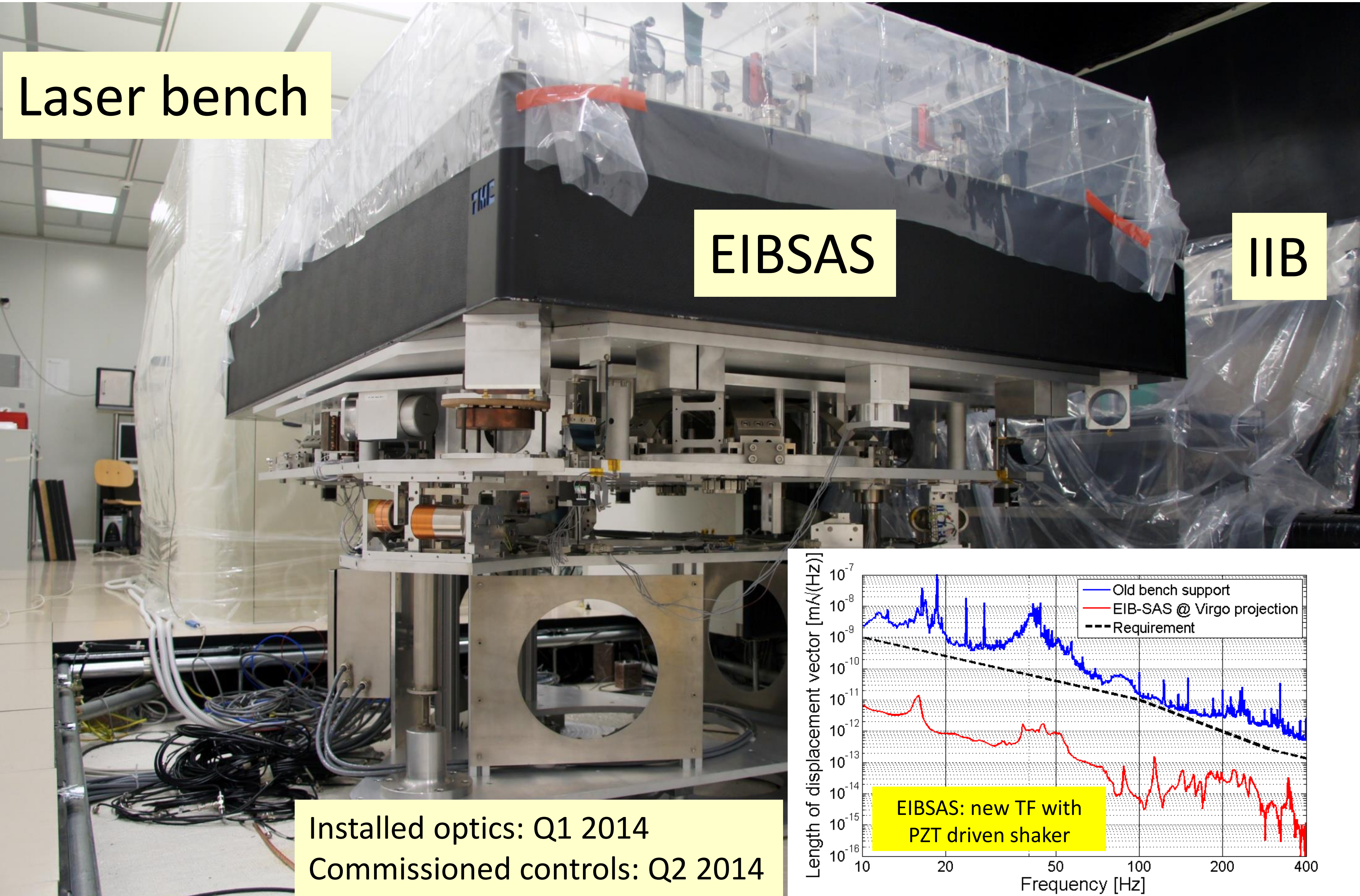
External injection bench

- Priority of commissioning
  - EIB is the last bench before laser beam enters the vacuum
  - First stage in the commissioning process



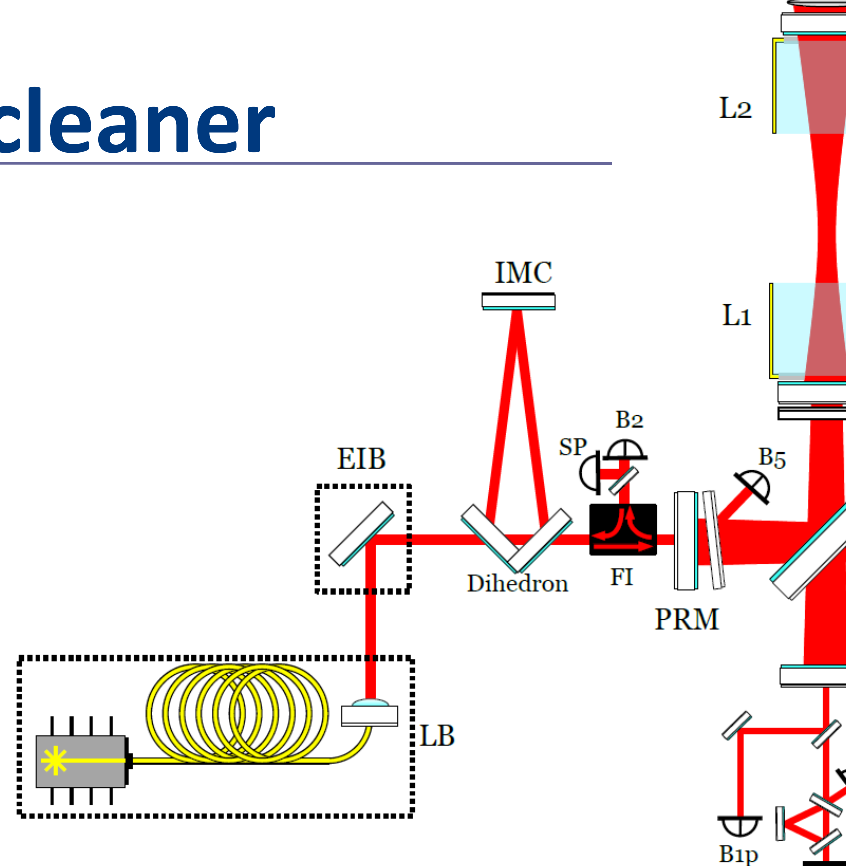


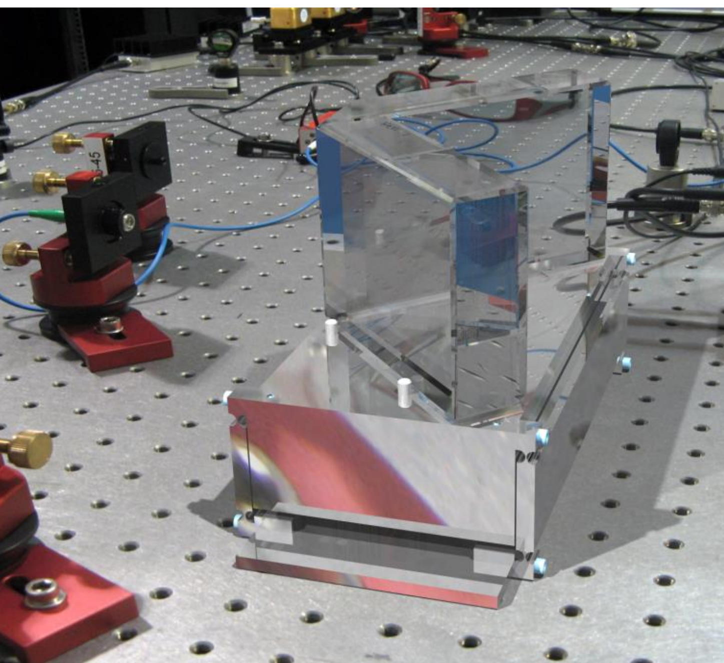
EIBSAS in Advanced Virgo

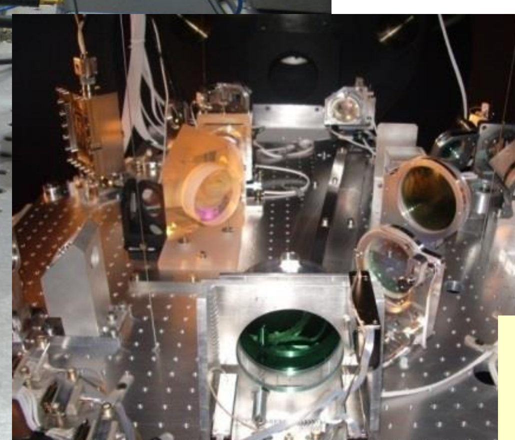


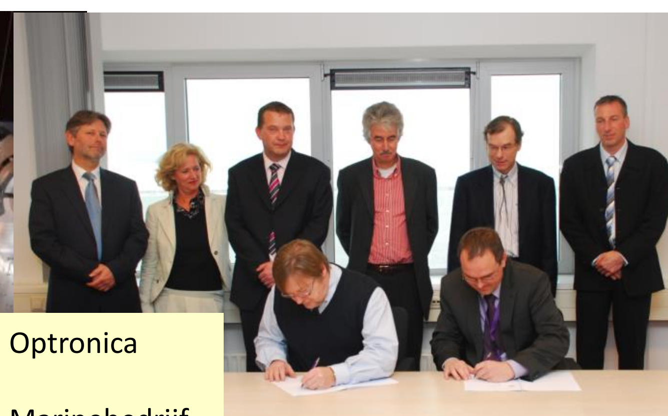
Input mode cleaner

- IMC
  - Triangular cavity
    - High finesse, 145 m length
    - First stage in frequency stabilization
- Dihedron
  - Complex optical component
  - Manufactured by Dutch industry: Optronica
    - Also produced the end mirror(s)









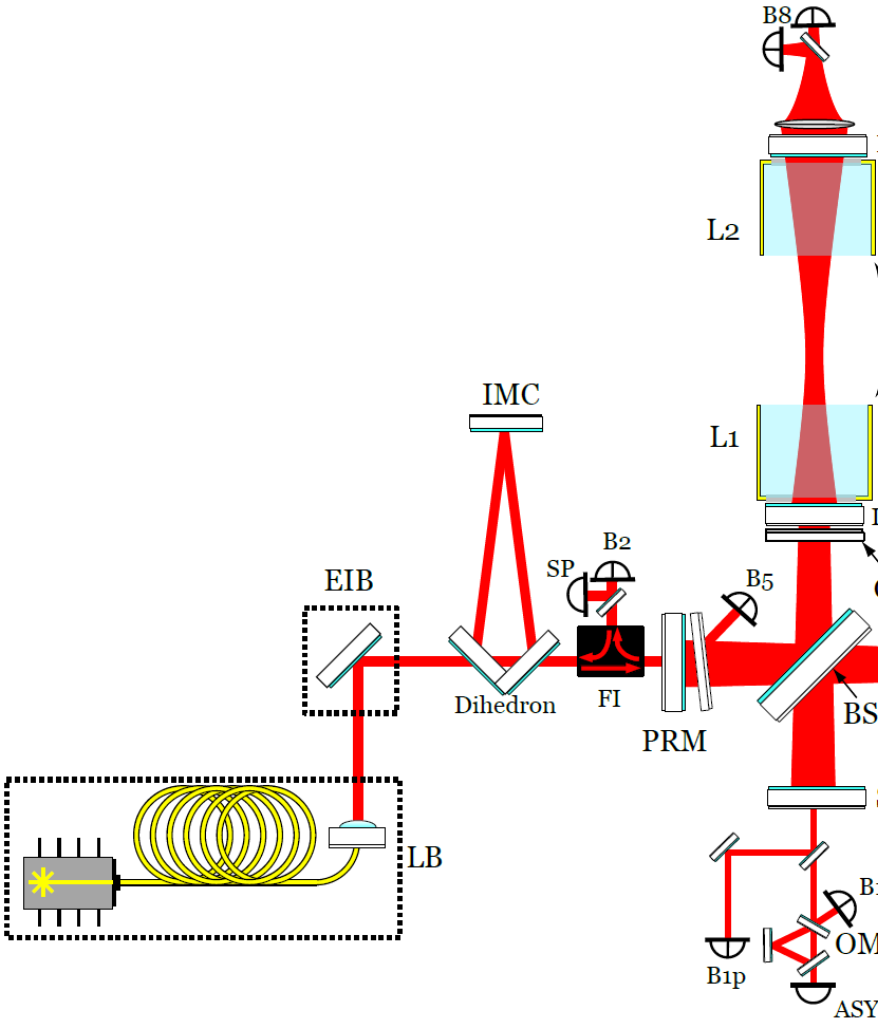
Optronica

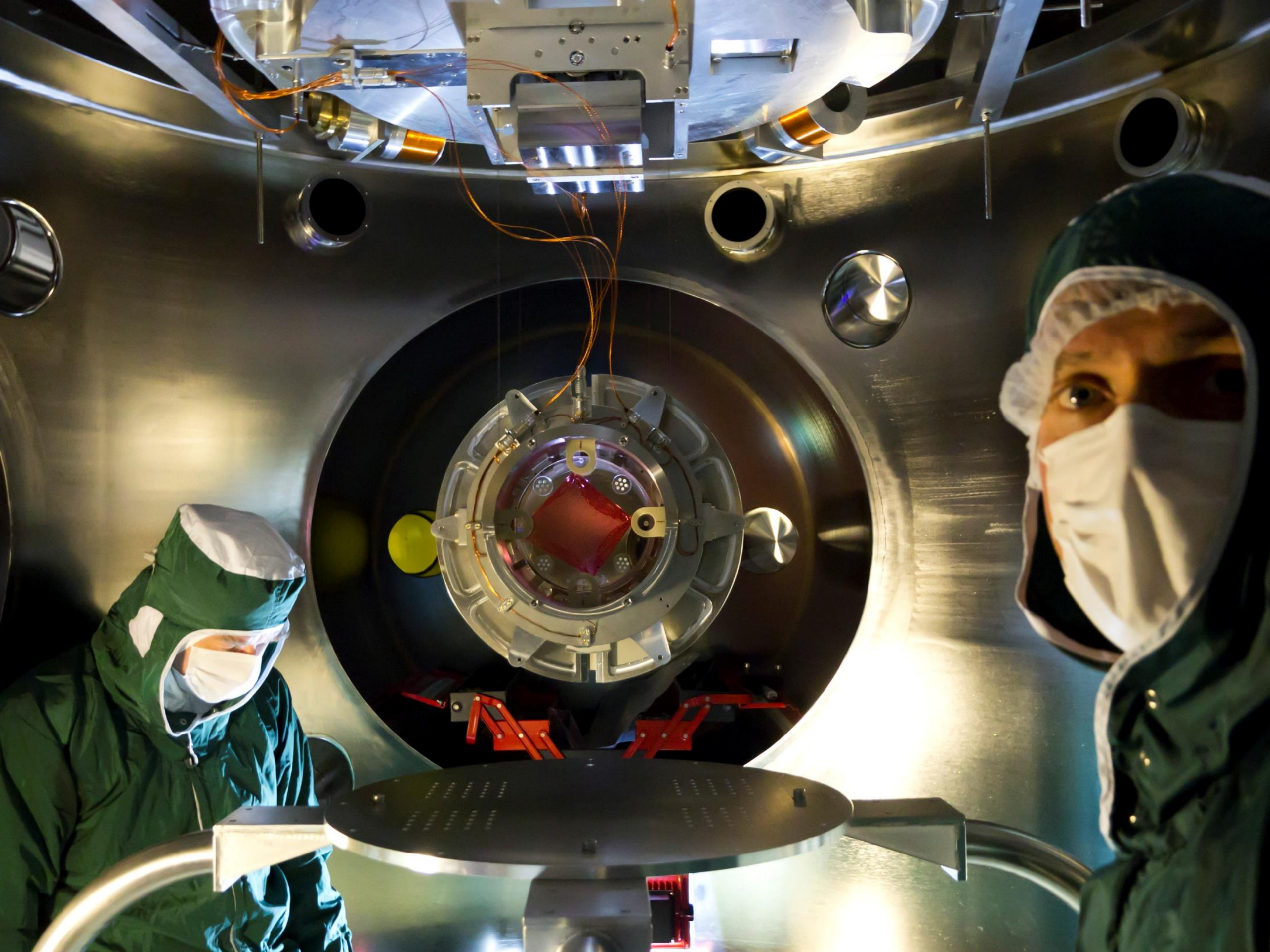
Marinebedrijf
Den Helder

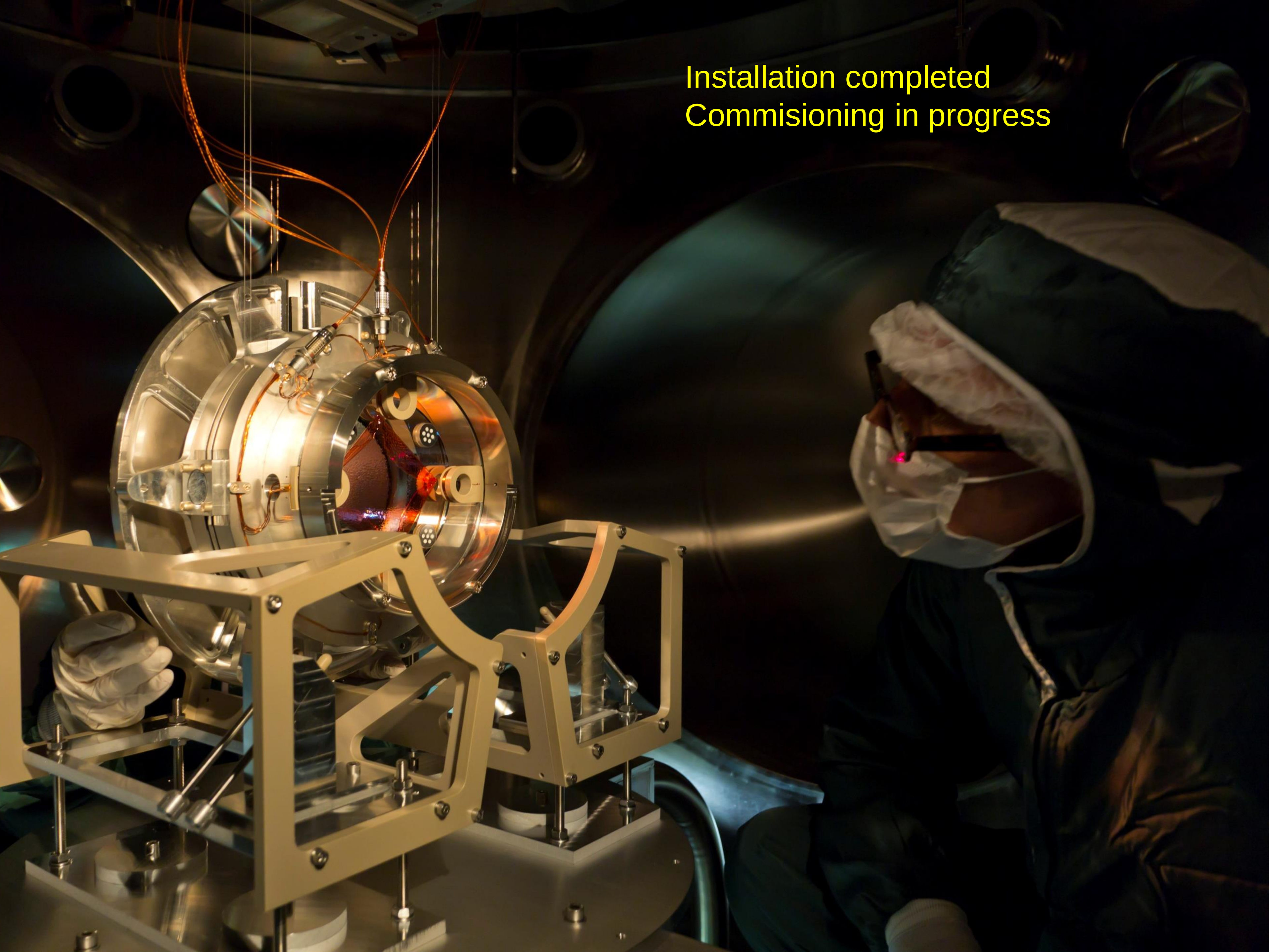
Input mode cleaner

Thomas Bauer
Marko Kraan

- IMC end-mirror system
  - Mirror payload
    - Including marionette
  - Installed in Q1 2014
    - First optical payload installed in Advanced Virgo
  - Commissioning now in progress
    - Crucial to stay on timeline

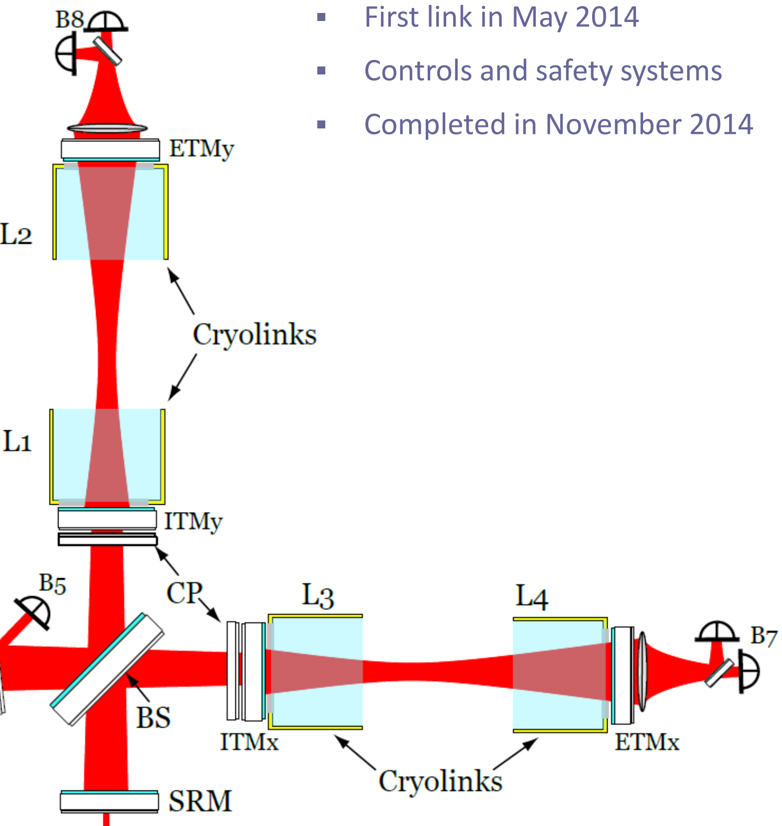


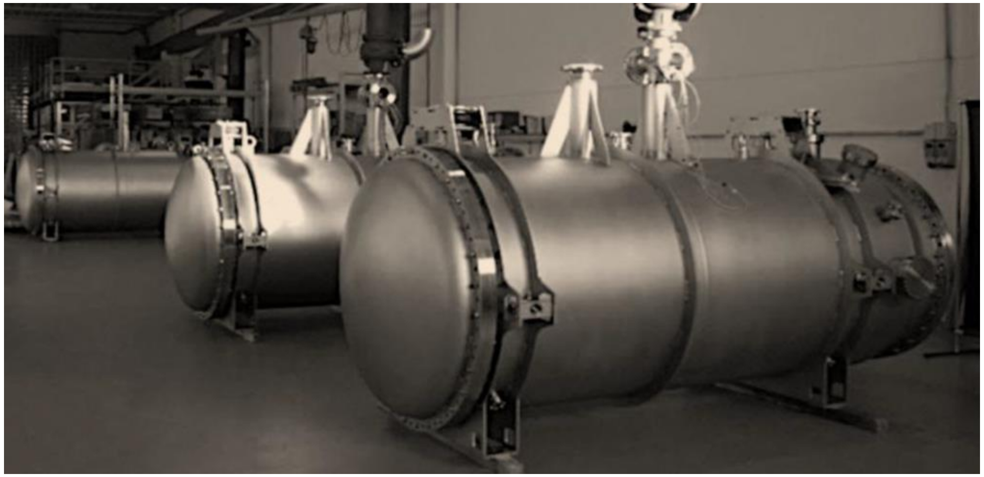



Installation completed
Commisioning in progress

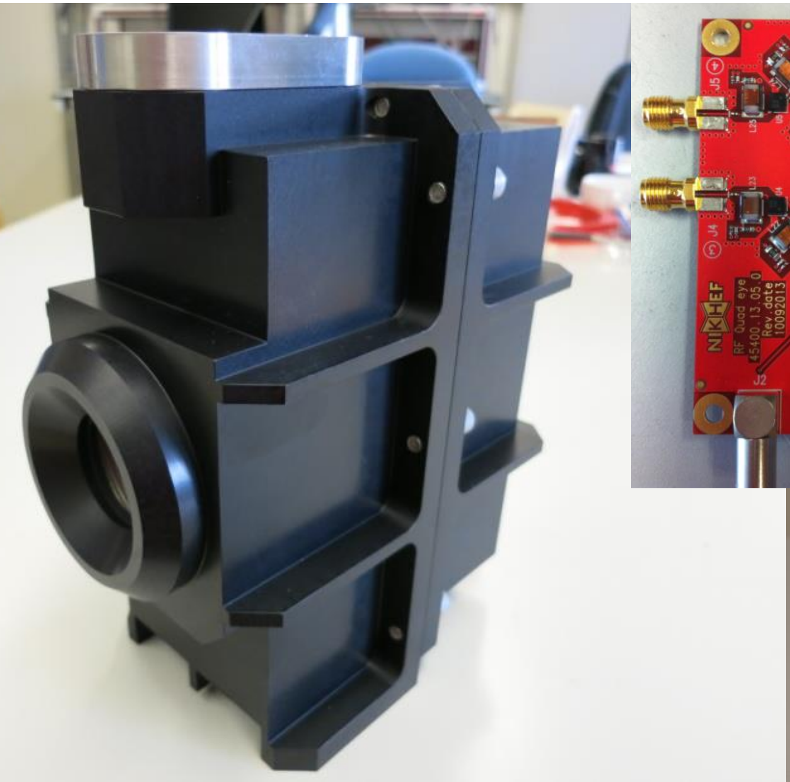
Cryolinks

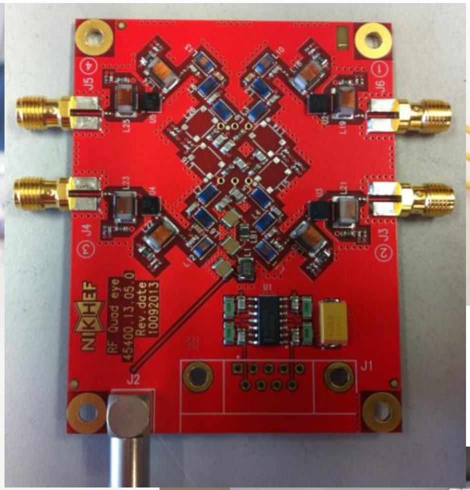
- Cryolink features
  - Four LN2 links: 10^{-10} mbar region
  - Designed by Nikhef
  - Factory acceptance completed
  - Installation schedule
    - First link in May 2014
    - Controls and safety systems
    - Completed in November 2014

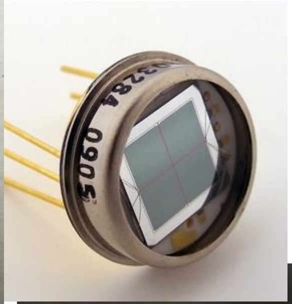


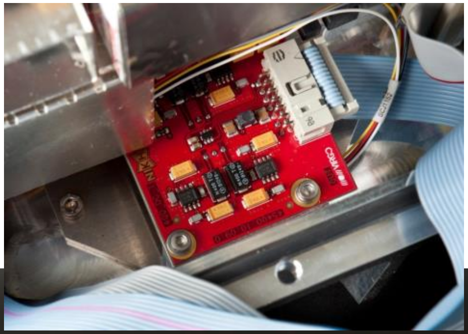


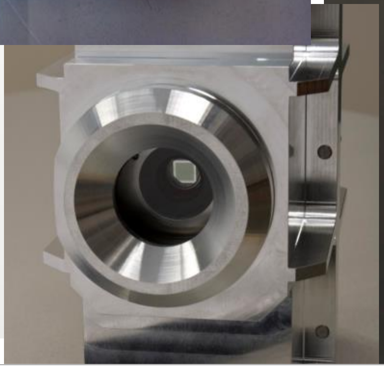
Optical sensing systems

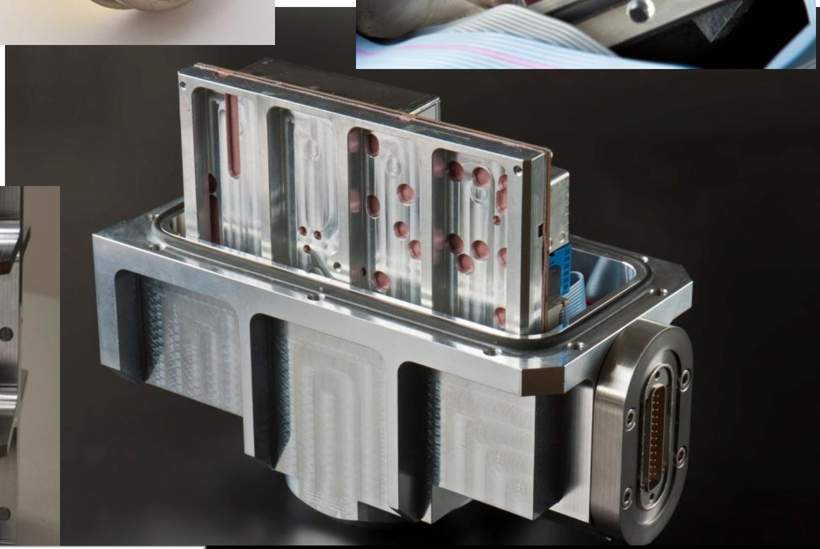


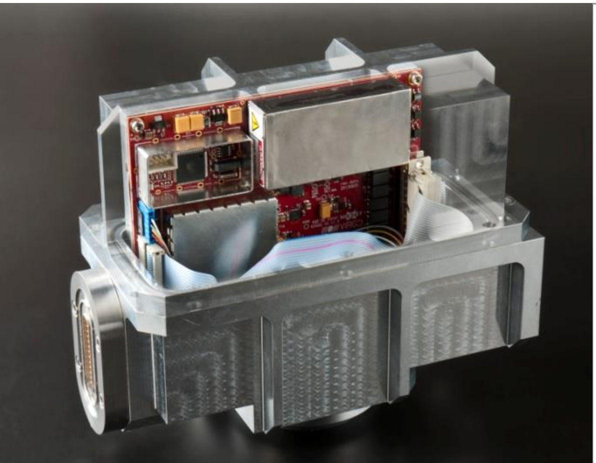


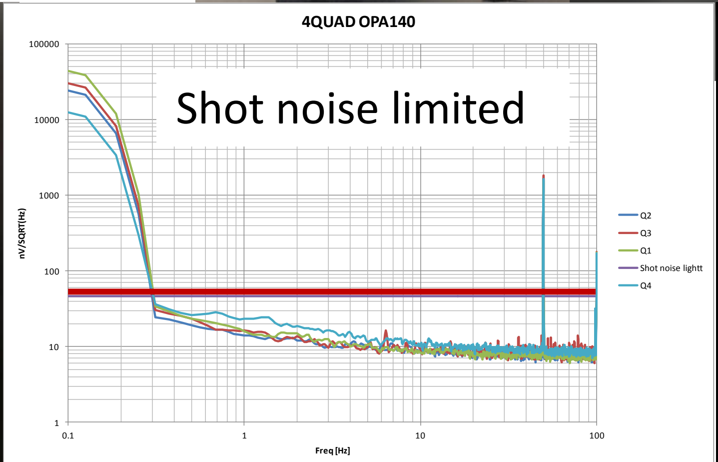


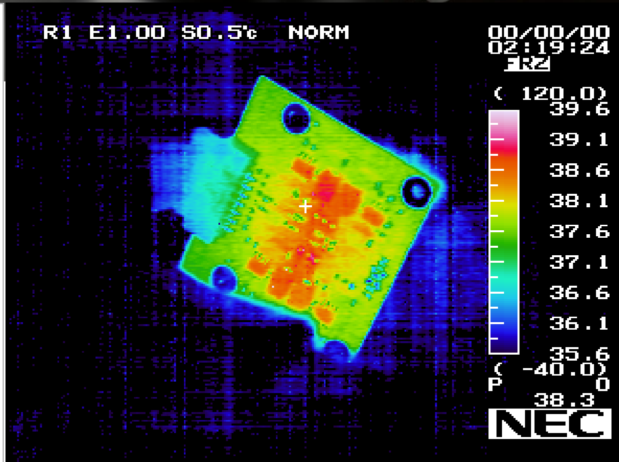








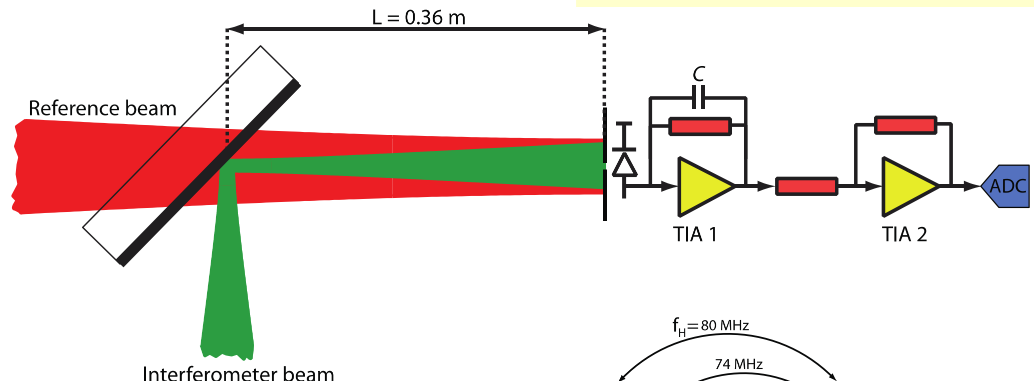


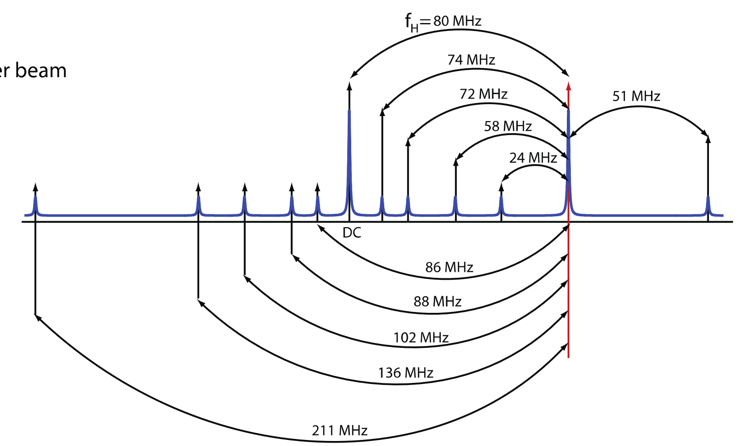


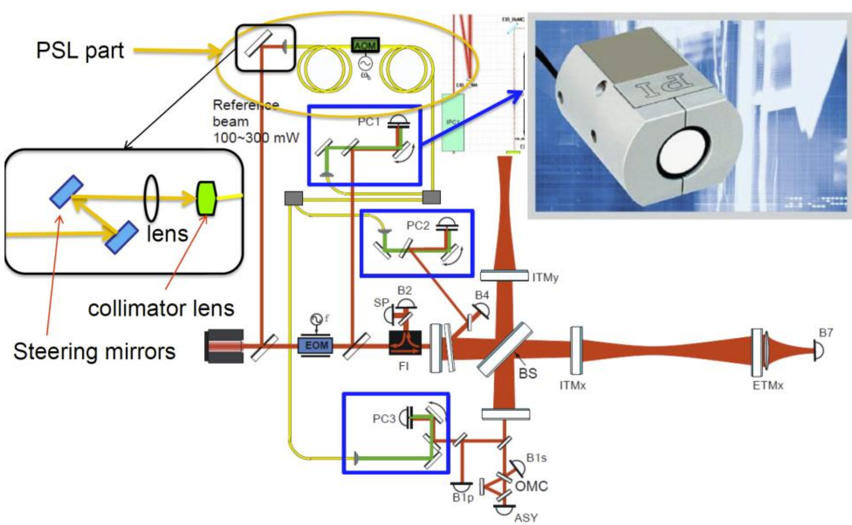
Phase camera's: 3D imaging

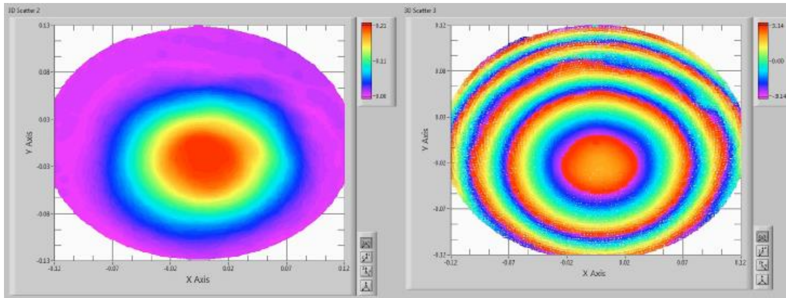
Martin van Beuzekom
Kazuhiro Agatsuma

- Imaging of cavity fields
  - Both carrier and sidebands
    - f1 = 6.270 777 MHz
    - f2 = 56.436 993 MHz
    - f3 = 8.361 036 MHz
    - f4 = 131.686 317 MHz
    - f5 = 22.38 MHz
    - fH= 80.00 MHz
  - Amplitude and phase
    - High speed imaging of HOM
    - Avoid moving parts (CCD based)
  - AdV optical design: MSRC
  - Main diagnostics for Advanced Virgo
  - Input for Thermal Compensation Systems



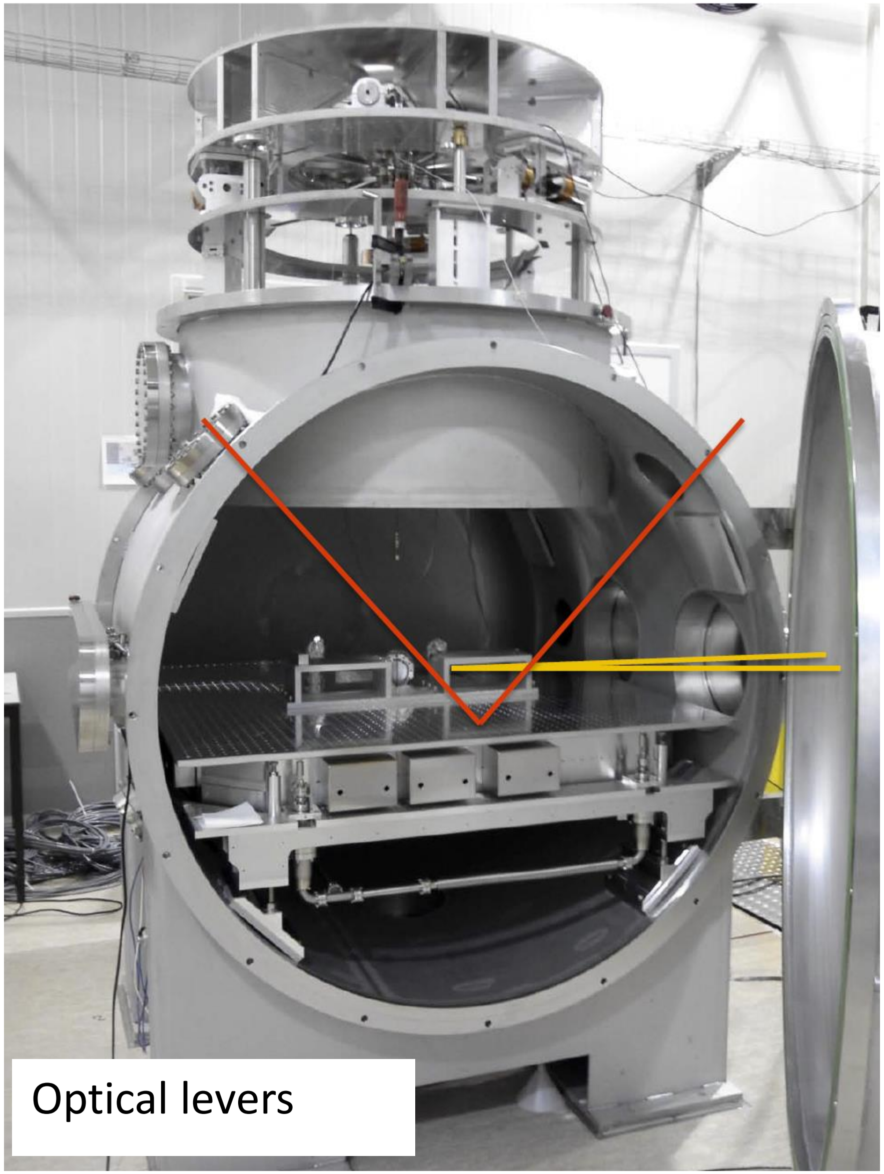


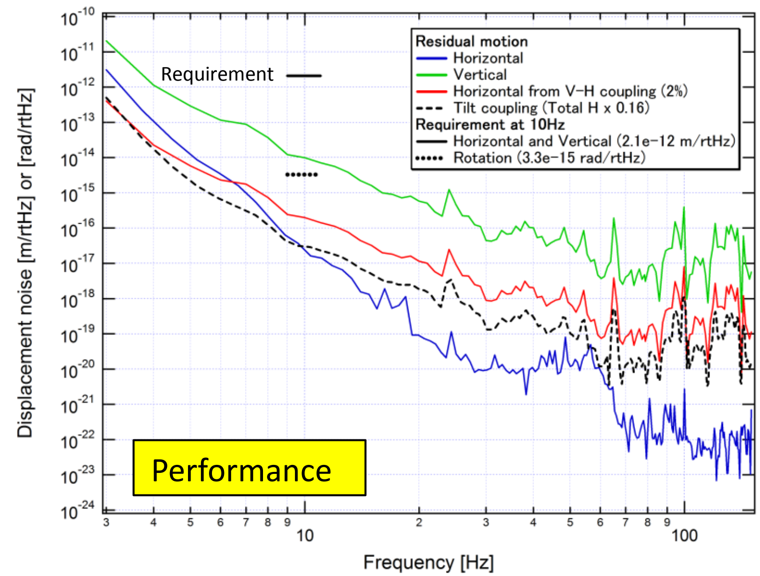


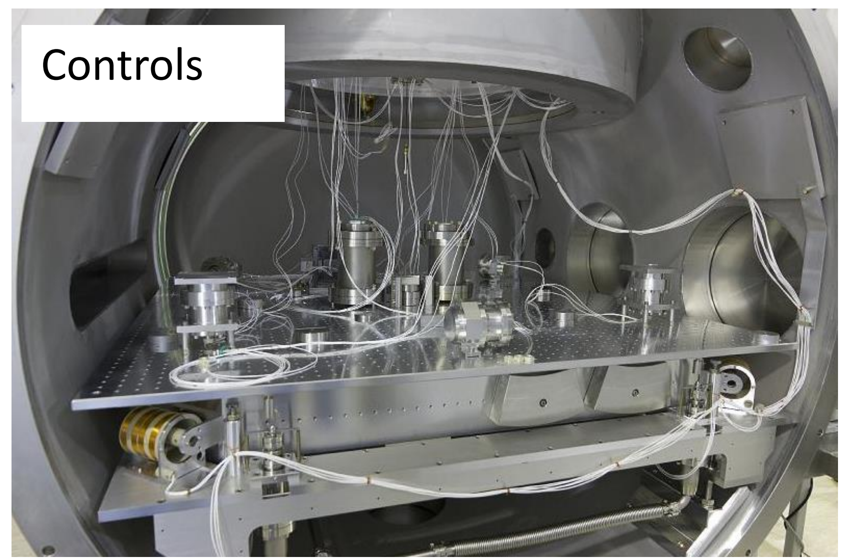


Femtometer/√Hz isolation

MultiSAS challenges

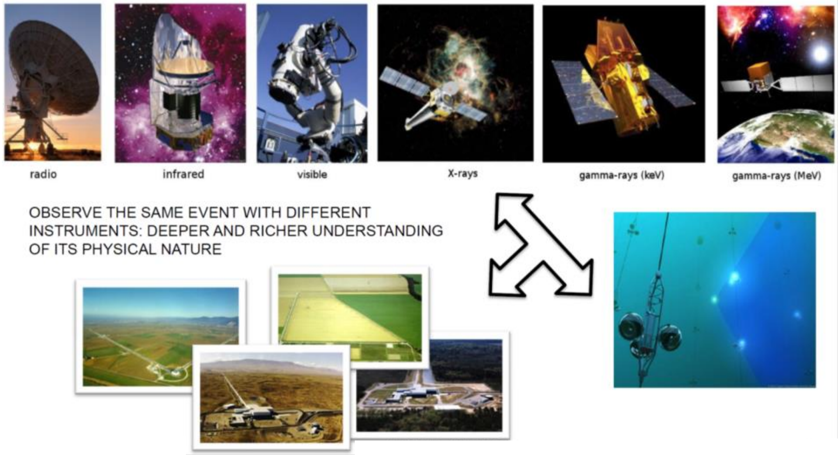






Multi-messenger astronomy

- GW signal in astrophysical context
- Give precise localization
  - Identify host galaxy
- Multi-messenger picture of most energetic events
  - Insight into physics of progenitors
    - Mass, spin, distance
    - Environment: temperature, density, redshift



LSC LIGO Scientific Collaboration — VIRGO

news | magazine | Advanced LIGO | science | students/teachers/public | multimedia | partners | about

Introduction | Popular Articles | LSC Scientific Publications | Science Summaries | Data Releases | GW-EM Alerts

IDENTIFICATION AND FOLLOW UP OF ELECTROMAGNETIC COUNTERPARTS OF GRAVITATIONAL WAVE CANDIDATE EVENTS

The LIGO Scientific Collaboration (LSC) and the Virgo Collaboration currently plan to start taking data in 2015, and we expect the sensitivity of the network to improve over time. Gravitational-wave transient candidates will be identified promptly upon acquisition of the data; we aim for distributing information with an initial latency of a few tens of minutes initially, possibly improving later. The LSC and the Virgo Collaboration (LVC) wish to enable multi-messenger observations of astrophysical events by GW detectors along with a wide range of telescopes and instruments of mainstream astronomy.

In 2012, the LVC approved a statement (LSC, Virgo) that broadly outlines LVC policy on releasing GW triggers (partially-validated event candidates). Initially, triggers will be shared promptly only with astronomy partners who have signed an Memorandum of Understanding (MoU) with LVC involving an agreement on deliverables, publication policies, confidentiality, and reporting. After four GW events have been published, further event candidates with high confidence will be shared immediately with the entire astronomy community (and the public), while lower-significance candidates will continue to be shared promptly only with partners who have signed a MoU.

Through June to October 2013, we organized rounds of consultations with groups of astronomers that have expressed interest in the GW-EM follow-up program. Thanks to these consultations, we could define the framework and guiding rules for this program that are collected into a standard MoU template.

OPEN CALL FOR PARTICIPATION TO GW-EM FOLLOW-UP PROGRAM, DUE FEB 16 2014.

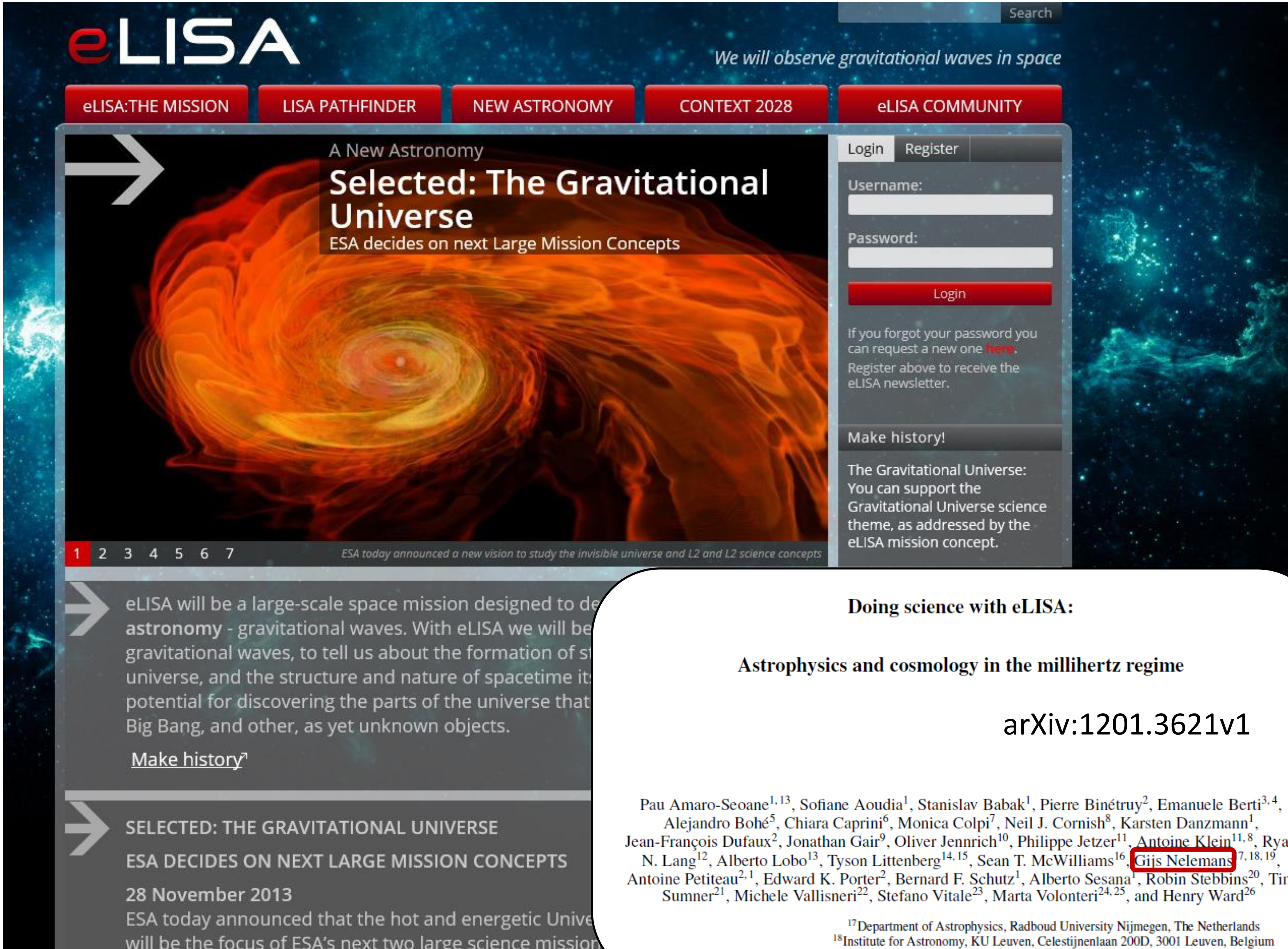
On Dec 16 2013, we issued a call for proposals to sign standard MoU with the LVC. This call is open to all professional astronomers with demonstrated experience, and require that a partner bring some useful observing resource(s), not just astronomy expertise, to participate. GW triggers will be sent to groups that are in position to make observations in the course of next science runs circa 2015-2017 (arXiv:1304.0670, LIGO-P1200087, VIR-0288A-12). Our intent is to accept and sign MoUs with all qualified applicants. We expect to issue this call yearly in spring.

If you are interested in signing this agreement with LSC and Virgo, please read this document that provides important details of the GW-EM follow-up program, fill the application form in LIGO-F1300021, and email it to emf@ligo.org. **Also**, please fill the information fields below (including the filename of the file you emailed to us) and submit it before Feb 16, 2014.

Devour thy Neighbor: An artist's illustration of two neutron stars close to merger look misshaped, becoming more oblong the closer they get to one another. A black hole is then formed and gamma rays shoot out as a GRB. (Credit: NASA/Swift)

Received 64 applications so far ...

November 28, 2013: *e*LISA approved!



Doing science with eLISA:

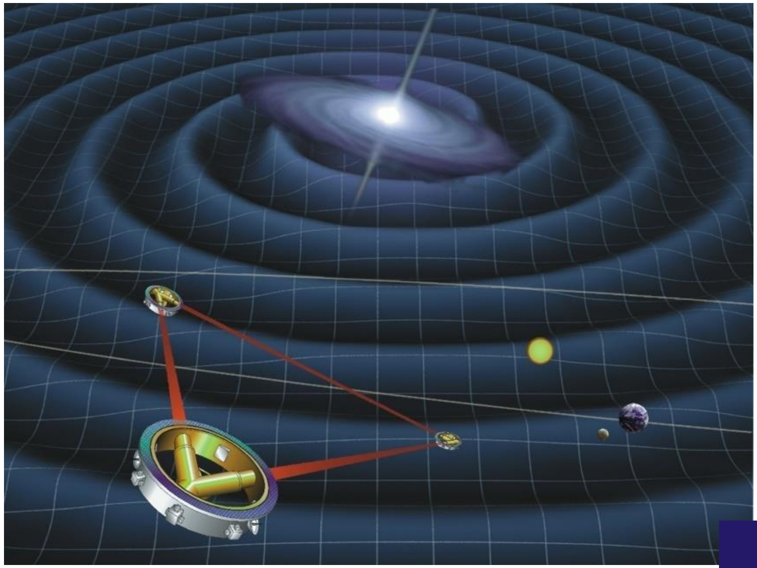
Astrophysics and cosmology in the millihertz regime

arXiv:1201.3621v1

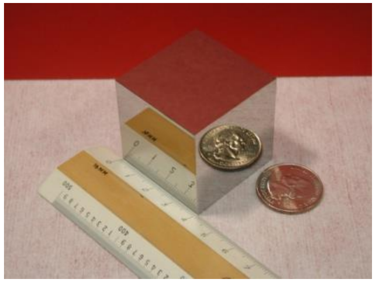
Pau Amaro-Seoane[1,13], Sofiane Aoudia[1], Stanislav Babak[1], Pierre Binétruy[2], Emanuele Berti[3,4], Alejandro Bohé[5], Chiara Caprini[6], Monica Colpi[7], Neil J. Cornish[8], Karsten Danzmann[1], Jean-François Dufaux[2], Jonathan Gair[9], Oliver Jennrich[10], Philippe Jetzer[11], Antoine Klein[11,8], Ryan N. Lang[12], Alberto Lobo[13], Tyson Littenberg[14,15], Sean T. McWilliams[16], Gijs Nelemans[7,18,19], Antoine Petiteau[2,1], Edward K. Porter[2], Bernard F. Schutz[1], Alberto Sesana[1], Robin Stebbins[20], Tim Sumner[21], Michele Vallisneri[22], Stefano Vitale[23], Marta Volonteri[24,25], and Henry Ward[26]

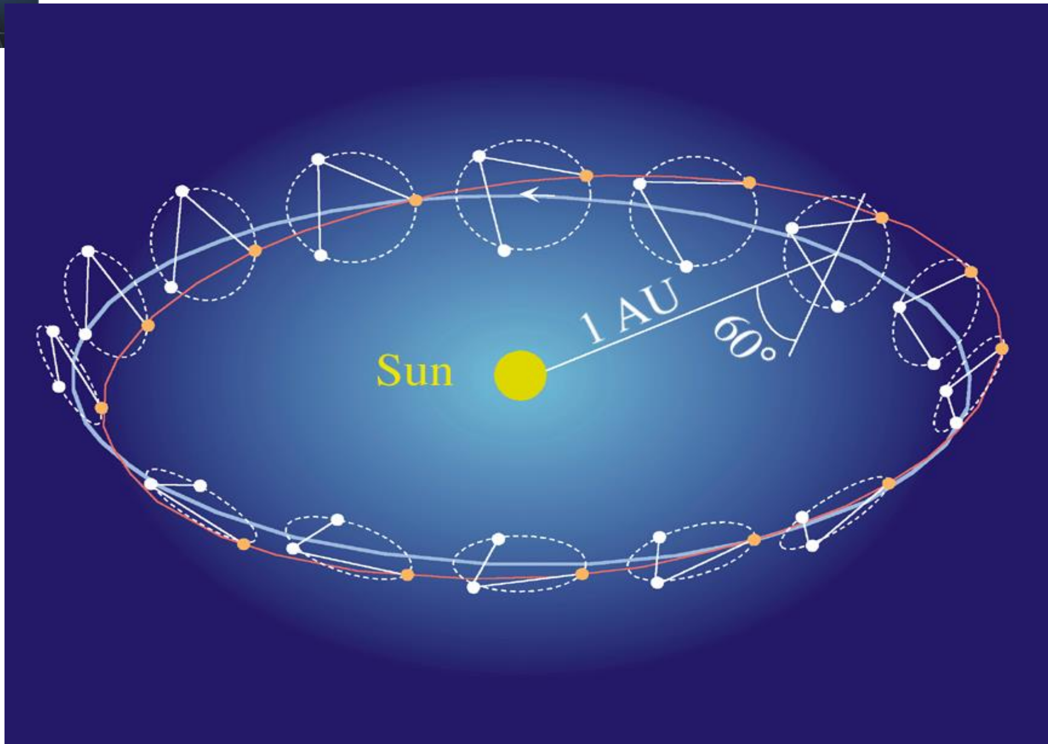
[17]Department of Astrophysics, Radboud University Nijmegen, The Netherlands
[18]Institute for Astronomy, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium
[19]Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands

GW antenna in space - *e*LISA

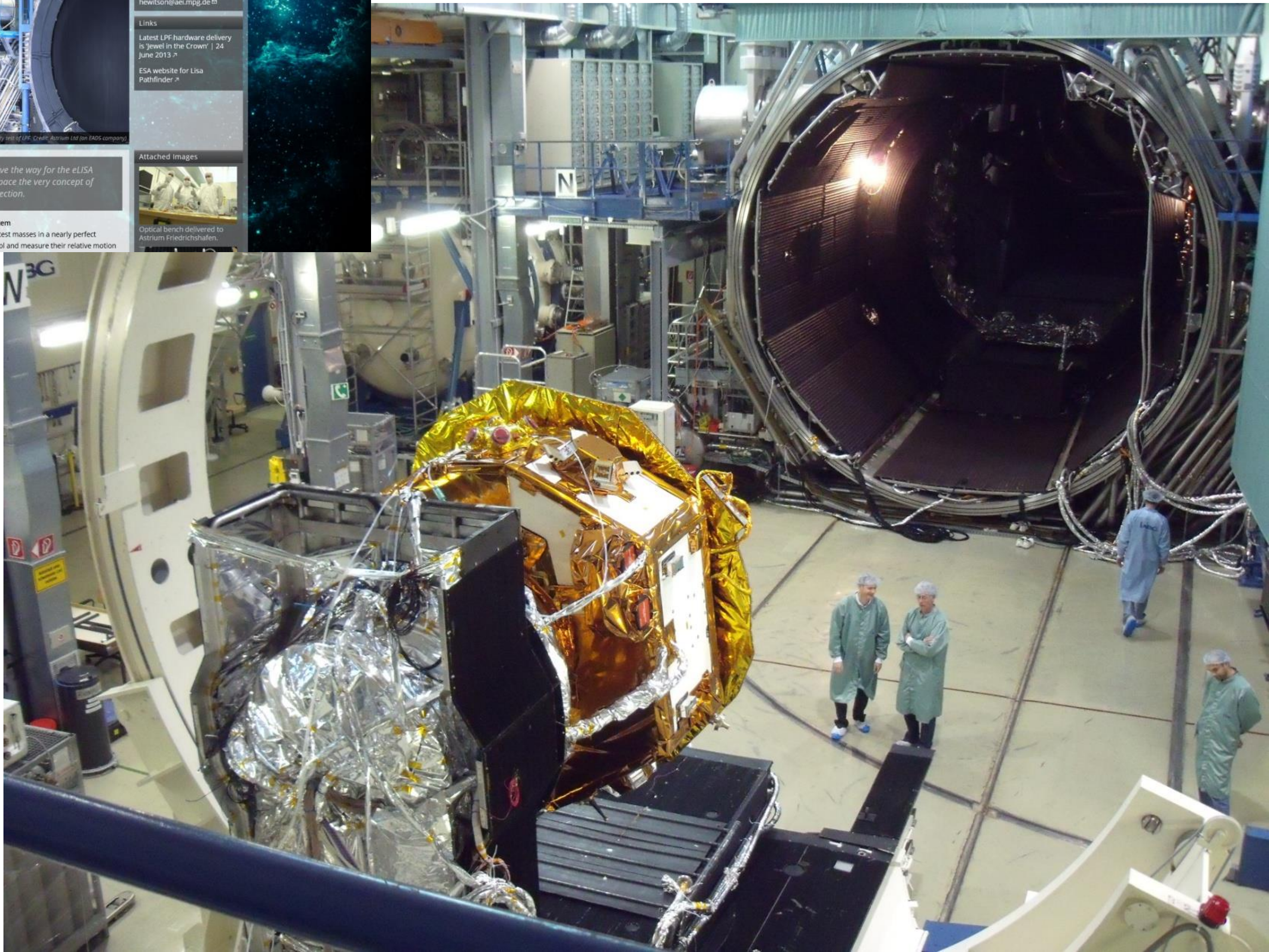


- 3 spacecraft in Earth-trailing solar orbit separated by 10^6 km.
- Measure changes in distance between fiducial masses in each spacecraft
- ESA funded
- Launch date 2034





LISA pathfinder

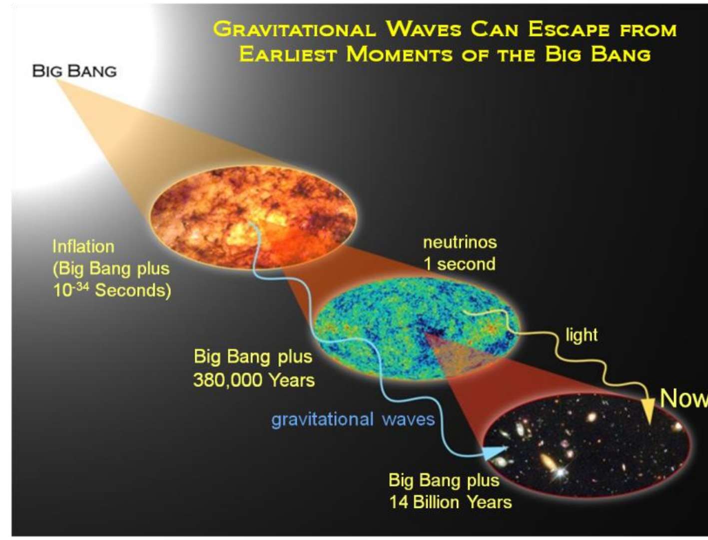


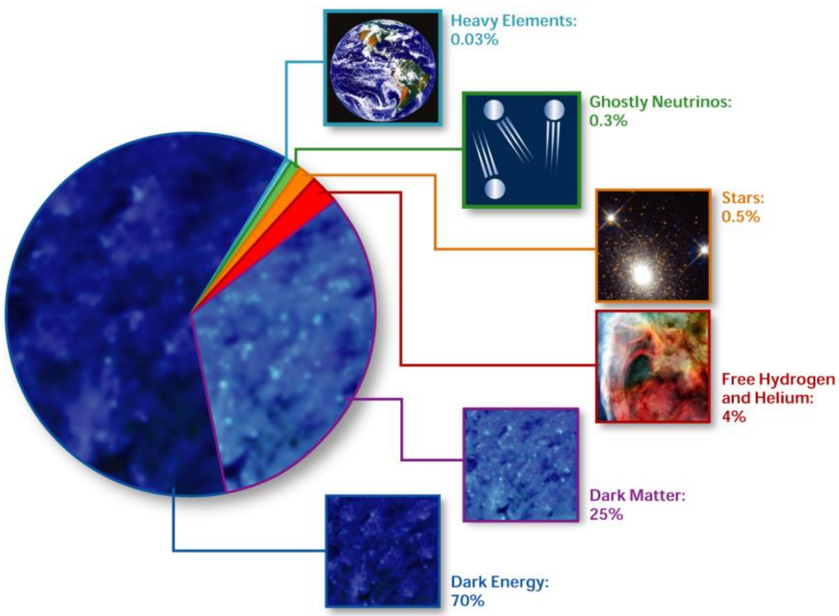
Science goals

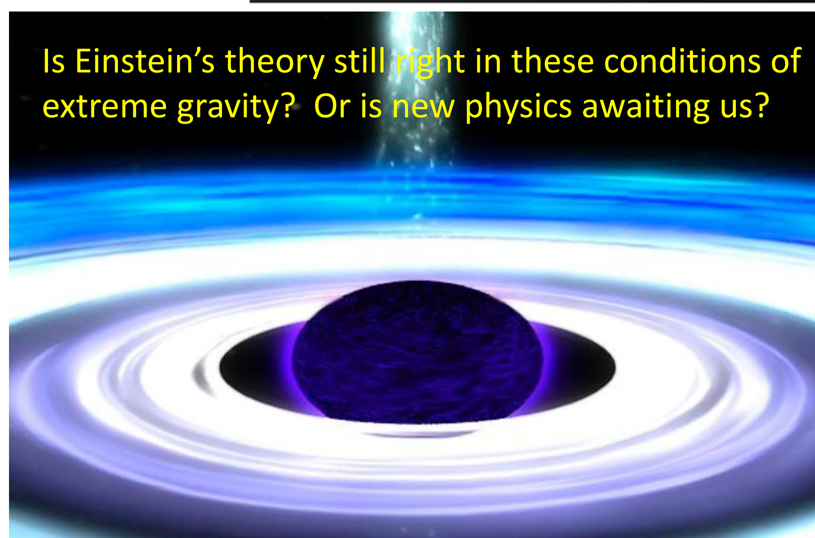
What happens at the edge of a Black Hole?

What is the mysterious Dark Energy pulling the Universe apart?

What powered the Big Bang?







Outreach and social relevance

- Nikhef spin out company
  - Commercialize “Gravitational Physics” instrumentation
    - Vibration isolation
    - Sensor networks
- Outreach publications

innoSeis
Science Park Amsterdam
info@innoseis.com

HANNOVER MESSE
7.–11. APRIL 2014

De door Nikhef aangeleverde spiegel voor de Input Mode Cleaner van VIRGO. De koperkleurige metalen ring hangt met vier rekvrije draadjes aan een zogenoemde superattenuator, die storende trillingen verzwakt. In de ring hangt de spiegel zelf, die doorzichtig is voor alle golflengtes behalve die van de VIRGO-laser.

VLAG VAN VIJF MILJOEN

54 www.kijk.nl oktober 2008

intermediair.nl
Nu met 4172 vacatures voor hoogopgeleiden

Ondergrondse telescoop moet zwaartekrachtgolven betrappen
Test voor Einstein

12-11-2008 | Auteur: Bruno van Wayenburg

Het klinkt belachelijk: een telescoop bouwen onder de grond. Toch heeft de Europese Commissie drie miljoen euro toegekend voor plannen voor de Einstein Telescoop voor zwaartekrachtgolven op tweehonderd meter onder het maaiveld, mogelijk in Nederland.

Een telescoop onder de grond?

De Einstein Telescoop (ET) detecteert geen licht, zoals gewone telescopen, maar zwaartekrachtgolven. Dat

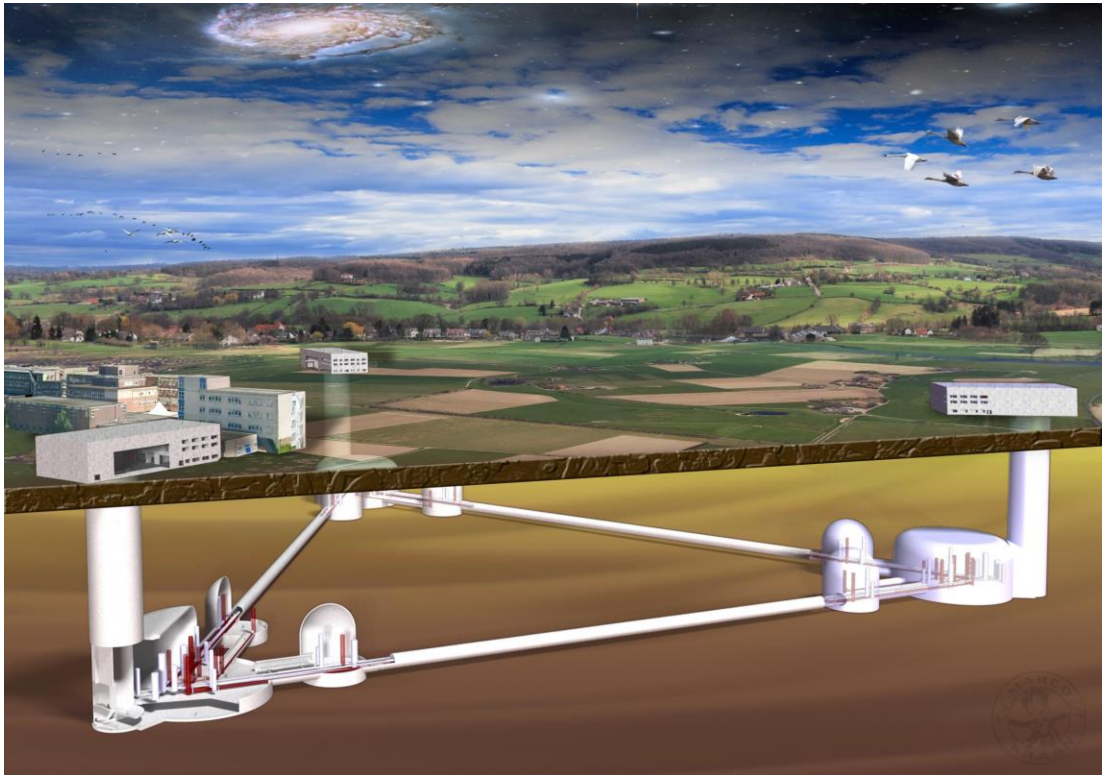
ENORME DETECTOR BIJ PISA MOET EINDELIJK ZWAARTEKRACHTGOLVEN METEN

Jagen op de ruimterimpel

Volgens Einstein moeten er zwaartekrachtgolven bestaan, rimpelingen van de ruimtetijd, maar ze zijn nooit gemeten. Een nieuwe detector bij Pisa doet zijn best, maar een passerende vrachtwagen kan de metingen al verstoren. *Bruno van Wayenburg*

International context

- Nikhef – Kagra collaboration in ELiTES
  - EU funded technology transfer from Nikhef to Kagra
- Einstein Telescope
  - On ApPEC readmap; Listed as A-Topic for Horizon 2020
  - Nikhef leads JRA3 on site selection and gravity gradient noise



Site studies

- Seismic studies
  - 15 sites in 11 countries
  - Typically 1 – 2 weeks of data
  - KNMI cross check
  - Worldwide effort
    - **Europe**
    - **Kagra, Japan**
    - **Homestake, USA**

Mark Beker, David Rabeling Nikhef
LCGT, Homestake, INFN, Hungary

Available infrastructure

Homestake - USA

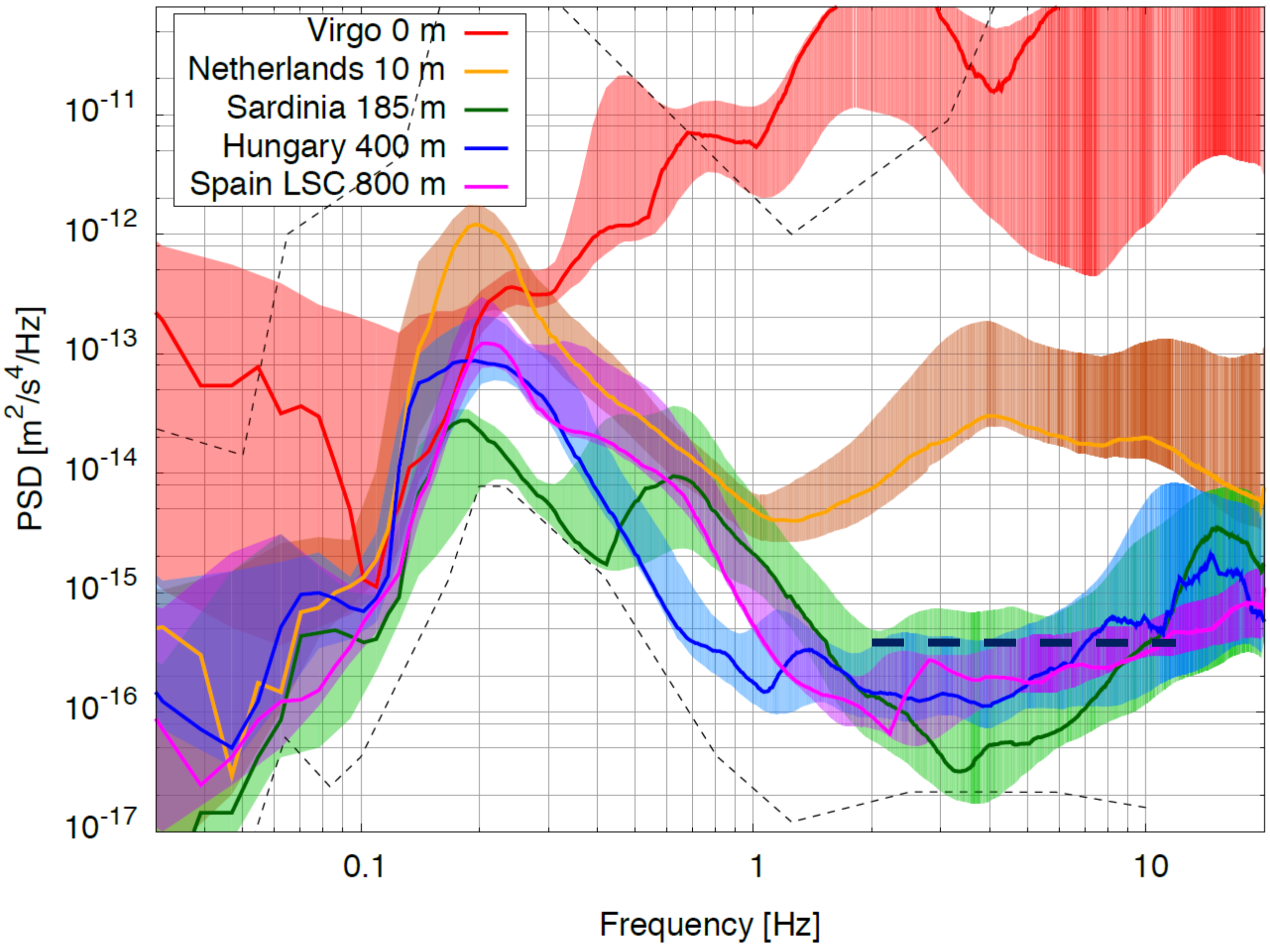
Safety issues: training, guides (by appointment)

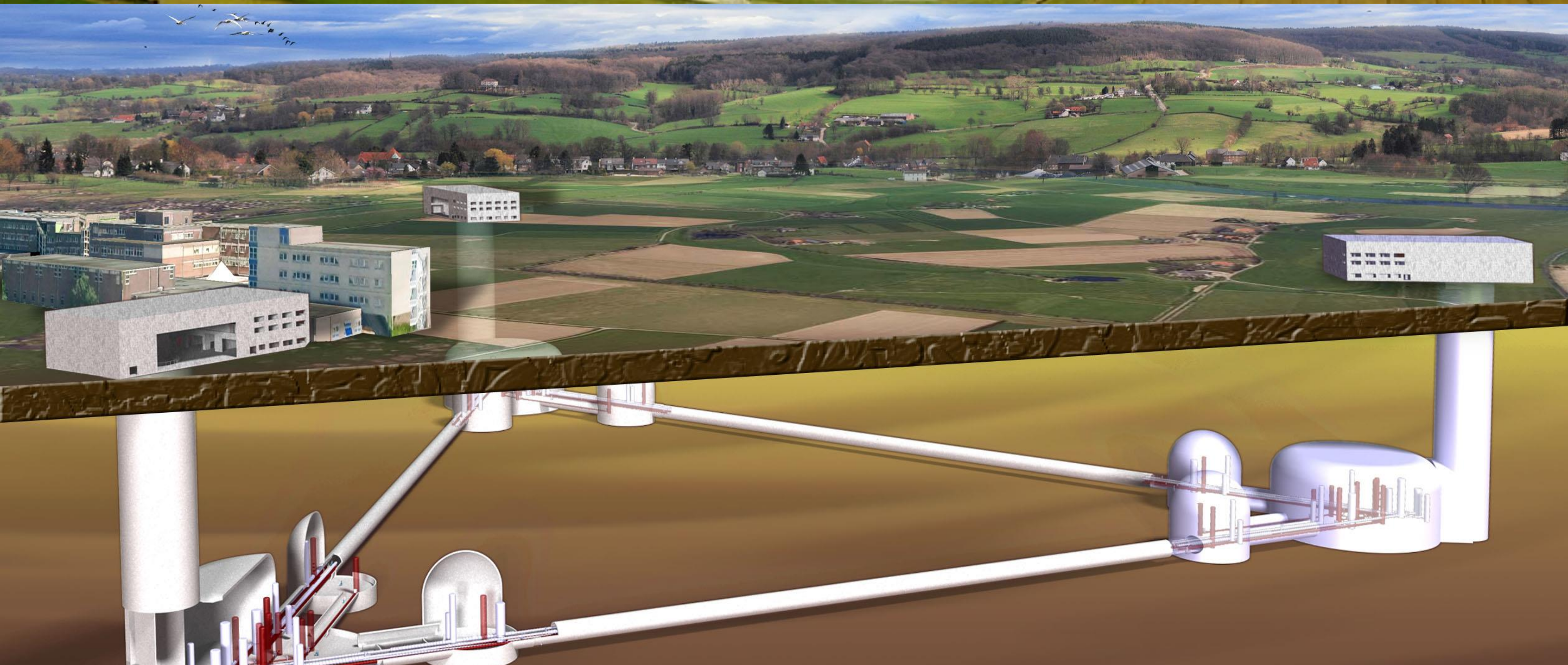
Elevators: access (operators)

Site studies

- Goal: significant reduction in PSD compared to *e.g.* Virgo site
- Comply with ET seismic requirements
  - 5×10^{-10} m/f^2
- Underground sites
  - Several 100 m

Mark Beker, David Rabeling, Nikhef
Fulvio Ricci *et al.*, Roma1

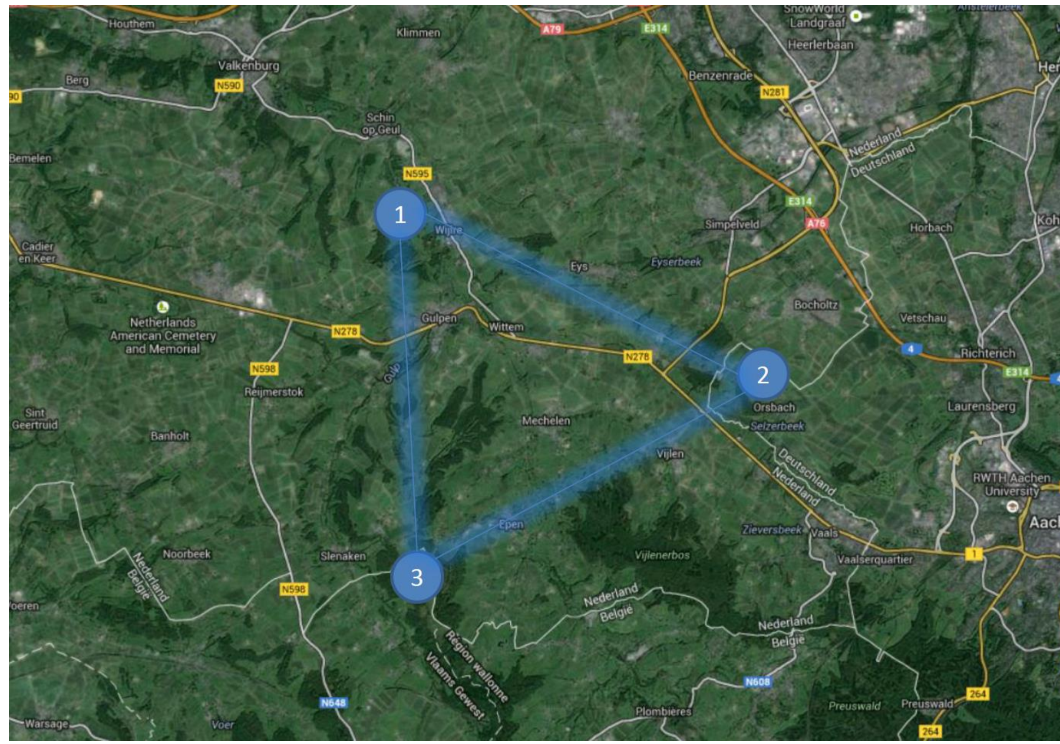


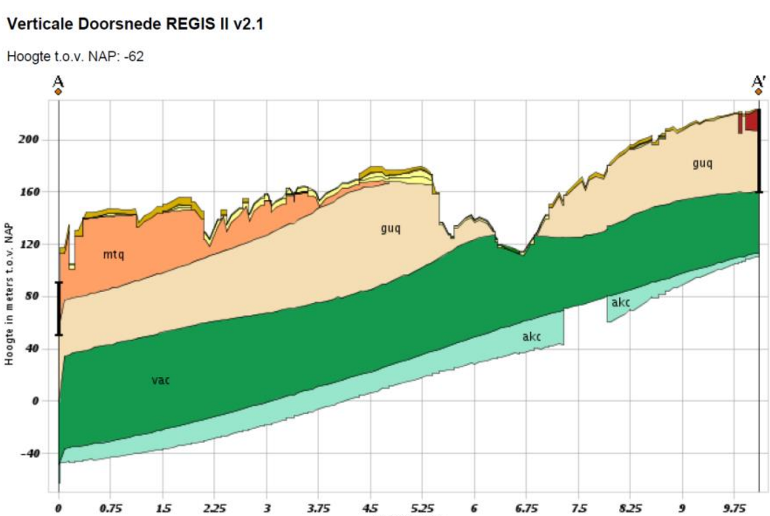



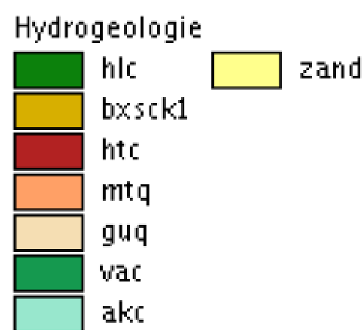
ET in The Netherlands

Grontmij

- Good seismic quality at surface level
- Next: underground data







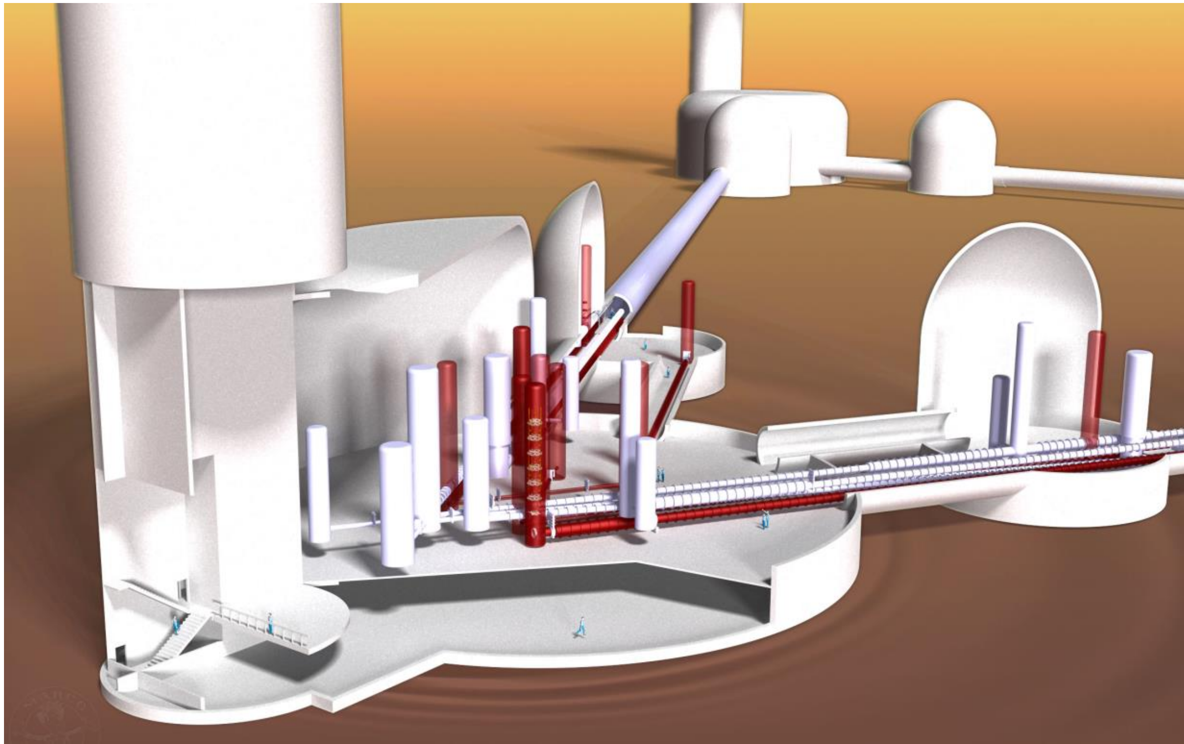
ET infrastructure

- Infrastructure: largest cost driver
  - Tunnels, caverns, buildings
  - Vacuum, cryogenics, safety systems
  - Collaborate with industry
    - COB (Amsterdam)
    - Saes Getters Italy
- Experience
  - LIGO, Virgo, GEO
  - Underground labs

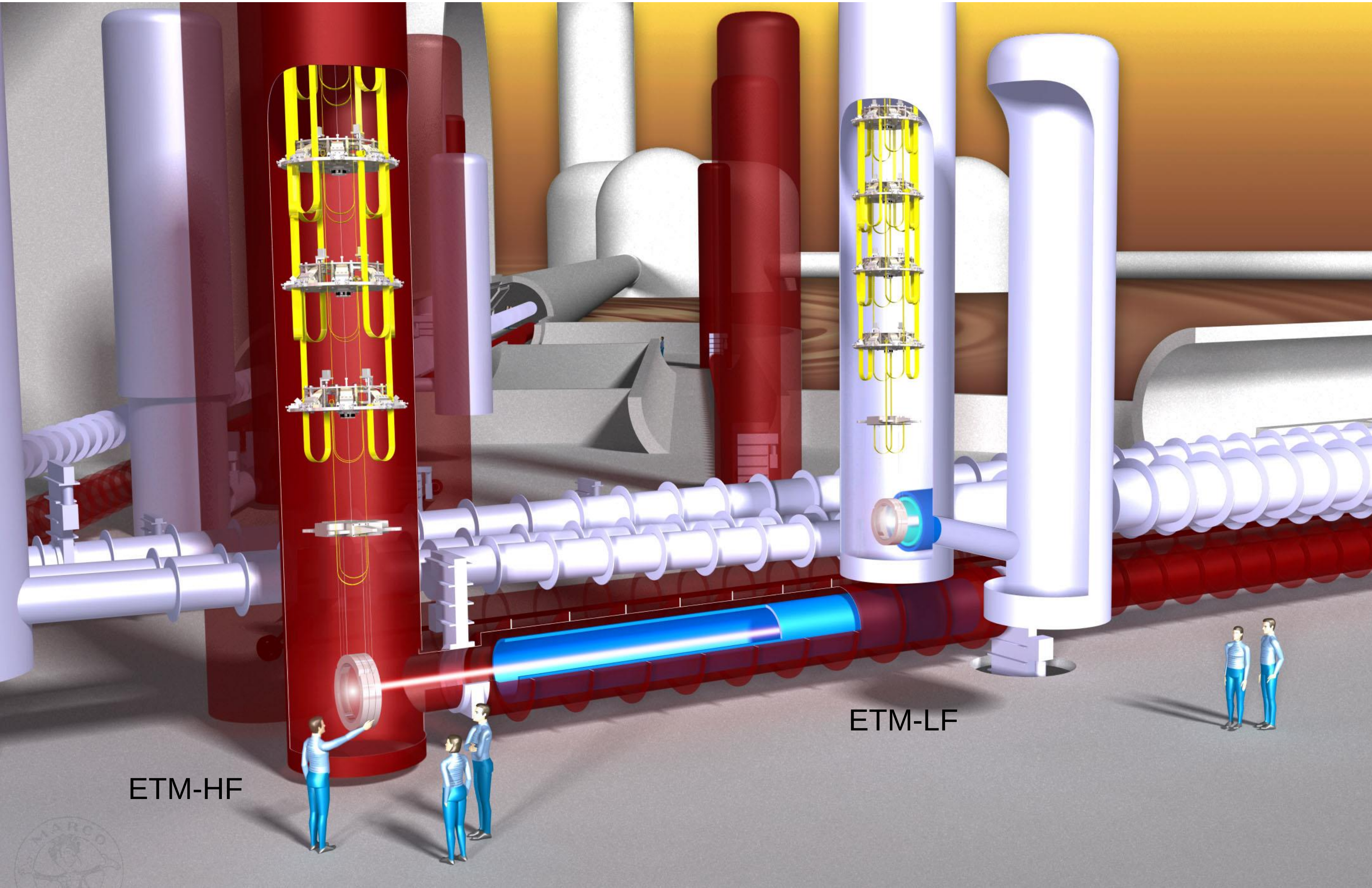
    Gran Sasso, Canfranc, Kamioka, Dusel, etc.
  - Mines
  - Particle physics

    ILC, Cern, Desy, FLNL
  - Seismology

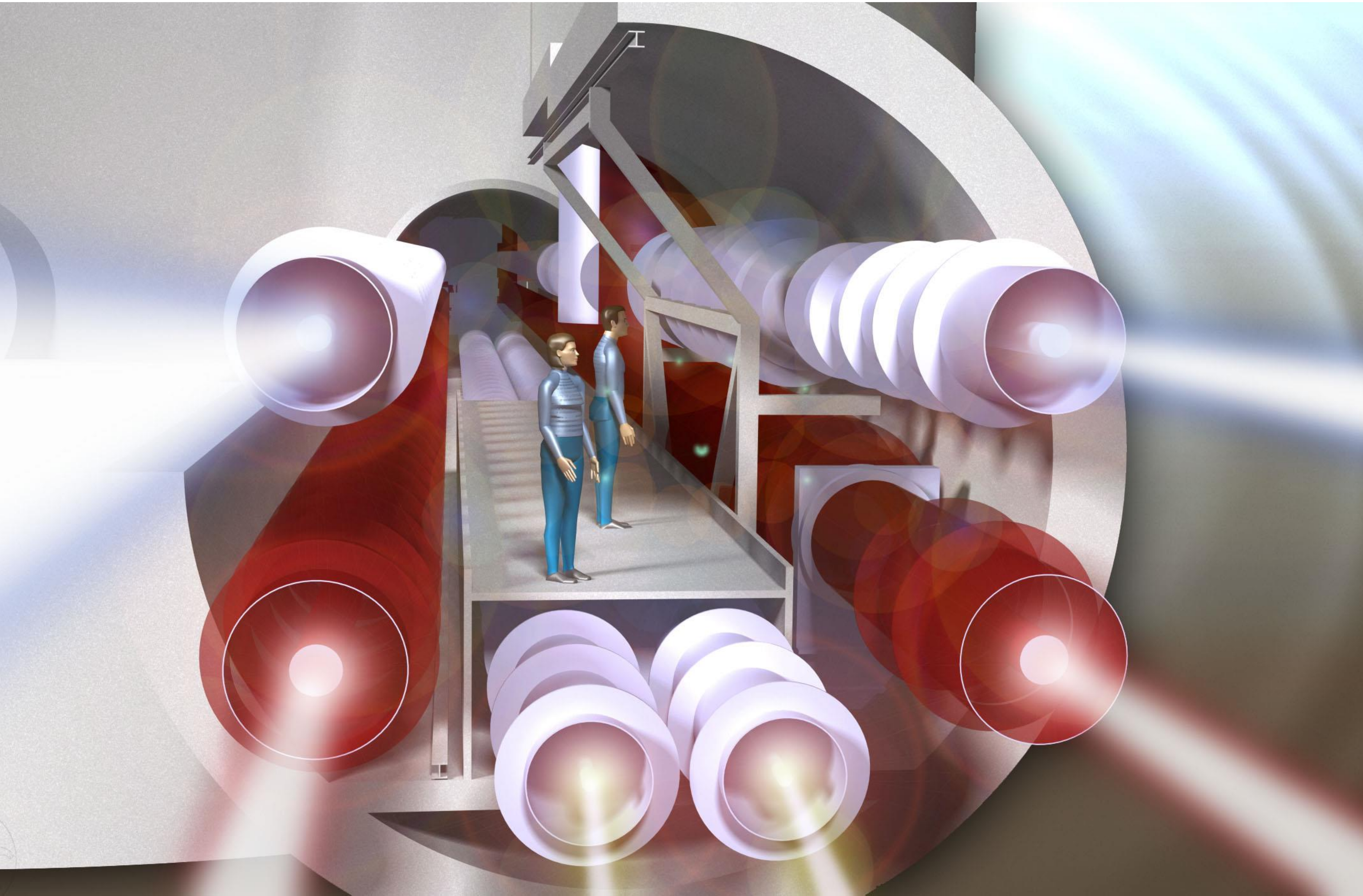
    KNMI, Orfeus
  - Geology



ET infrastructure

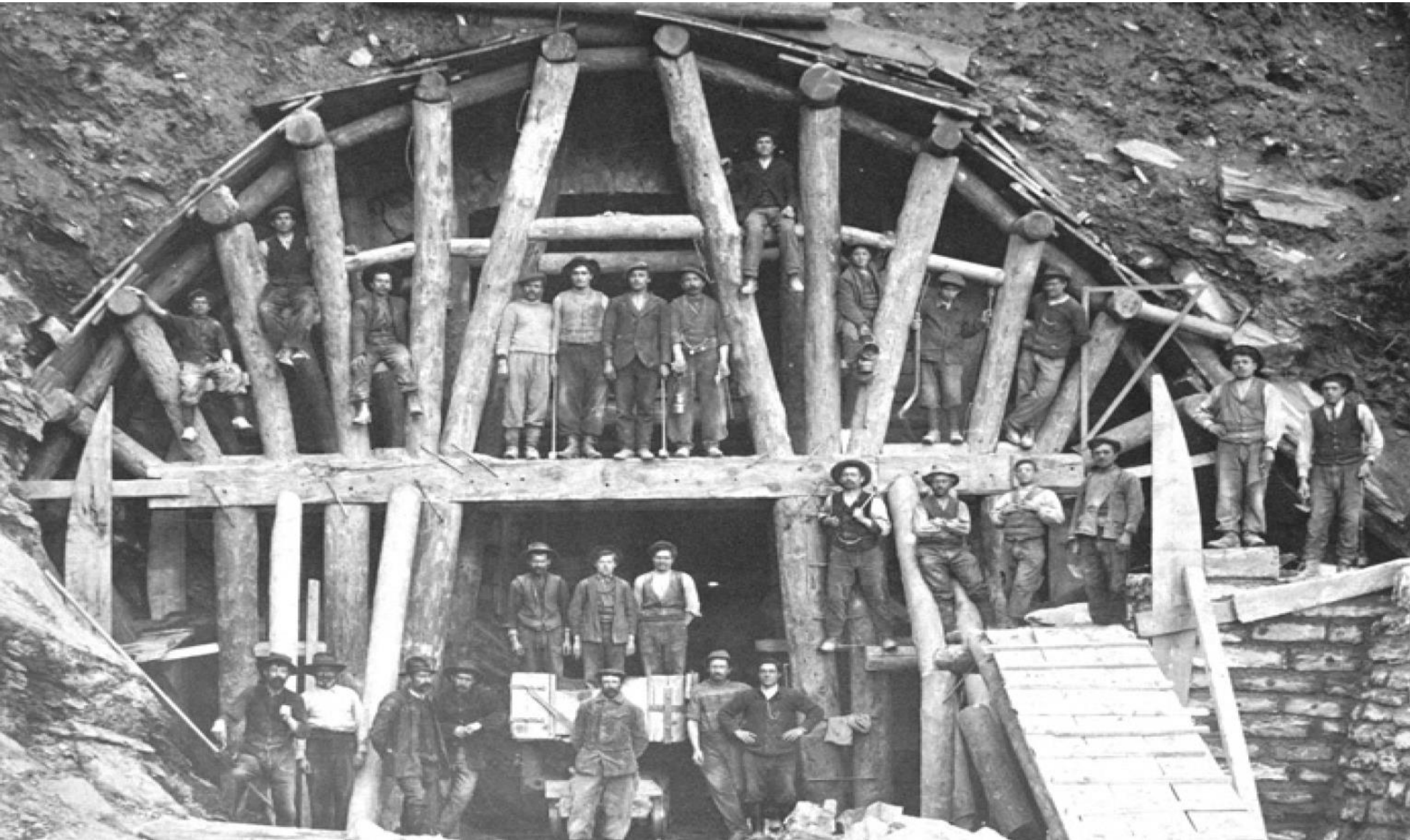


ET infrastructure

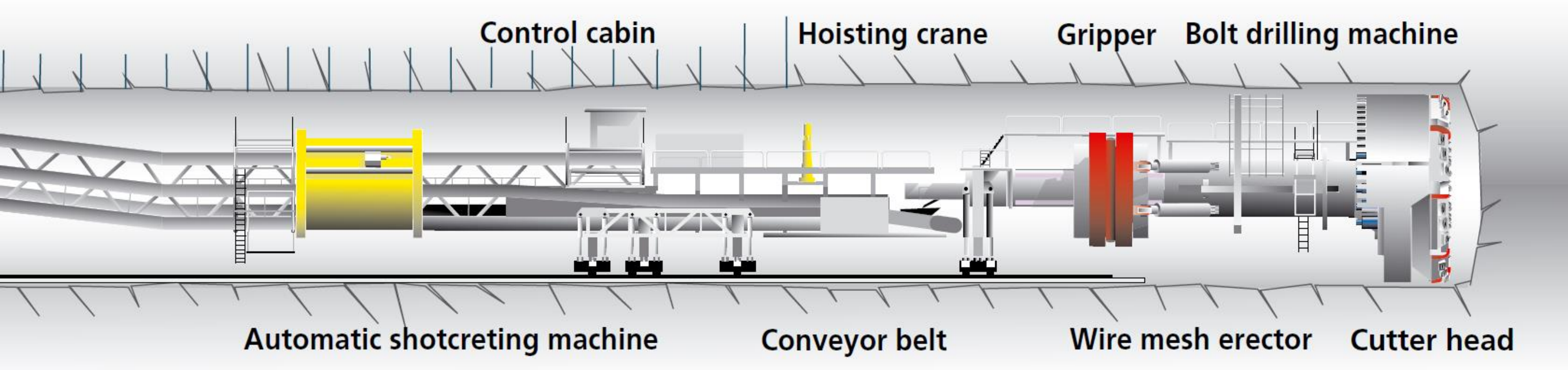


How to construct ET facility?

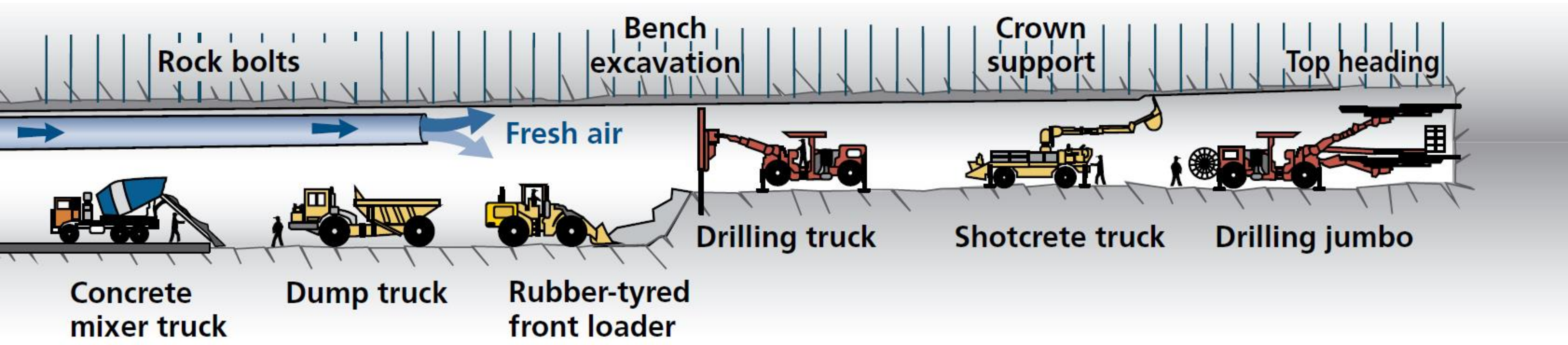
Grontmij
+ Bjorn Vink



Tunnel Boring Machines



Drill & Blast



Rock bolts
Bench excavation
Crown support
Top heading
Fresh air
Drilling truck
Shotcrete truck
Drilling jumbo
Concrete mixer truck
Dump truck
Rubber-tyred front loader


Hydropower station

LHC project: CMS cavern

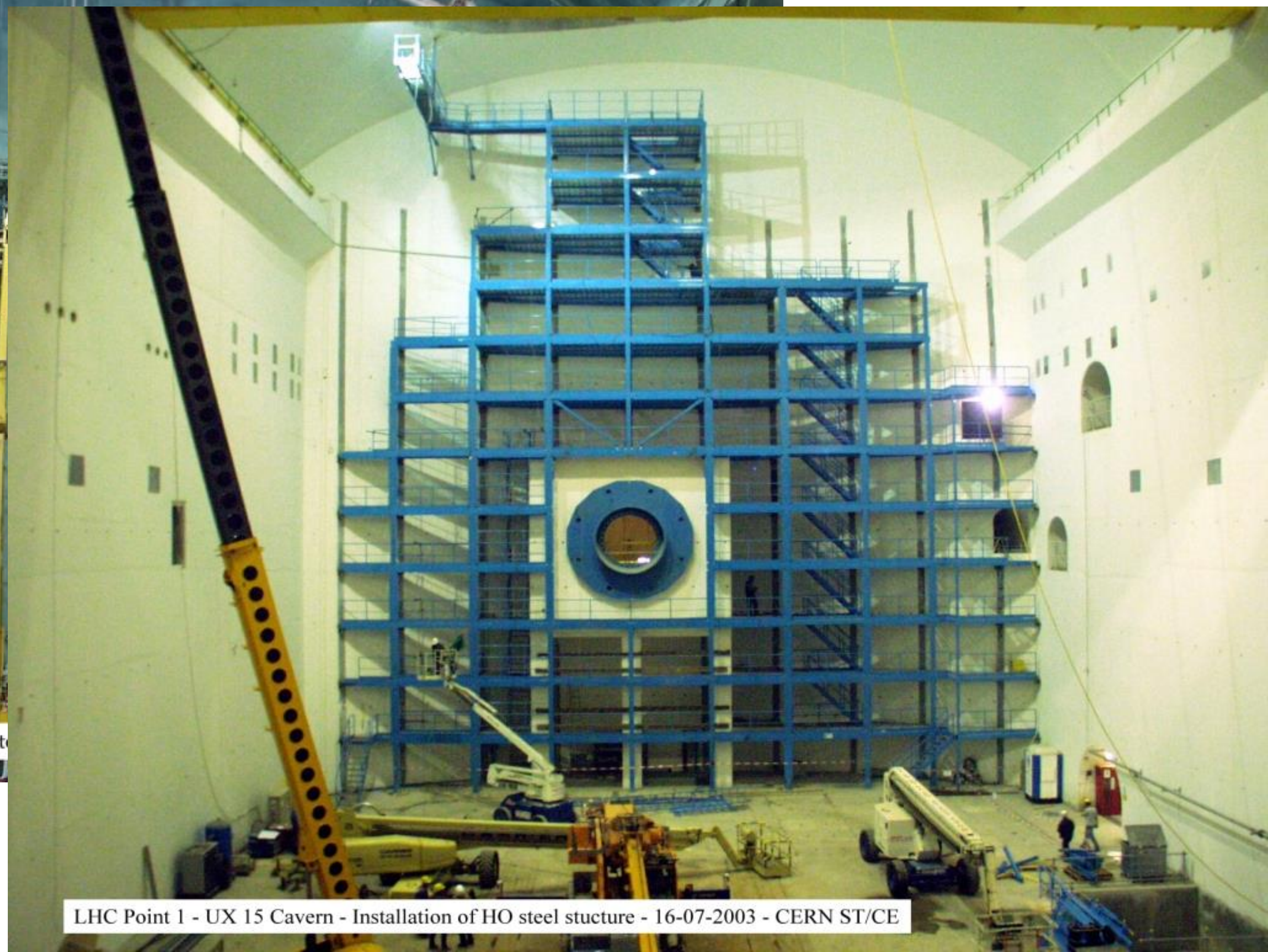

LHC Point 5 - UXC55 Point 4 End Crown Falsework - 29-03-2004 - CERN TS-CE


Point 6 headwall - 20-06-2003 - CERN ST/CE

LHC project: CMS cavern

LHC project: Atlas cavern

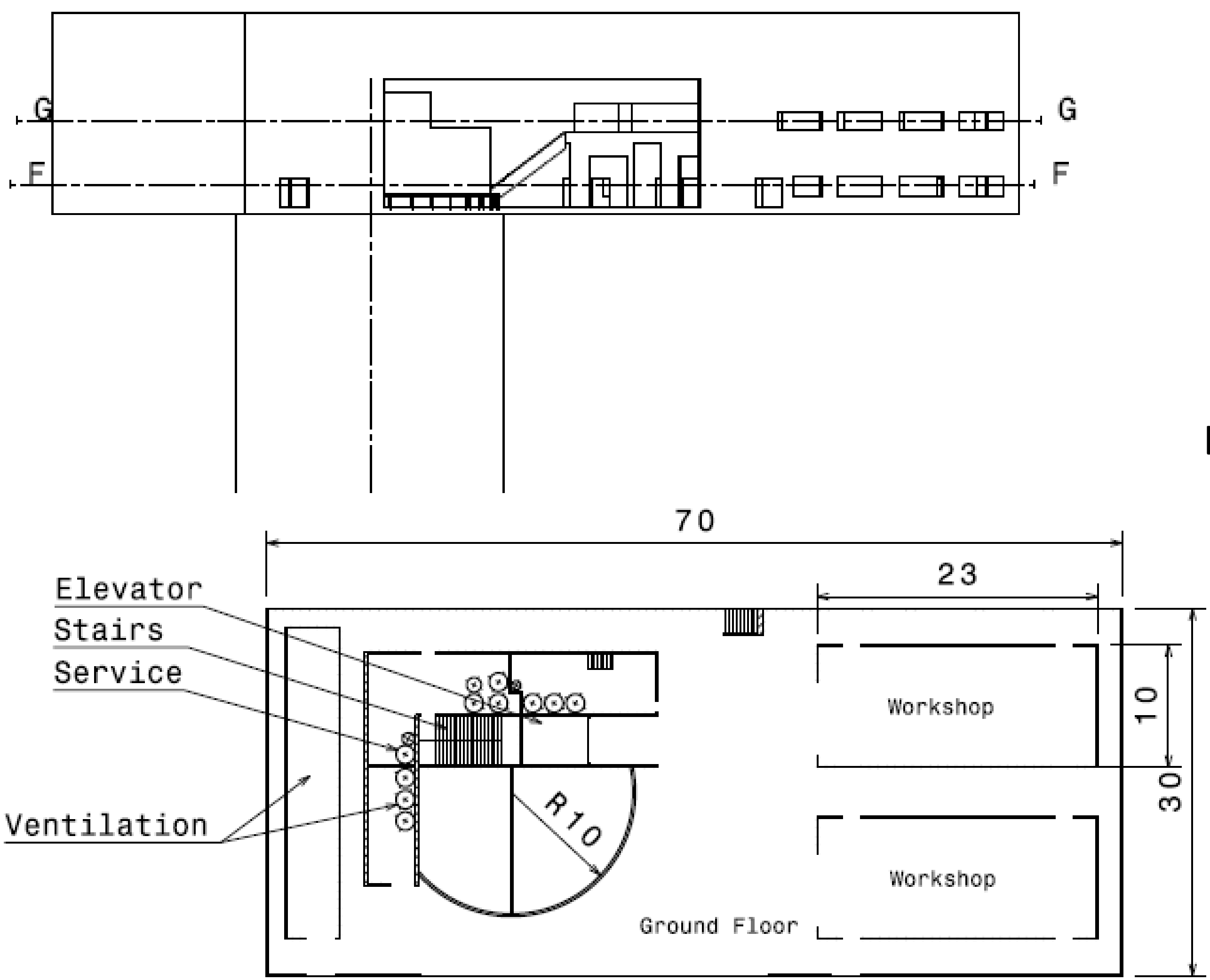
LHC Point 1 - UX 15 Cavern - Concret



LHC Point 1 - UX 15 Cavern - Installation of HO steel stucture - 16-07-2003 - CERN ST/CE

LHC project: CMS shaft

Surface buildings



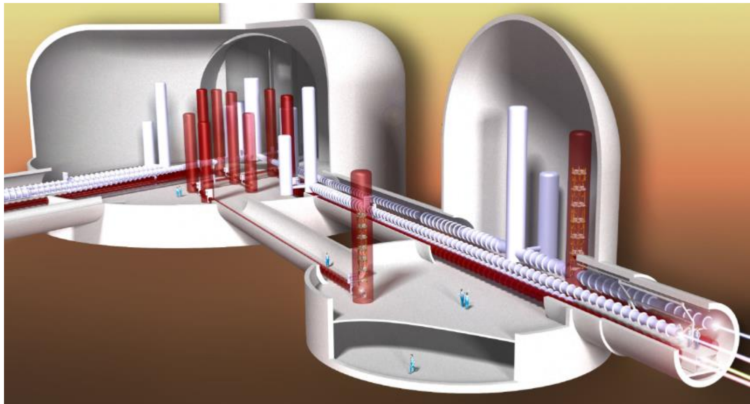
Section view F-F
Scale: 1:500

Ground floor
- L = 70 m, W = 30 m
- 2 workshops (23 m x 10 m)
  - o vacuum tubes
  - o cleanrooms later?
- Large entrance doors
- Ventilation system (outside?)
- Cryocoolers?
- Services

Lifting facility
- D = 20 m
- Excavation entrance (TBMs?)
- Stairs, Elevator

Executive summary – ET WG1

- Site studies
  - 15 locations in 11 different countries
  - Several promising EU underground sites exist
    - Low seismic environment
  - Discussions with experts
    - Geologists
    - Observatories and Research Facilities for European Seismology (ORFEUS)
    - Seismology department of Royal Dutch Meteorological Institute (KNMI)
    - Underground laboratories: LNGS, LSM, Canfranc, Hades, Dusel and Kamioka
    - Mines: Finland, Germany, Hungary, Italy and Romania
    - Particle physics: CERN, DESY and ILC
    - Industry: Center for Underground Construction, Grontmij, STUVA, ITA
- Infrastructure Reference Design
  - Tunnels, caverns, shafts, surface buildings
  - Vacuum system
  - Cryogenic infrastructure



CONCLUDING REMARKS

- **Interferometer technology demonstrated**
- **LIGO/Virgo upgrades to 2nd generation funded, construction in progress. More detectors to come.**
- **Preparing for multi-messenger observation**
- **First long run in 2016: stay tuned!**

2016: CENTENNIAL OF GENERAL RELATIVITY
We look forward to celebrating it with a discovery