The Status of Virgo

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Contents

Virgo Collaboration is growing and new groups are being integrated into Virgo

Virgo Collaboration

Virgo is a European collaboration with more than 300 members

Advanced Virgo (AdV): upgrade of the Virgo interferometric detector

Participation by scientists from France, Italy, Belgium, The Netherlands, Poland, Hungary, Spain, Germany

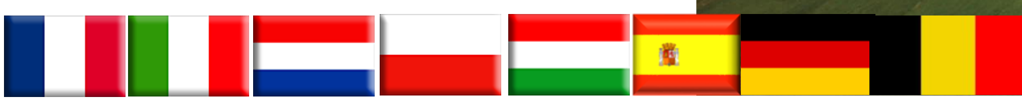
- 24 laboratories, about 280 authors
  - APC Paris
  - ARTEMIS Nice
  - EGO Cascina
  - IFAE Barcelona
  - INFN Firenze-Urbino
  - INFN Genova
  - INFN Napoli
  - INFN Perugia
  - INFN Pisa
  - INFN Roma La Sapienza
  - INFN Roma Tor Vergata
  - INFN Trento-Padova
  - LAL Orsay – ESPCI Paris
  - LAPP Annecy
  - LKB Paris
  - LMA Lyon
  - Nikhef Amsterdam
  - POLGRAW(Poland)
  - RADBOUD Uni. Nijmegen
  - RMKI Budapest
  - UCLouvain
  - ULiege
  - Univ. of Barcelona
  - Univ. of Valencia
  - University of Jena

Advanced Virgo project has been formally completed on July 31, 2017

Part of the international network of 2nd generation detectors

Joined the O2 run on August 1, 2017

8 European countries

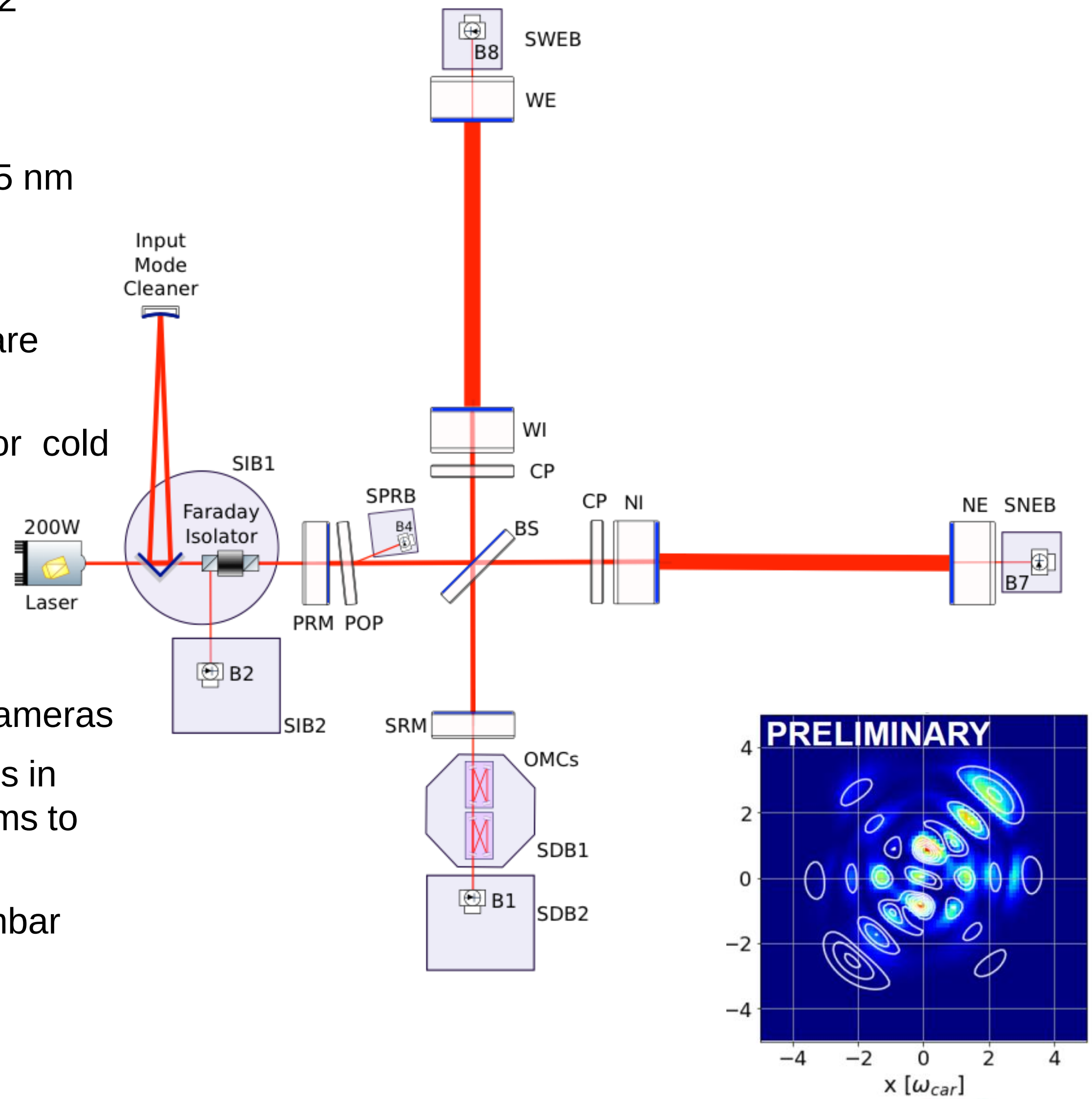


Advanced Virgo

Most infrastructure installed for Advanced Virgo. It features many improvements with respect to Virgo and Virgo+. However the absence of Signal Recycling has great impact

Instrumentation improvements for Observing run 2

- Larger beam: 2.5x larger at ITMs
- Heavier mirrors: 2x heavier
- Higher quality optics: residual roughness < 0.5 nm
- Improved coatings for lower losses: absorption < 0.5 ppm, scattering < 10 ppm
- Reducing shot noise: arm finesse of cavities are 3 x larger than in Virgo+
- Thermal control of aberrations: compensate for cold and hot defects on the core optics:
  - ring heaters
  - double axicon CO_2 actuators
  - CO_2 central heating
  - diagnostics: Hartmann sensors & phase cameras
- Stray light control: suspended optical benches in vacuum, and new set of baffles and diaphragms to catch diffuse light
- Improved vacuum: 10^{-9} mbar instead of 10^{-7} mbar



2018: IFAE and UBarcelona, ULiège and UCLouvain

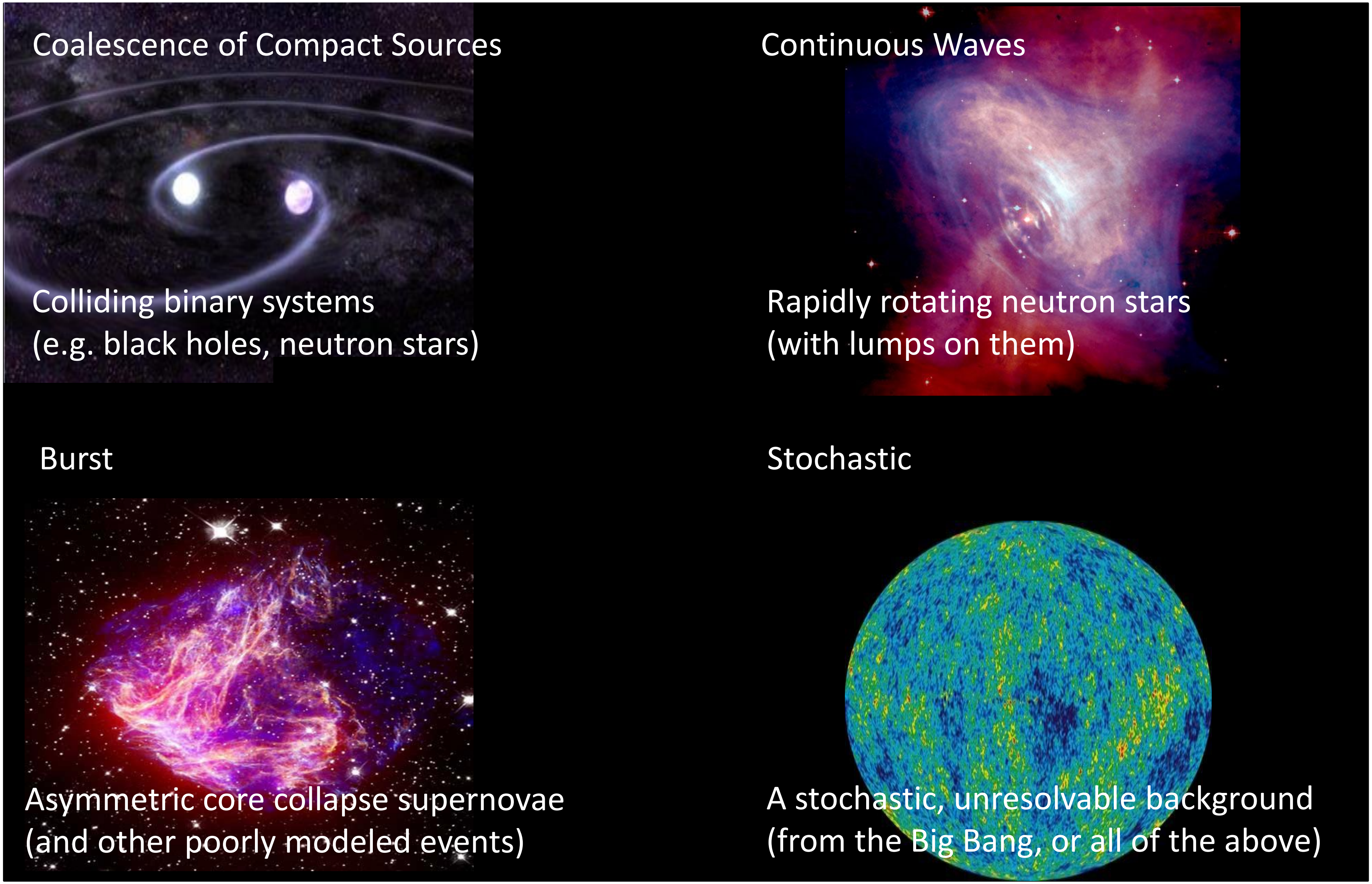
New groups strengthen Virgo in areas as Computing and Stray Light Mitigation

Groups from UTorino, UMaastricht, USannio, USardinia joined Virgo indirectly

LVC scientific output

LIGO-Virgo analyses for sources of gravitational waves

Sources can be transient or of continuous nature, and can be modeled or unmodeled



Scientific achievements: properties of black holes

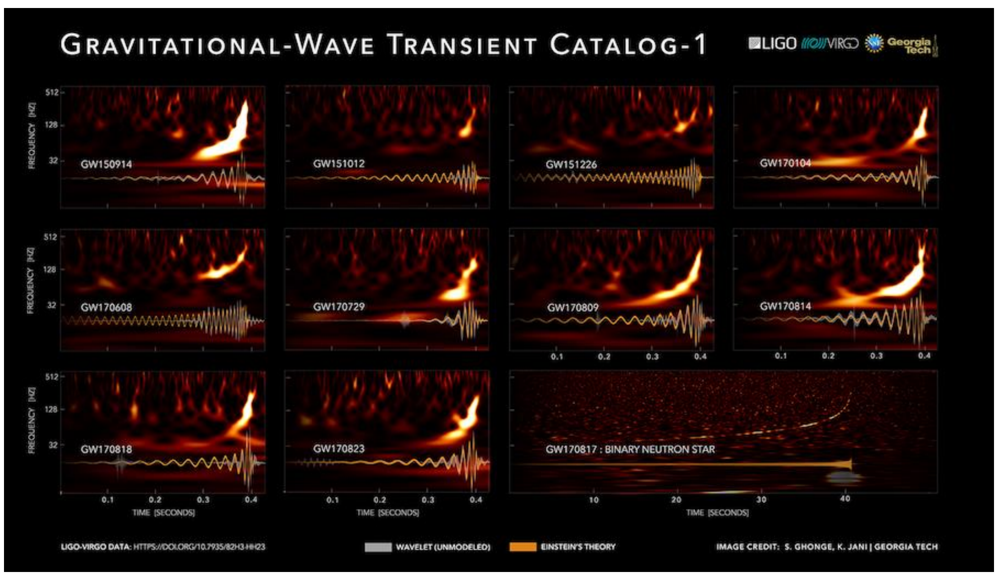
Extract information on masses, spins, energy radiated, position, distance, inclination, polarization. Population distribution may shed light on formation mechanisms

LVC reported on 10 BBH mergers (and 1 BNS)

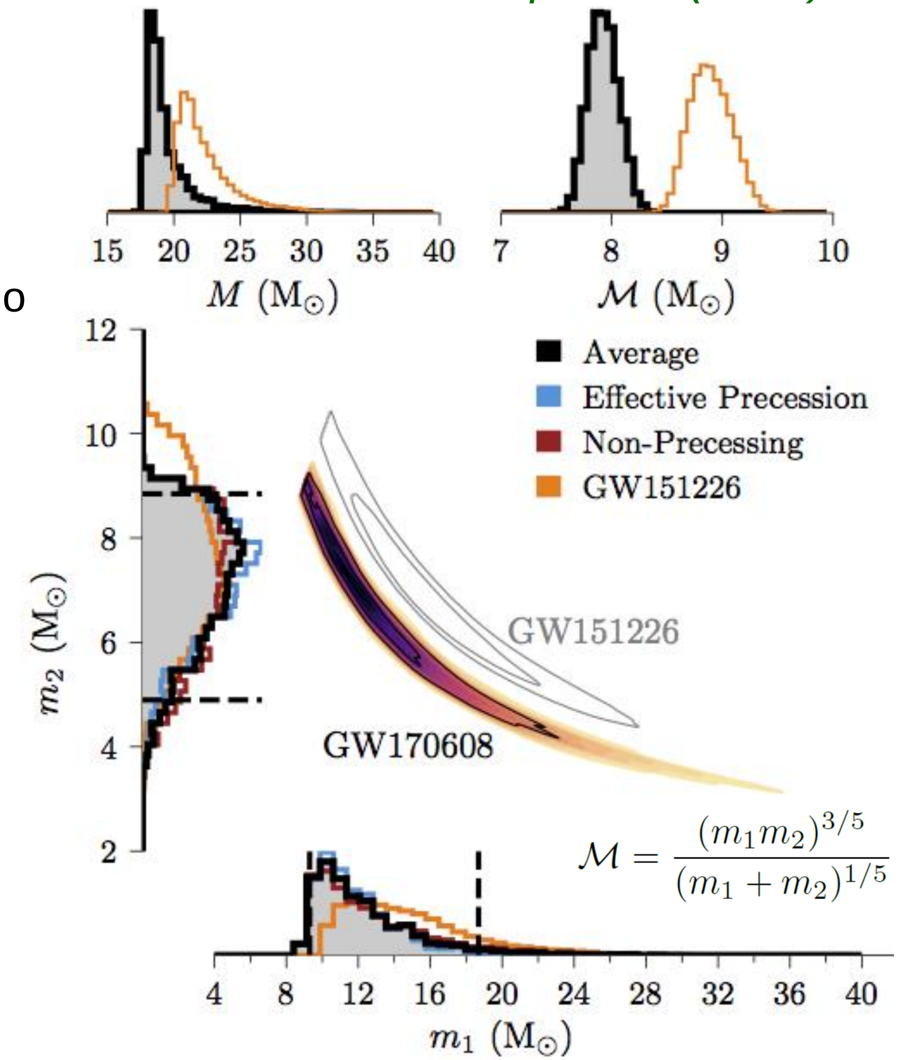
Chirp mass is well inferred

Merger dynamics more sensitive to total mass

“GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs”, The LIGO Virgo Collaboration, [arXiv:1811.12907](https://arxiv.org/abs/1811.12907)



Abbott et al. ApJ 851 (2017) L35



Properties of black holes

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

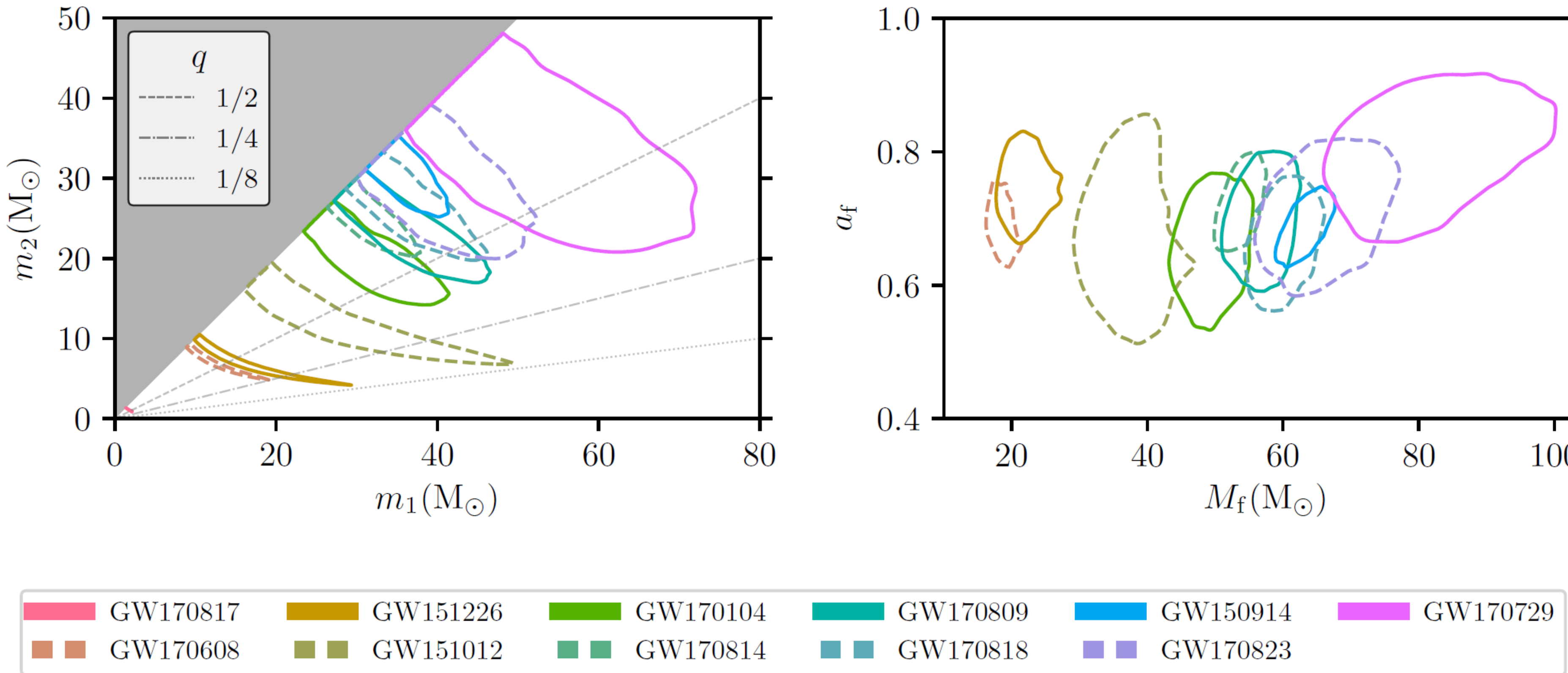


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Table of O1 and O2 triggers with source properties

See https://dcc.ligo.org/LIGO-G1801864

Event	$m_1/M_\odot$	$m_2/M_\odot$	$\mathcal{M}/M_\odot$	$\chi_{\rm eff}$	$M_{\rm f}/M_\odot$	$a_{\rm f}$	$E_{\rm rad}/(M_\odot c^2)$	$\ell_{\rm peak}/(\mathrm{erg\,s^{-1}})$	$D_{\rm L}/\mathrm{Mpc}$	z	$\Delta\Omega/\mathrm{deg}^2$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$	$3.1^{+0.4}_{-0.4}$	$3.6^{+0.4}_{-0.4}\times10^{56}$	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$	194
GW151012	$23.2^{+14.0}_{-5.4}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.2}$	$0.04^{+0.28}_{-0.19}$	$35.7^{+9.9}_{-3.7}$	$0.67^{+0.13}_{-0.11}$	$1.5^{+0.5}_{-0.5}$	$3.2^{+0.8}_{-1.7}\times10^{56}$	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$	1491
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$	$1.0^{+0.1}_{-0.2}$	$3.4^{+0.7}_{-1.7}\times10^{56}$	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$	1075
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	$49.4^{+5.2}_{-3.9}$	$0.66^{+0.09}_{-0.11}$	$2.2^{+0.5}_{-0.5}$	$3.2^{+0.7}_{-1.0}\times10^{56}$	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$	912
GW170608	$11.2^{+5.4}_{-1.9}$	$7.5^{+1.5}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.04^{+0.19}_{-0.06}$	$17.9^{+3.4}_{-0.7}$	$0.69^{+0.04}_{-0.04}$	$0.8^{+0.1}_{-0.1}$	$3.4^{+0.5}_{-1.3}\times10^{56}$	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$	524
GW170729	$50.7^{+16.3}_{-10.2}$	$34.4^{+8.9}_{-10.2}$	$35.8^{+6.3}_{-4.9}$	$0.37^{+0.21}_{-0.26}$	$80.3^{+14.5}_{-10.3}$	$0.81^{+0.07}_{-0.13}$	$4.9^{+1.6}_{-1.7}$	$4.2^{+0.8}_{-1.5}\times10^{56}$	2760^{+1290}_{-1350}	$0.48^{+0.18}_{-0.21}$	1069
GW170809	$35.2^{+8.3}_{-5.9}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.17}_{-0.16}$	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$	$2.7^{+0.6}_{-0.6}$	$3.5^{+0.6}_{-0.9}\times10^{56}$	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$	310
GW170814	$30.7^{+5.5}_{-2.9}$	$25.6^{+2.8}_{-4.0}$	$24.3^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$	$53.6^{+3.2}_{-2.5}$	$0.73^{+0.07}_{-0.05}$	$2.8^{+0.4}_{-0.3}$	$3.7^{+0.5}_{-0.5}\times10^{56}$	560^{+140}_{-210}	$0.12^{+0.03}_{-0.04}$	99
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	≤ 2.8	≤ 0.89	≥ 0.04	$\geq 0.1\times10^{56}$	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$	22
GW170818	$35.5^{+7.5}_{-4.7}$	$26.9^{+4.4}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	$59.8^{+4.8}_{-3.7}$	$0.67^{+0.07}_{-0.08}$	$2.7^{+0.5}_{-0.5}$	$3.4^{+0.5}_{-0.7}\times10^{56}$	1020^{+430}_{-370}	$0.20^{+0.07}_{-0.07}$	35
GW170823	$39.5^{+10.1}_{-6.6}$	$29.4^{+6.5}_{-7.1}$	$29.3^{+4.2}_{-3.1}$	$0.08^{+0.19}_{-0.22}$	$65.6^{+9.3}_{-6.5}$	$0.71^{+0.08}_{-0.09}$	$3.3^{+0.9}_{-0.8}$	$3.6^{+0.6}_{-0.9}\times10^{56}$	1860^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$	1780

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Virgo data contributed to Parameter Estimation of 5 events

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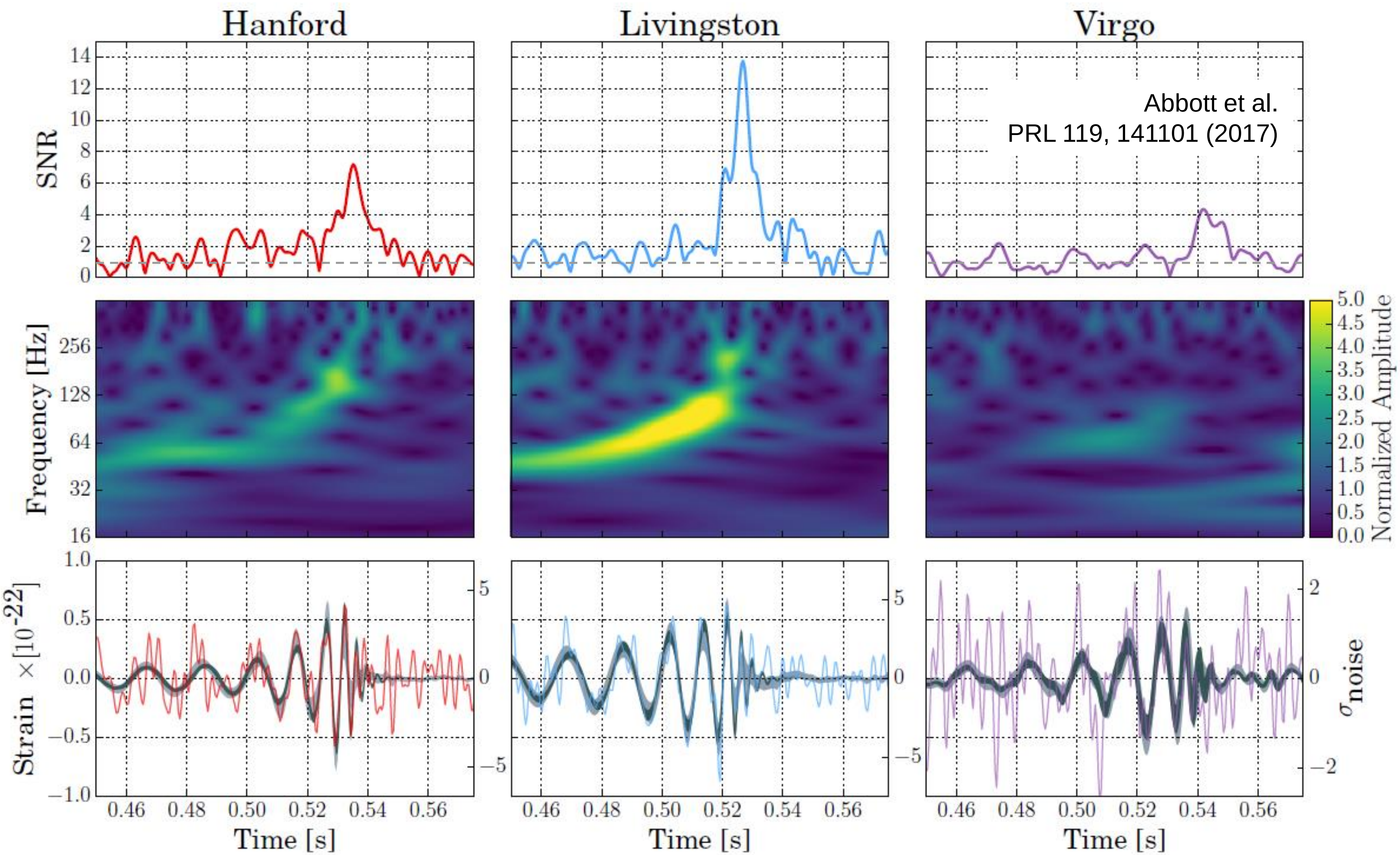
European Gravitational Observatory

LIGO Scientific Collaboration

First triple detection by Virgo and LIGO

August 14, 2017 three detectors observed BBH. Initial black holes were 31 and 25 solar mass, while the final black hole featured 53 solar masses. About 3 solar mass radiated as pure GWs

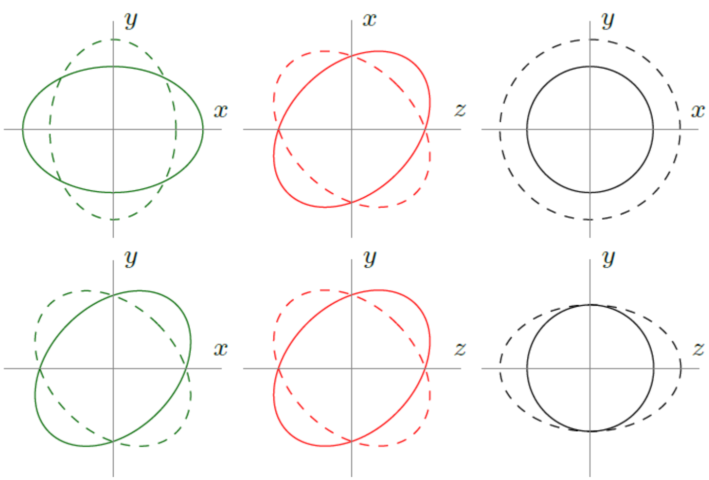


Polarization of gravitational waves

Polarization is a fundamental property of spacetime. It determined how spacetime can be deformed. General metric theories allow six polarizations. General Relativity allows two (tensor) polarizations

GR only allows (T) polarizations

General metric theories also know vector (V) and scalar (S) polarizations



Theory	+	x	x	y	b	l
General Relativity	allowed	allowed	forbidden	forbidden	forbidden	forbidden
GR in noncompactified 4/6D Minkowski	allowed	allowed	allowed	allowed	allowed	allowed
Einstein-Æther	allowed	allowed	allowed	allowed	allowed	allowed
5D Kaluza-Klein	allowed	allowed	allowed	allowed	allowed	forbidden
Randall-Sundrum braneworld	allowed	allowed	forbidden	forbidden	forbidden	forbidden
Dvali-Gabadadze-Porrati braneworld	allowed	allowed	depends	depends	depends	depends
Brans-Dicke	allowed	allowed	forbidden	forbidden	allowed	allowed
f(R) gravity	allowed	allowed	forbidden	forbidden	allowed	allowed
Bimetric theory	allowed	allowed	allowed	allowed	allowed	allowed
Four-Vector Gravity	forbidden	forbidden	allowed	allowed	forbidden	forbidden

Nishizawa et al., Phys. Rev. D 79, 082002 (2009) [except G4v & Einstein-Æther].

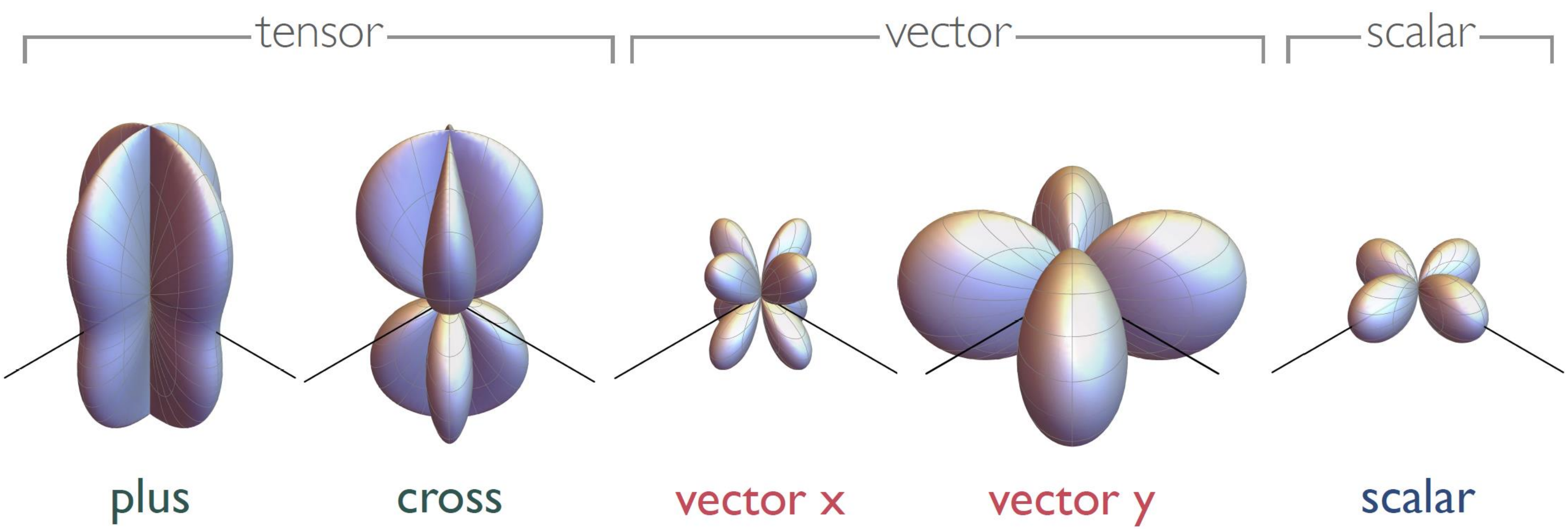
allowed / depends / forbidden

First test of polarizations of gravitational waves

According to Einstein's General Relativity there exist only two polarizations. General metric theories of gravity allow six polarizations. GW170814 confirms Einstein's prediction

Angular dependence (antenna-pattern) differs for T, V, S

LIGO and Virgo have different antenna-patterns
This allows for a fundamental of the polarizations of spacetime



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tensor vector scalar

Our analysis favors tensor polarizations in support of General Relativity

Our data favor tensor structure over vector by about a (Bayes) factor 200
And tensor over scalar by about a factor 1000

This is a first test, and for BBH we do not know the source position very well

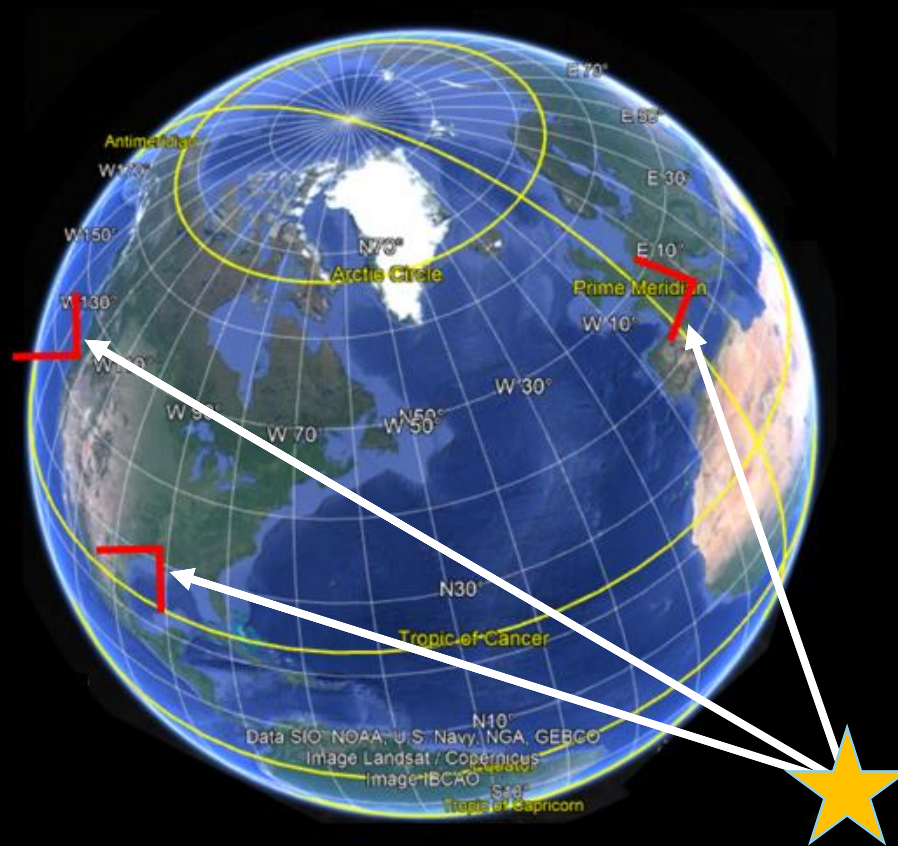
Virgo allowed source location via triangulation

GW170817 first arrived at Virgo, after 22 ms it arrived at LLO, and another 3 ms later LLH detected it

Virgo, Cascina, Italy

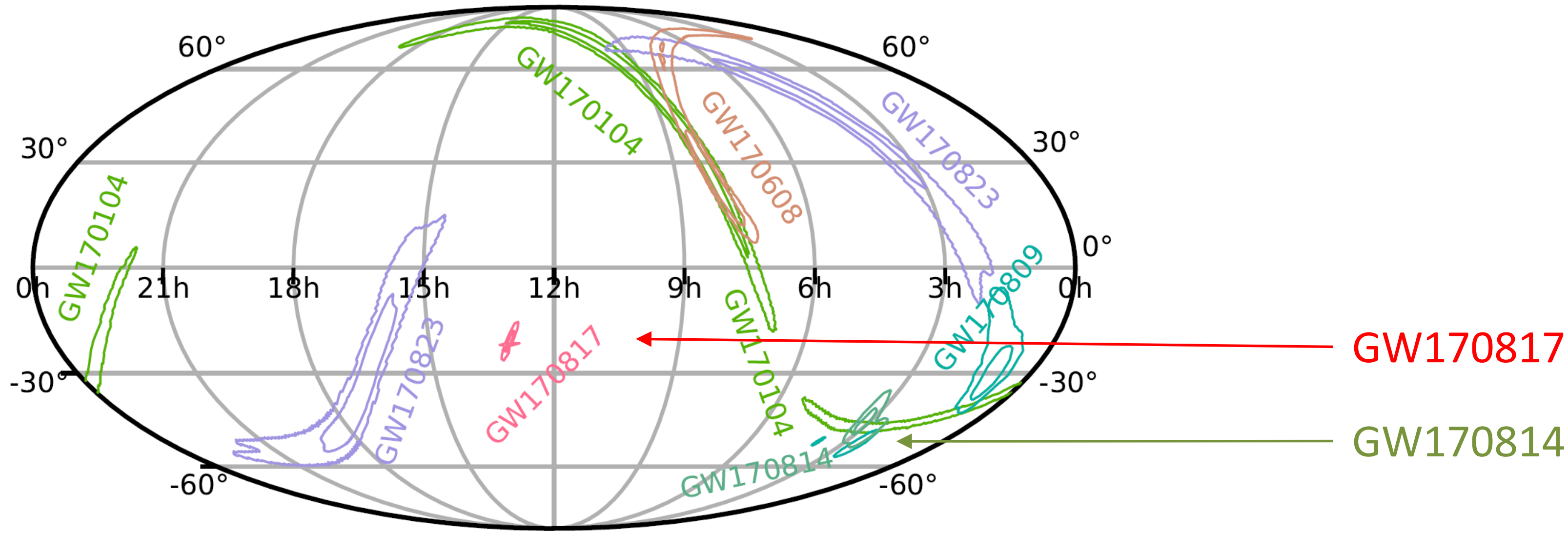
LIGO, Livingston, LA

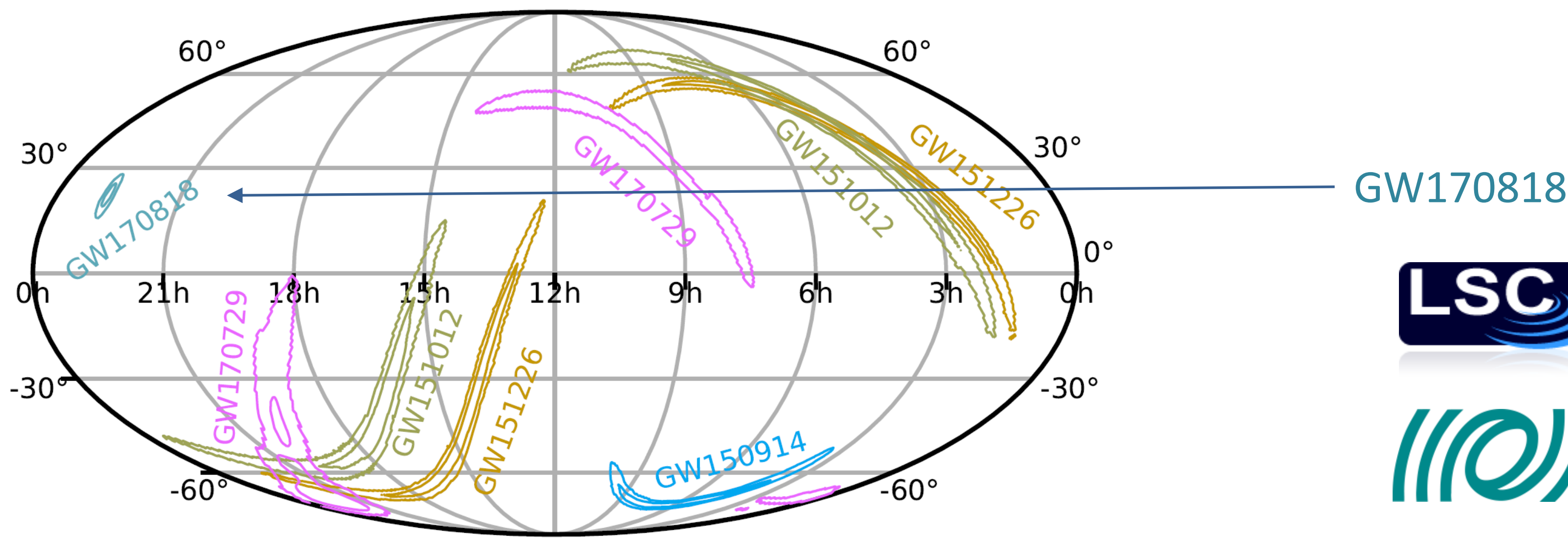
LIGO, Hanford, WA



Distributed skymaps

See https://dcc.ligo.org/LIGO-G1801864





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, primordial, no-hair
Black hole mimickers, 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, stochastic background

Nuclear physics

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

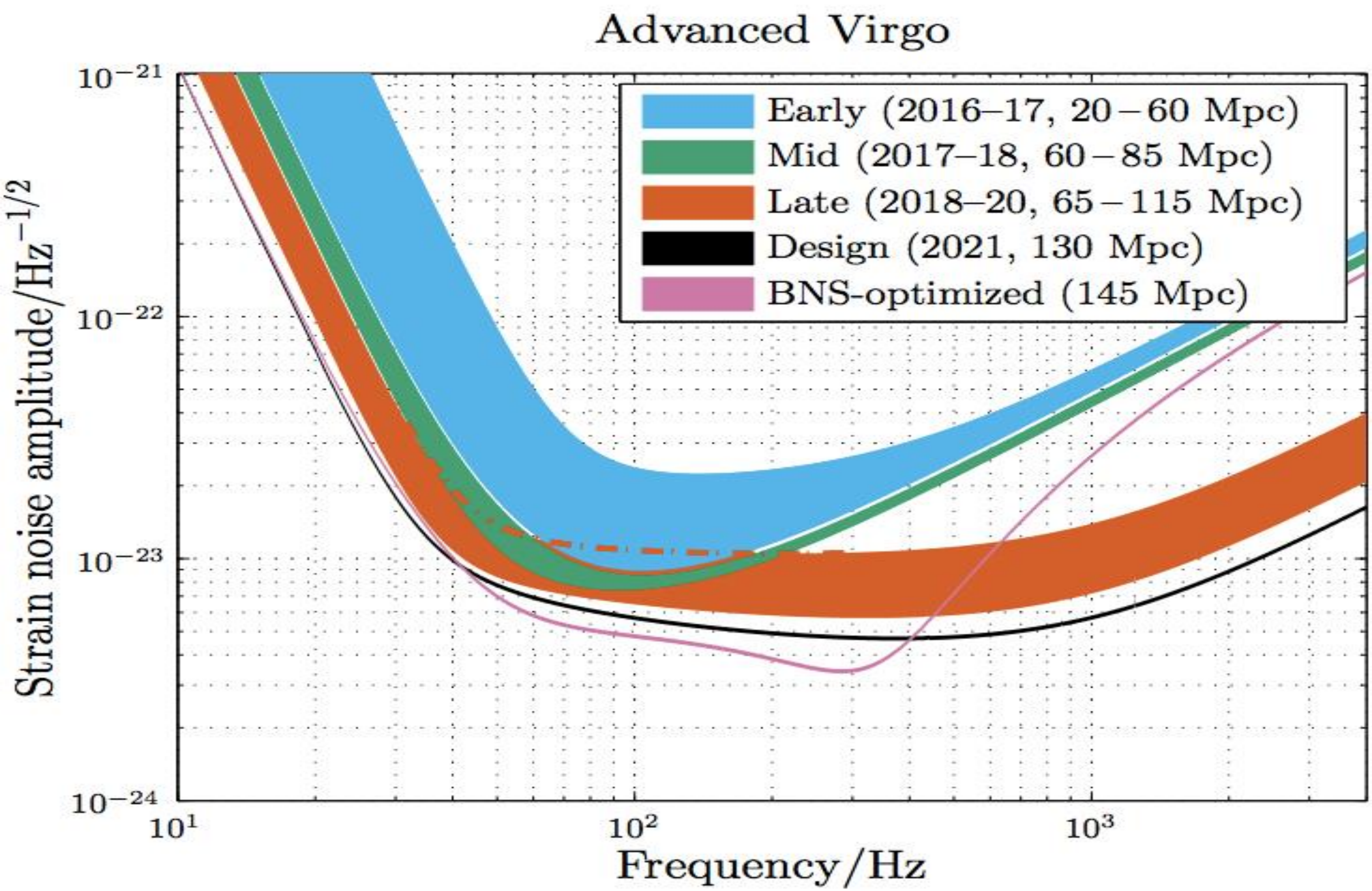
LVC will be back with improved instruments to start the next observation run (O3) early this year

Advanced Virgo

Commissioning

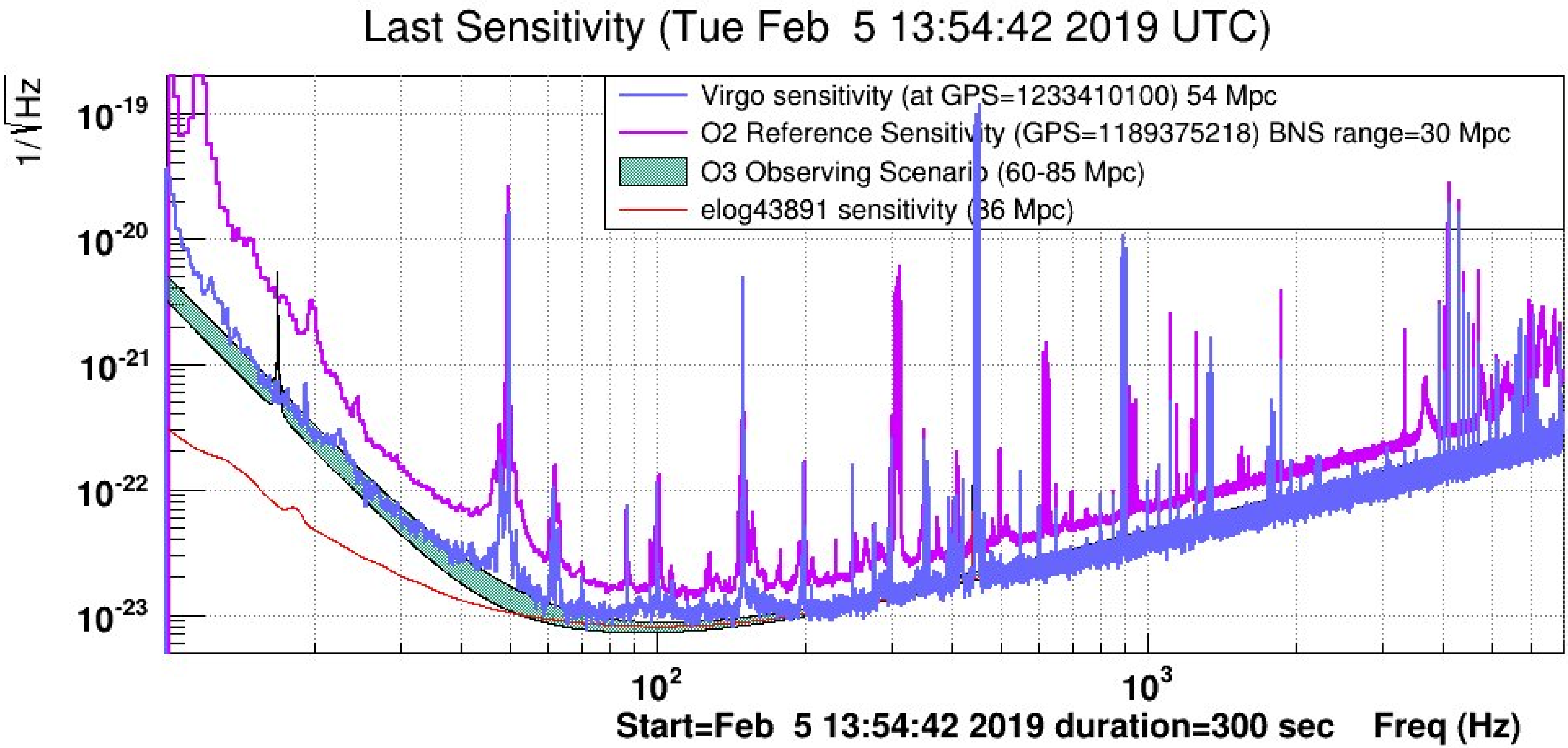
Projected sensitivity evolution for Virgo

From the 2013 ‘‘Observing Scenario’’, arXiv:1304.0670. We projected at least 60 Mpc for O3.
Note that LIGO aims at > 120 Mpc



Virgo sensitivity: significant improvement wrt O2

Comparison to the best sensitivity obtained in O2. Monolithic suspensions are now installed
Flat noise contribution in mid-frequency range, and significant 50 Hz noise

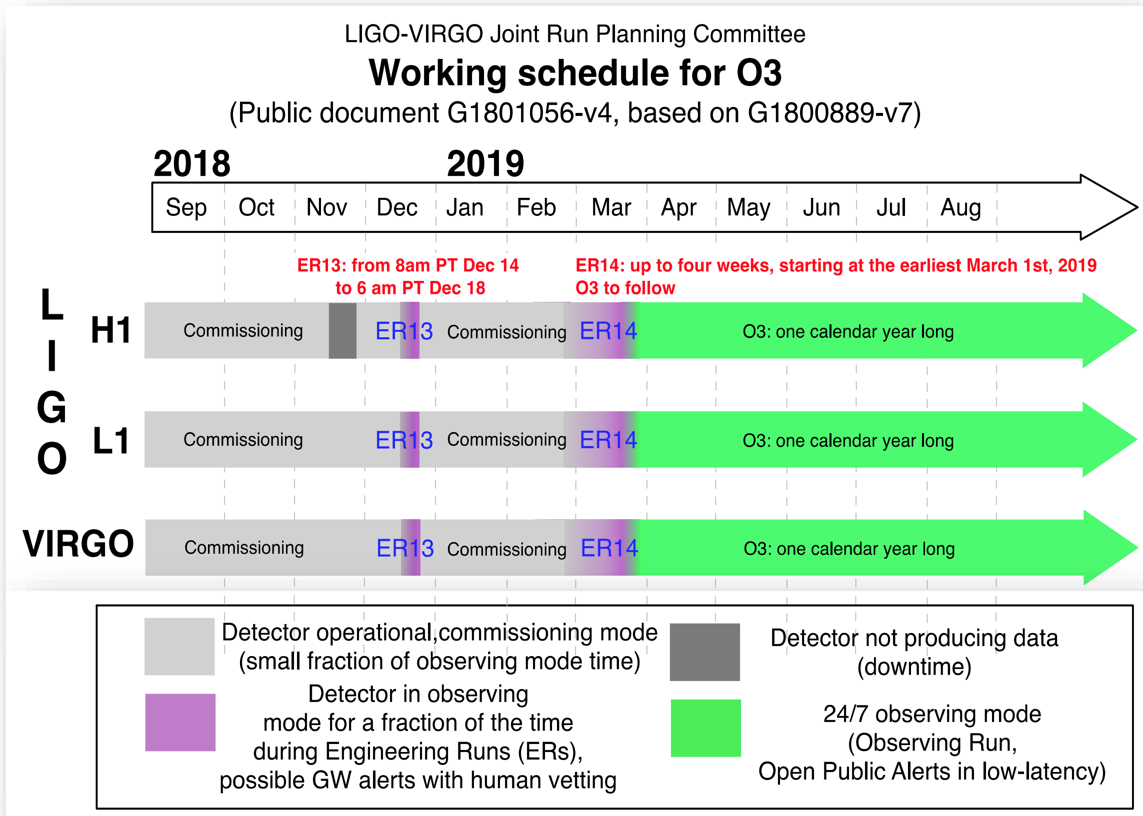


Engineering runs and next observation run

LIGO and Virgo scheduled ER13 and ER14 engineering runs to prepare for observation run O3

ITF input power 18 W

- ER13 (4 days) just completed
- ER14 (4 weeks) starts around March 1, 2019
- O3 begins in April 2019

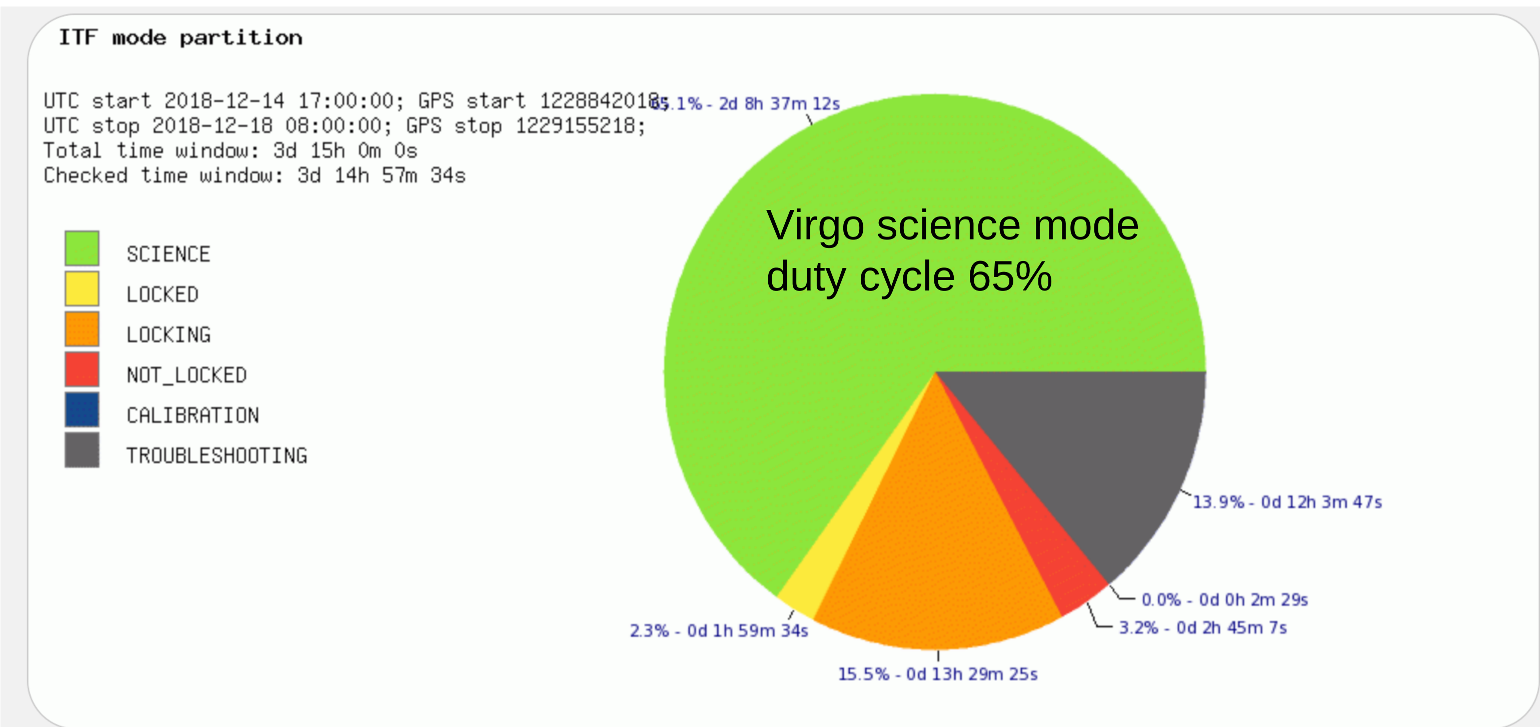


Engineering run ER13

ER13 lasted from December 14 – 18, 2018

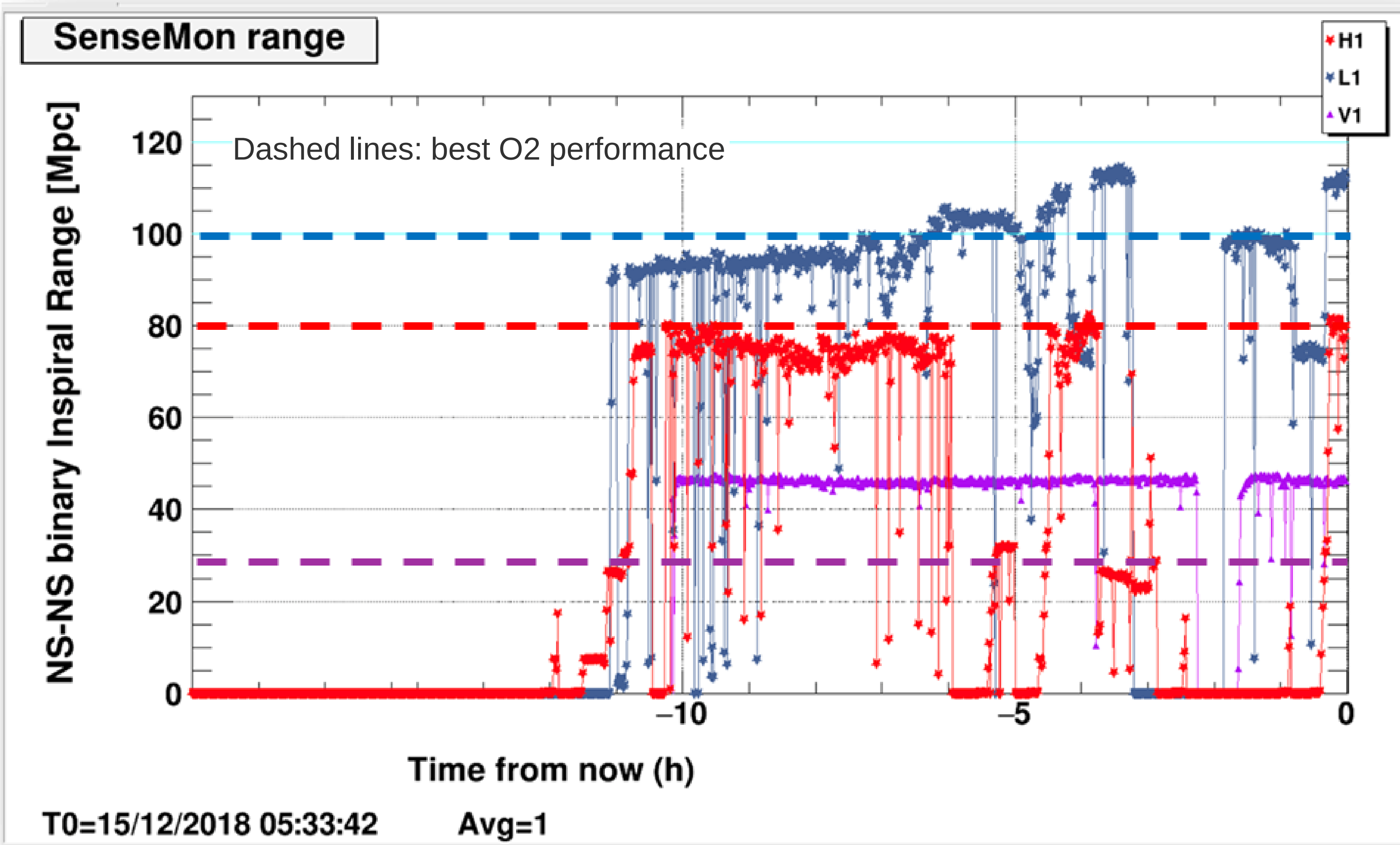
Goals of ER13

- End-to-end test of the Open Public Alert (OPA) software
- Rapid Response Team (RRT) exercise
- Test of new Data Quality Reporting on online data



Engineering run ER13

Comparison to the best sensitivity obtained in O2

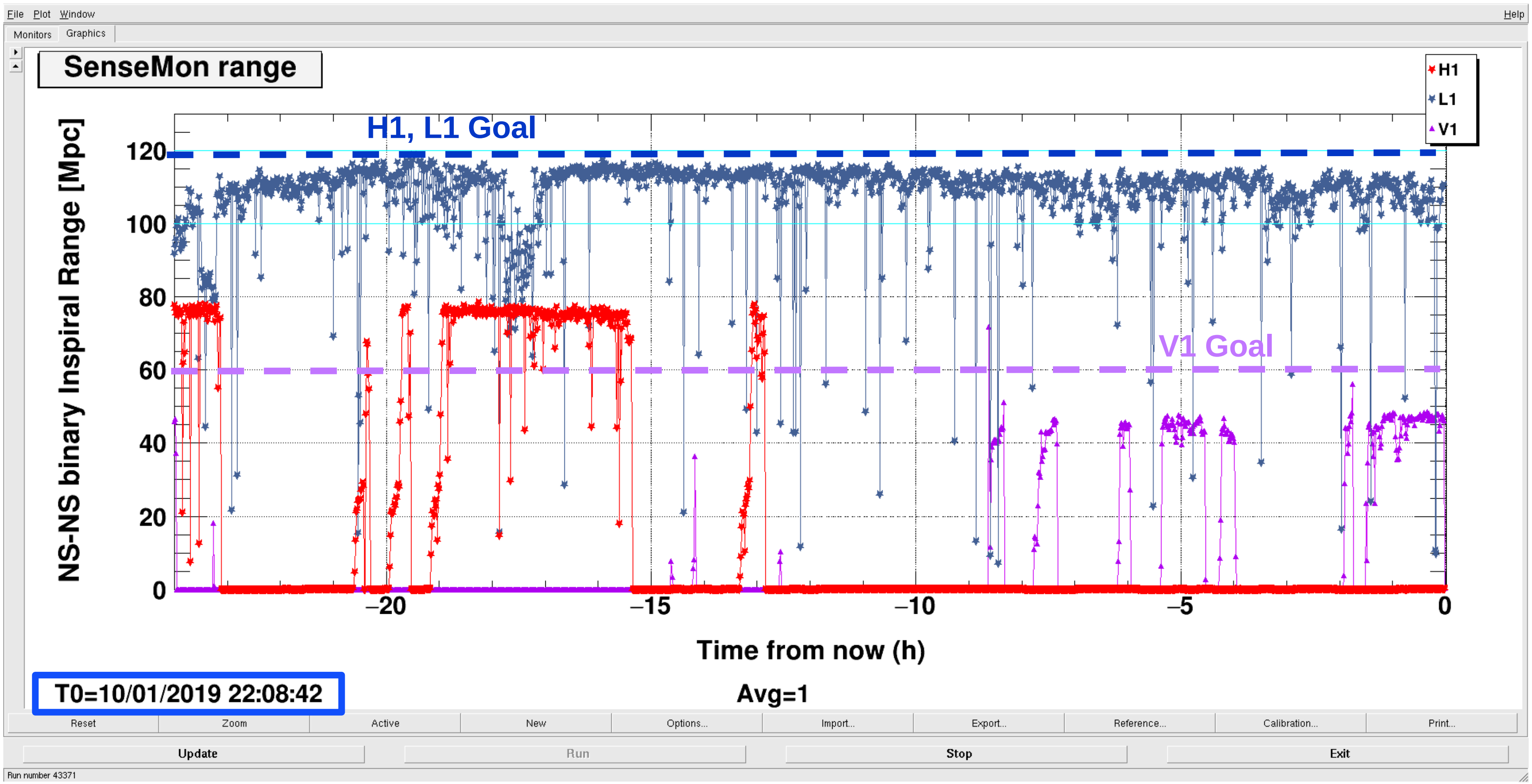


Engineering run ER13

Comparison to goals set for O3

Virgo aims at BNS range > 60 Mpc

- Commissioning in progress. Also at LIGO

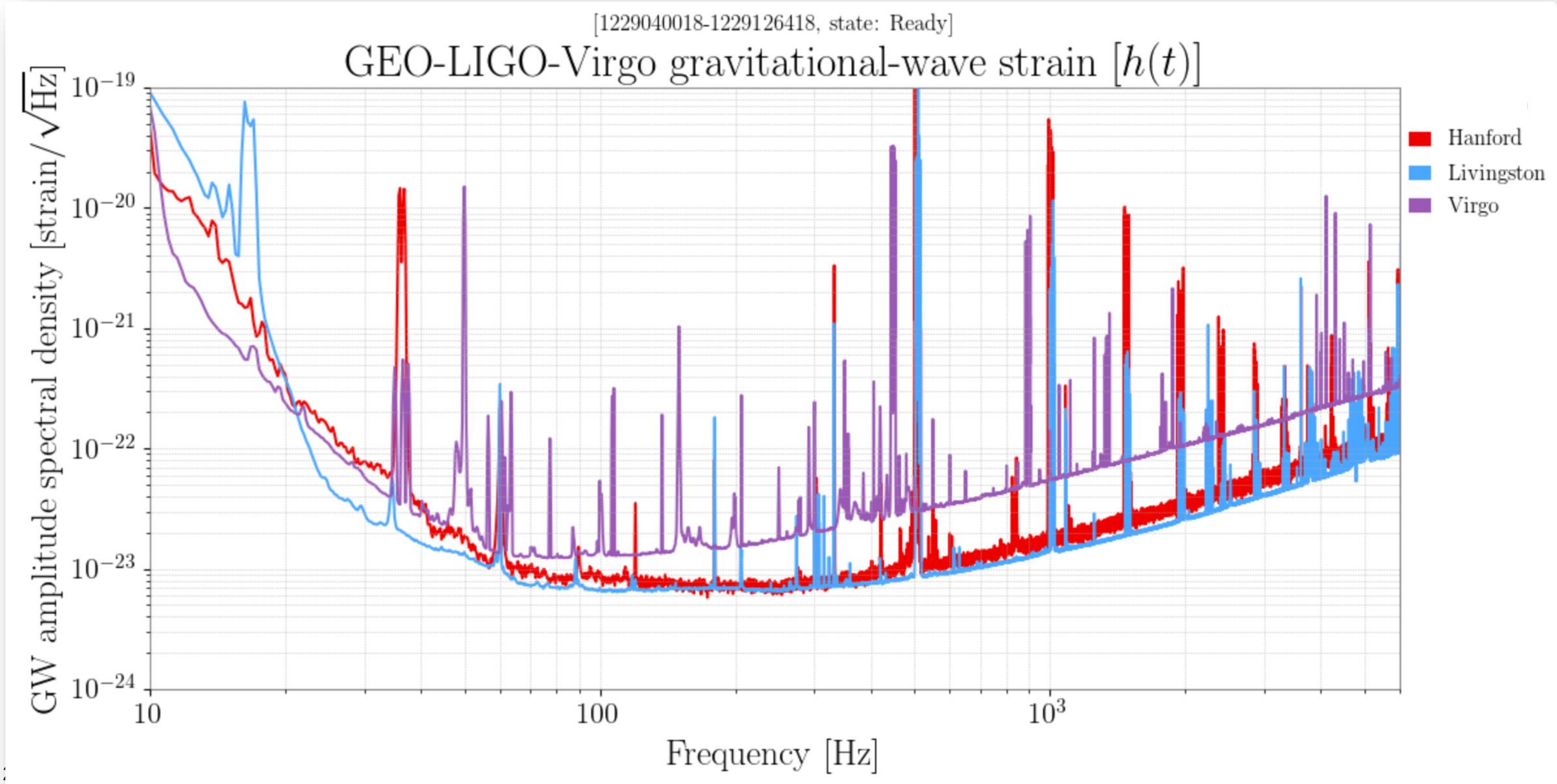


Virgo will implemented signal recycling after O3

Comparison to L1 and H1

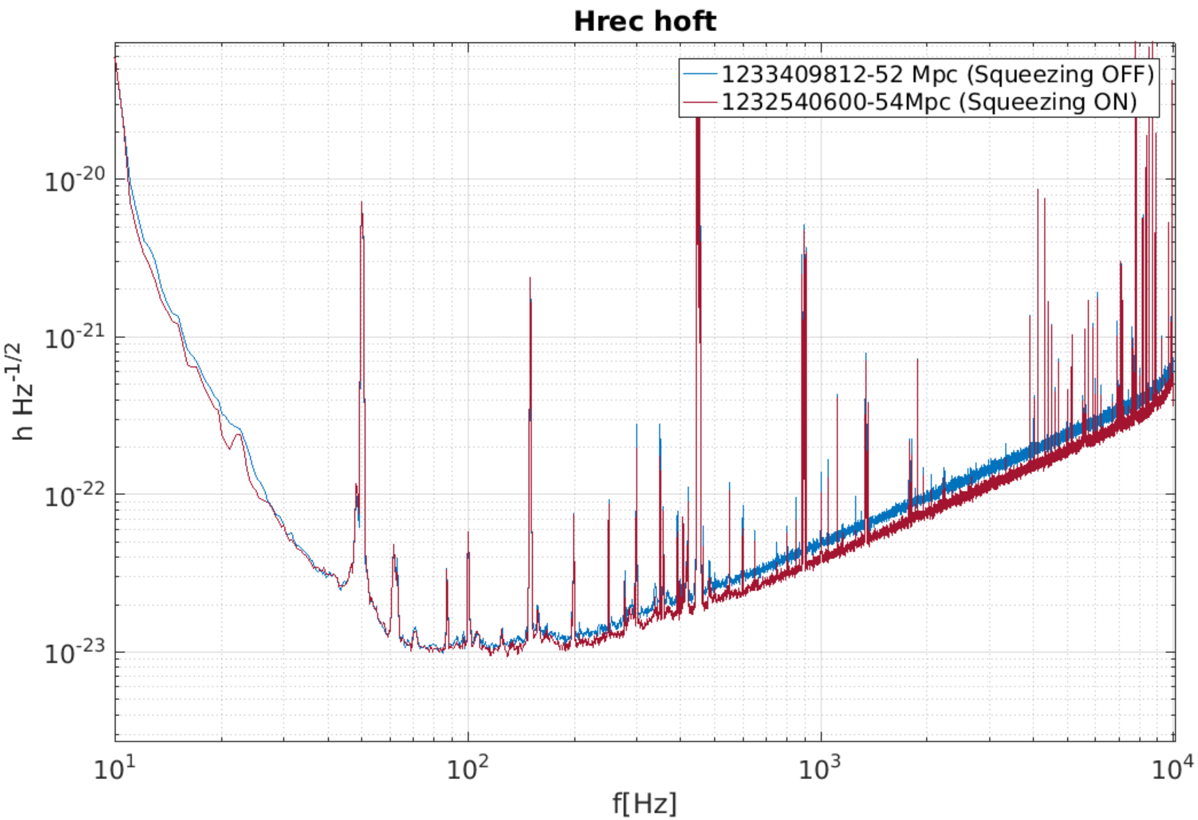
Virgo's strain sensitivity

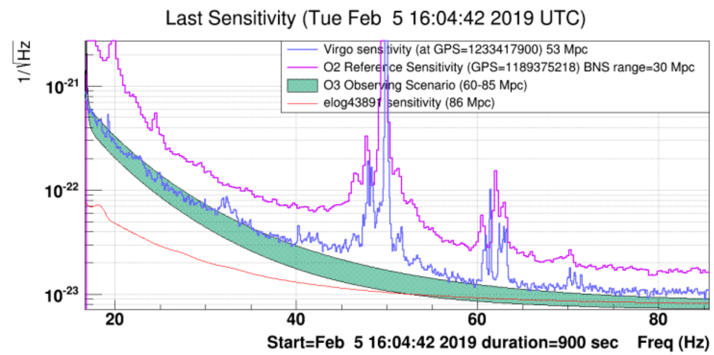
- Effect of no signal recycling is apparent. Also injected laser power 18 W, no squeezing, 3 km, …

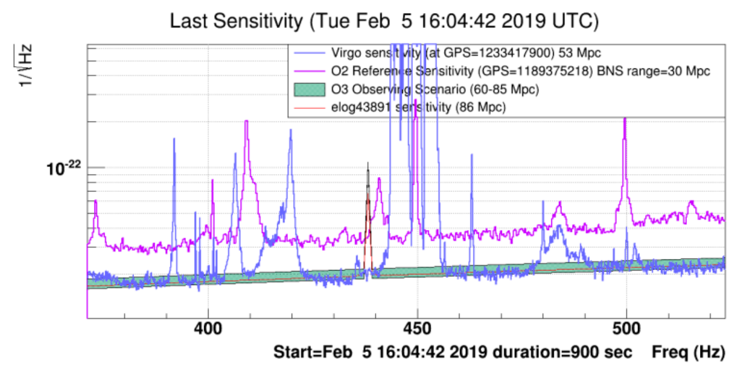


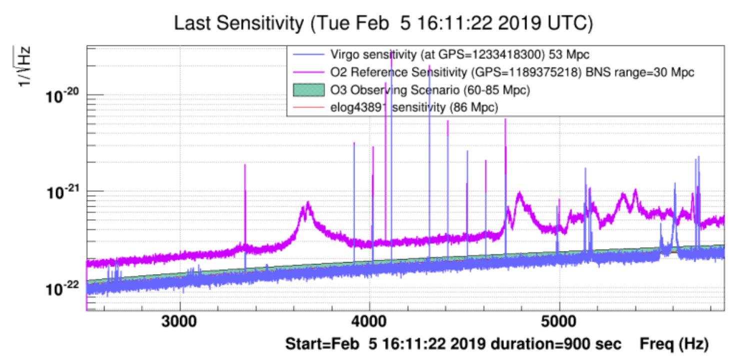
Virgo's best sensitivity so far

Sensitivity (BNS range) has now reached 55 Mpc. Further improvements are explored: implement squeezing, reduce 50 Hz noise, and/or reduce "flat" noise contribution









Squeezing

The AEI squeezer installed in Virgo's DET lab. Squeezer can deliver up to 14 dB of squeezed light

Squeezer connected with electronics, and operating: same squeezing level obtained as in Hannover
Set up external bench (telescopes,...), replaced in-vacuum Faraday isolator, alignment and commissioning

Squeezing

Implementation of frequency independent squeezing is underway

Main activities

Significant priority since October 2018

Completed hardware installation: injection 10 dB and expected losses = 40% (see VIR-0745A-18)

+10% (technical noise) = 50%

Set up and optimize control loops: coherent control and automatic alignment

Mitigation of back-scattered light

Preliminary results

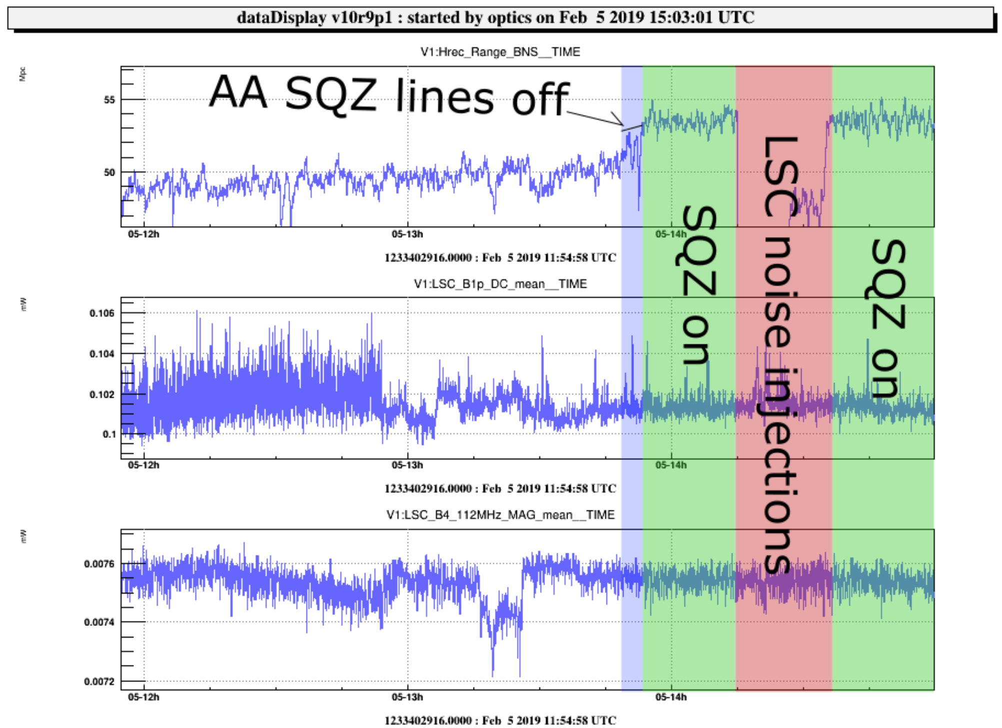
Measured a peak SQZ injection of almost 2 dB

(3 dB is our O3 target)

BNS range improvement of 2-3 Mpc to 55 Mpc

Inferred losses 60-70%

Need to improve stability



Commissioning has the highest priority

Main objective
Identify technical noise contributions at mid frequency

Carry out a *systematic* study to identify technical performance. Identify tests, interpret test results, generate ideas for new tests. Rapid turn around with help of PhD students, postdocs

Current candidate: working point of ITF

Full priority over all other ITF activities: CC sets priority

Meetings: dedicated discussions tagged on to weekly Commissioning and Detchar meetings

Wiki to list status and progress: https://wiki.virgo-gw.eu/Commissioning/FlatNoise

Parallel activities
Electronics to achieve improved 50 Hz robustness is under preparation

System to discharge mirrors is under investigation

Focus on stability

Reliability and risk reduction

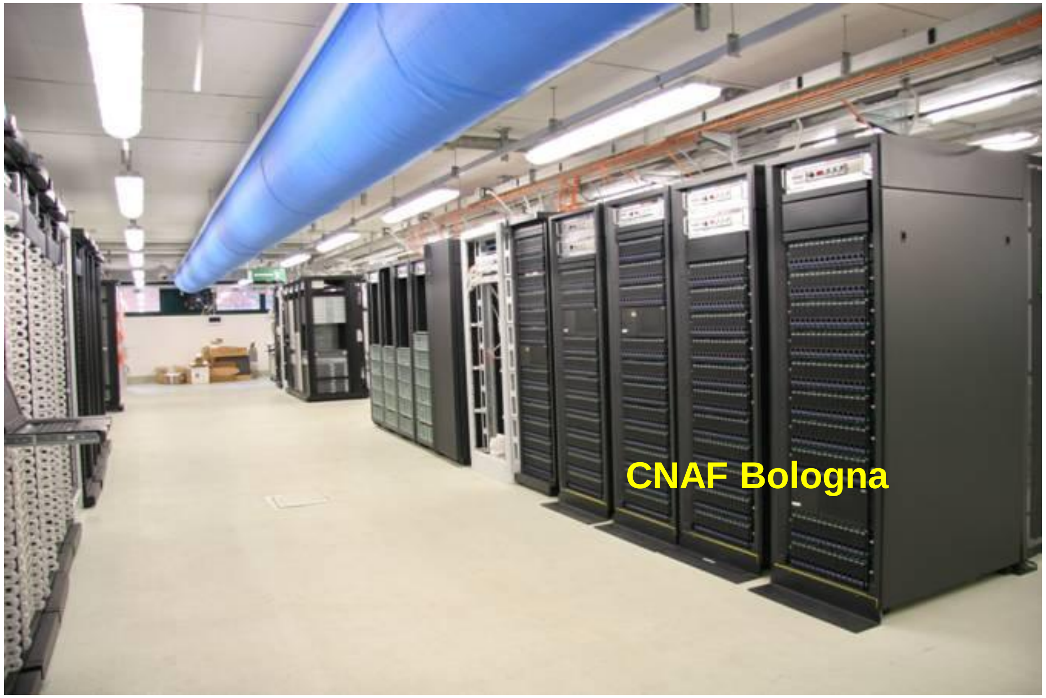
Virgo Computing and Data Processing

Virgo Computing and offline Data processing

Recent developments and boundary conditions

Computing situation for LVC is becoming a bottleneck

- Virgo is making an effort to increase its contribution to LVC computing resources for DA
- Recent focus on LV Continuous Wave analysis
- Note that all O2 data will become public in February 2019



Advanced Virgo

Virgo Computing and Data Processing

VSC agreed (August 29, 2018) to implement a new Virgo CDP subsystem (supersede VDAS). New structure is also recommended by ECC

New organization

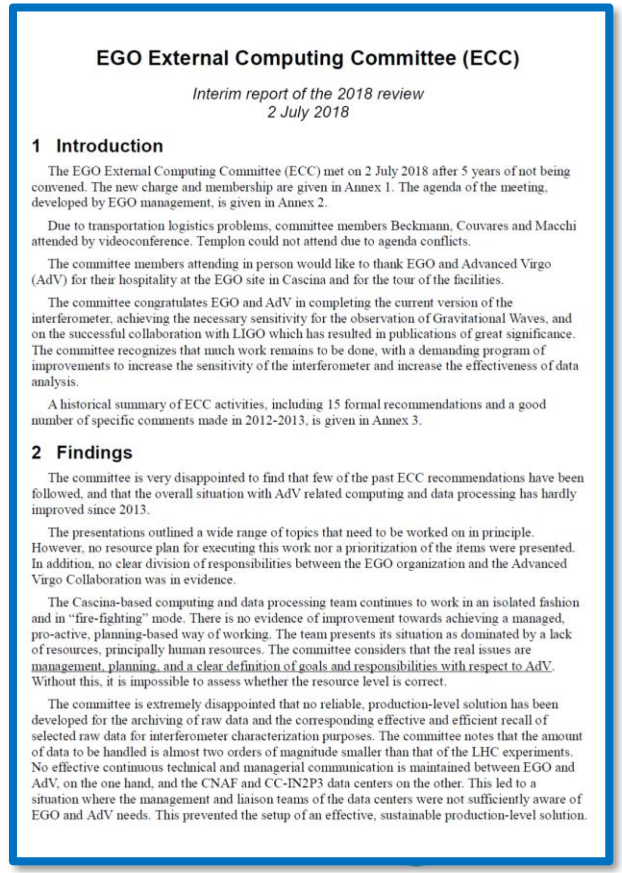
- Local computing and low latency computing
- Offline computing management

Management

- DPI: EGO-Virgo Data Processing Infrastructure coordinator
- CDP: Virgo Computing and Data Processing coordinator

Scope

- DPI and CDP will work closely with other coordinators (DAQ and DA)
- Report to EGO Director and Virgo Spokesperson



EGO External Computing Committee (ECC)

Interim report of the 2018 review
2 July 2018

1 Introduction

The EGO External Computing Committee (ECC) met on 2 July 2018 after 5 years of not being convened. The new charge and membership are given in Annex 1. The agenda of the meeting, developed by EGO management, is given in Annex 2.

Due to transportation logistics problems, committee members Beckmann, Couvares and Macchi attended by videoconference. Templon could not attend due to agenda conflicts.

The committee members attending in person would like to thank EGO and Advanced Virgo (AdV) for their hospitality at the EGO site in Cascina and for the tour of the facilities.

The committee congratulates EGO and AdV in completing the current version of the interferometer, achieving the necessary sensitivity for the observation of Gravitational Waves, and on the successful collaboration with LIGO which has resulted in publications of great significance. The committee recognizes that much work remains to be done, with a demanding program of improvements to increase the sensitivity of the interferometer and increase the effectiveness of data analysis.

A historical summary of ECC activities, including 15 formal recommendations and a good number of specific comments made in 2012-2013, is given in Annex 3.

2 Findings

The committee is very disappointed to find that few of the past ECC recommendations have been followed, and that the overall situation with AdV related computing and data processing has hardly improved since 2013.

The presentations outlined a wide range of topics that need to be worked on in principle. However, no resource plan for executing this work nor a prioritization of the items were presented. In addition, no clear division of responsibilities between the EGO organization and the Advanced Virgo Collaboration was in evidence.

The Cascina-based computing and data processing team continues to work in an isolated fashion and in "fire-fighting" mode. There is no evidence of improvement towards achieving a managed, pro-active, planning-based way of working. The team presents its situation as dominated by a lack of resources, principally human resources. The committee considers that the real issues are management, planning, and a clear definition of goals and responsibilities with respect to AdV. Without this, it is impossible to assess whether the resource level is correct.

The committee is extremely disappointed that no reliable, production-level solution has been developed for the archiving of raw data and the corresponding effective and efficient recall of selected raw data for interferometer characterization purposes. The committee notes that the amount of data to be handled is almost two orders of magnitude smaller than that of the LHC experiments. No effective continuous technical and managerial communication is maintained between EGO and AdV, on the one hand, and the CNAF and CC-IN2P3 data centers on the other. This led to a situation where the management and liaison teams of the data centers were not sufficiently aware of EGO and AdV needs. This prevented the setup of an effective, sustainable production-level solution.

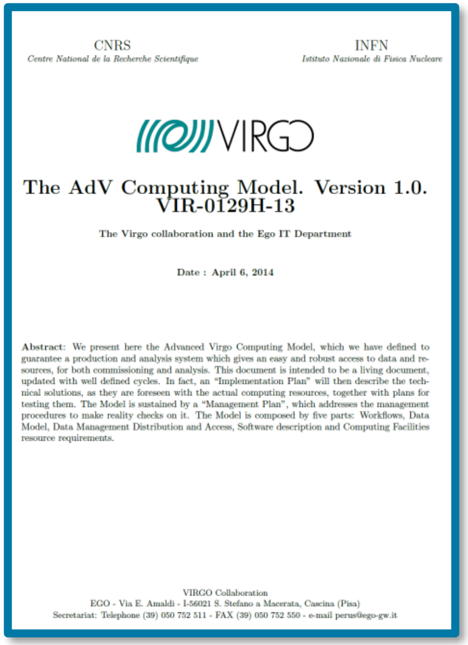
Project deliverables

WBS and Projects with clear deliverables have been defined. Resources have been allocated

CW: Complete LV data analyses on Continuous Waves and secure LVC publications

GstLAL: Allow most important CBC pipelines to run on European grid-computing resources. Start with GstLAL, but expand to other LV pipelines

LVC: I. Update VCDP Computing Model, Implementation Plan, and Management Plan (involve DA and CDP coordinators), and II. Prepare a strategy in collaboration with LSC and Computing Centers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VIRGO

The AdV Computing Model. Version 1.0. VIR-0129H-13

The Virgo collaboration and the Ego IT Department

Date : April 6, 2014

Abstract: We present here the Advanced Virgo Computing Model, which we have defined to guarantee a production and analysis system which gives an easy and robust access to data and resources, for both commissioning and analysis. This document is intended to be a living document, updated with well defined cycles. In fact, an "Implementation Plan" will then describe the technical solutions, as they are foreseen with the actual computing resources, together with plans for testing them. The Model is sustained by a "Management Plan", which addresses the management procedures to make reality checks on it. The Model is composed by five parts: Workflows, Data Model, Data Management Distribution and Access, Software description and Computing Facilities resource requirements.

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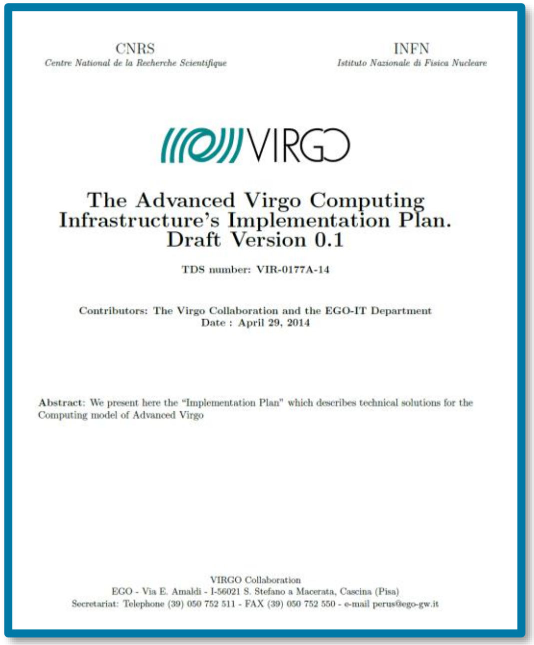
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VIRGO

The Advanced Virgo Computing Infrastructure's Implementation Plan. Draft Version 0.1

TDS number: VIR-0177A-14

Contributors: The Virgo Collaboration and the EGO-IT Department
Date : April 29, 2014

Abstract: We present here the "Implementation Plan" which describes technical solutions for the Computing model of Advanced Virgo

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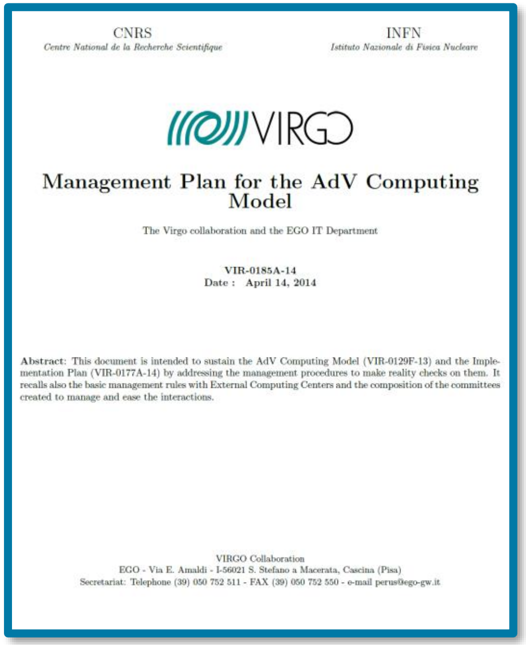
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VIRGO

Management Plan for the AdV Computing Model

The Virgo collaboration and the EGO IT Department

VIR-0185A-14
Date : April 14, 2014

Abstract: This document is intended to sustain the AdV Computing Model (VIR-0129F-13) and the Implementation Plan (VIR-0177A-14) by addressing the management procedures to make reality checks on them. It recalls also the basic management rules with External Computing Centers and the composition of the committees created to manage and ease the interactions.

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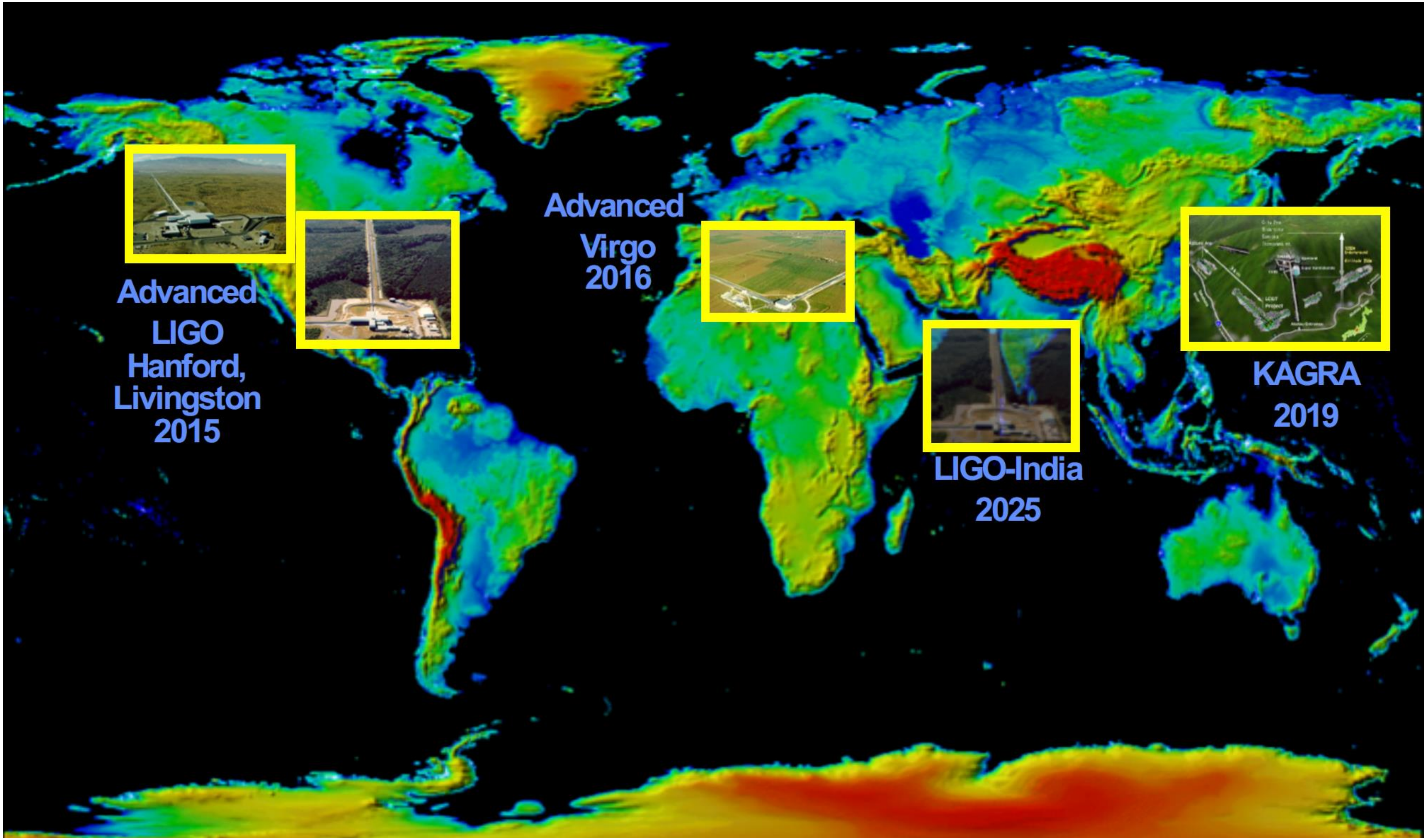
Advanced Virgo

What's next?

Towards a global network

KAGRA expected to join LIGO and Virgo in Observation run 3

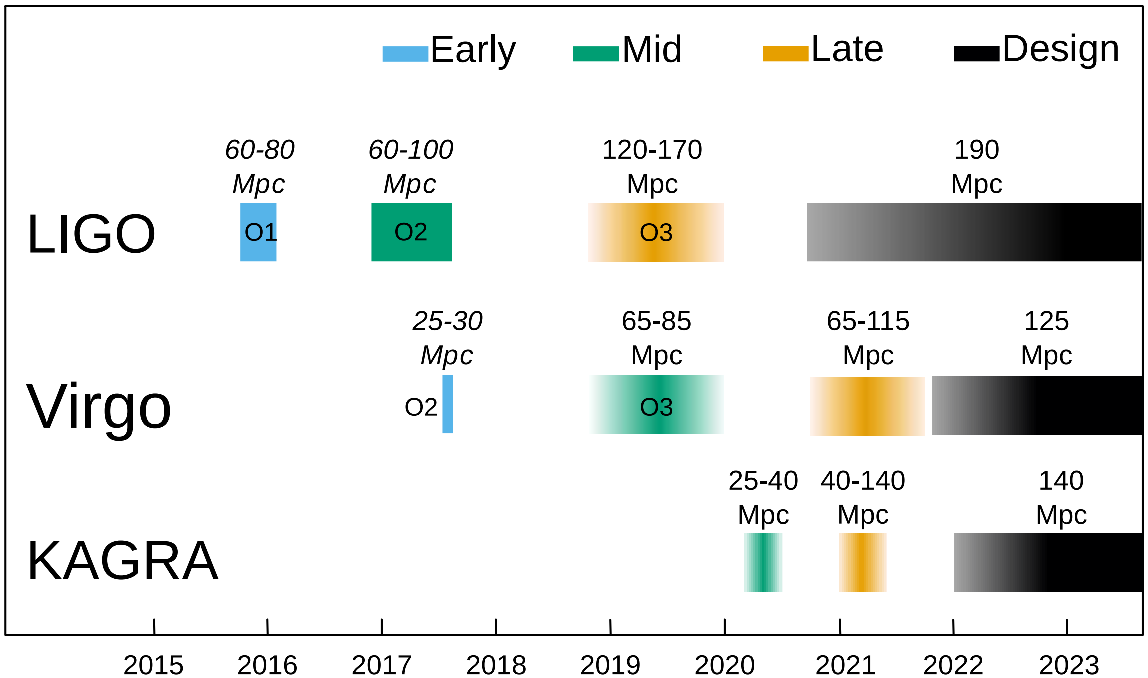


Planned observing timeline

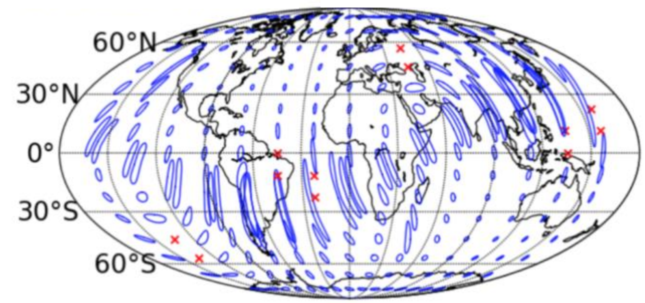
One-year O3 planned to start in April 2019 with about twice the sensitivity in O3 (thus about 2^3 in rate).
In O3 LIGO and Virgo will release Open Public Alerts

Observation run O3

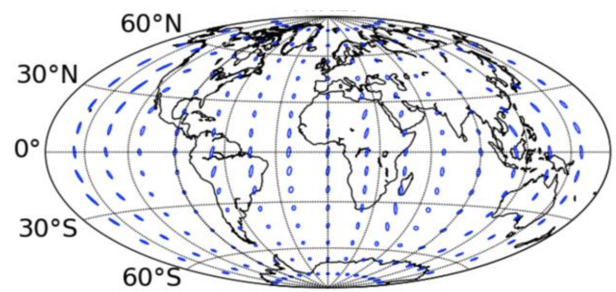
Three detectors and perhaps 1 event per week
KAGRA expected to join at the end of O3
Contribute to sky localization and PE



~20% in 20 sq deg HLV 2019



~60% in 10 sq deg HIKLV 2024



B. P. Abbott et al., *Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA*, 2016, Living Rev. Relativity 19

AdV+ as the next incremental step forward in sensitivity

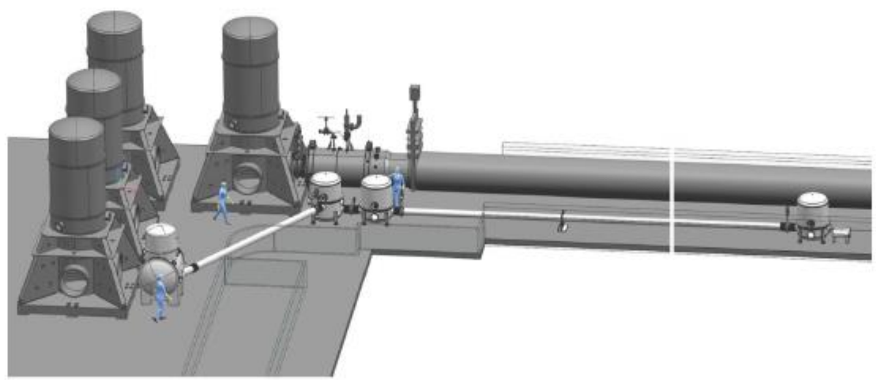
AdV+ is the plan to maximize Virgo's sensitivity within the constrains of the EGO site. It has the potential to increase Virgo's detection rate by up to an order of magnitude

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
- Attractive for 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



Phase I

Quantum noise will be tackled after the O3 science run in Phase 1: **installation in 2020**

Power increase

All in-fiber 200 W laser system for 125 W after the IMC

Foreseen as part of AdV

Tuned signal recycling: 120 Mpc

Install SR mirror

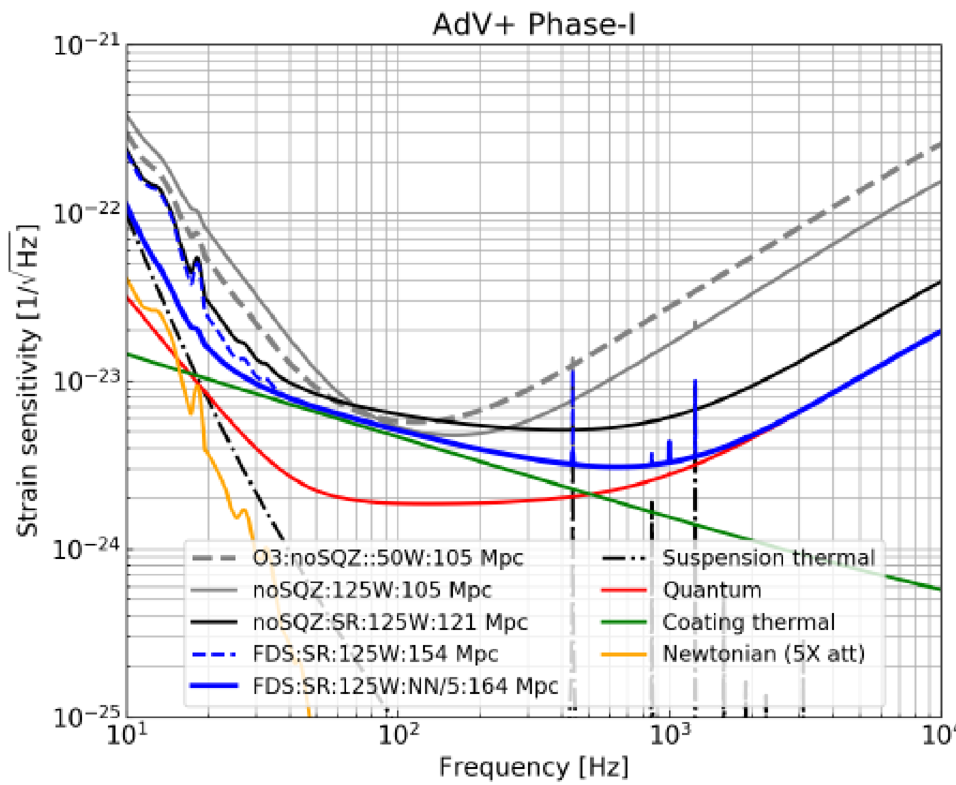
Control additional DOF (auxiliary lasers?)

Frequency dependent squeezing: 150 Mpc

Squeezed light source and filter cavity

Newtonian noise cancellation: 160 Mpc

Seismic sensor networks



Phase II

Reduce thermal noise: modify optical design of the Fabry-Perot arms to accommodate larger beams and heavier test masses

Larger mirrors

Diameter: 550 mm, thickness: 200 mm, mass: 105 kg

Scenario 1: ETM-only → 200 Mpc

Scenario 2: full upgrade → 230 Mpc

Coating research

Factor three reduction in CTN

Scenario 1: ETM-only → 260 Mpc

Scenario 2: full upgrade → 300 Mpc

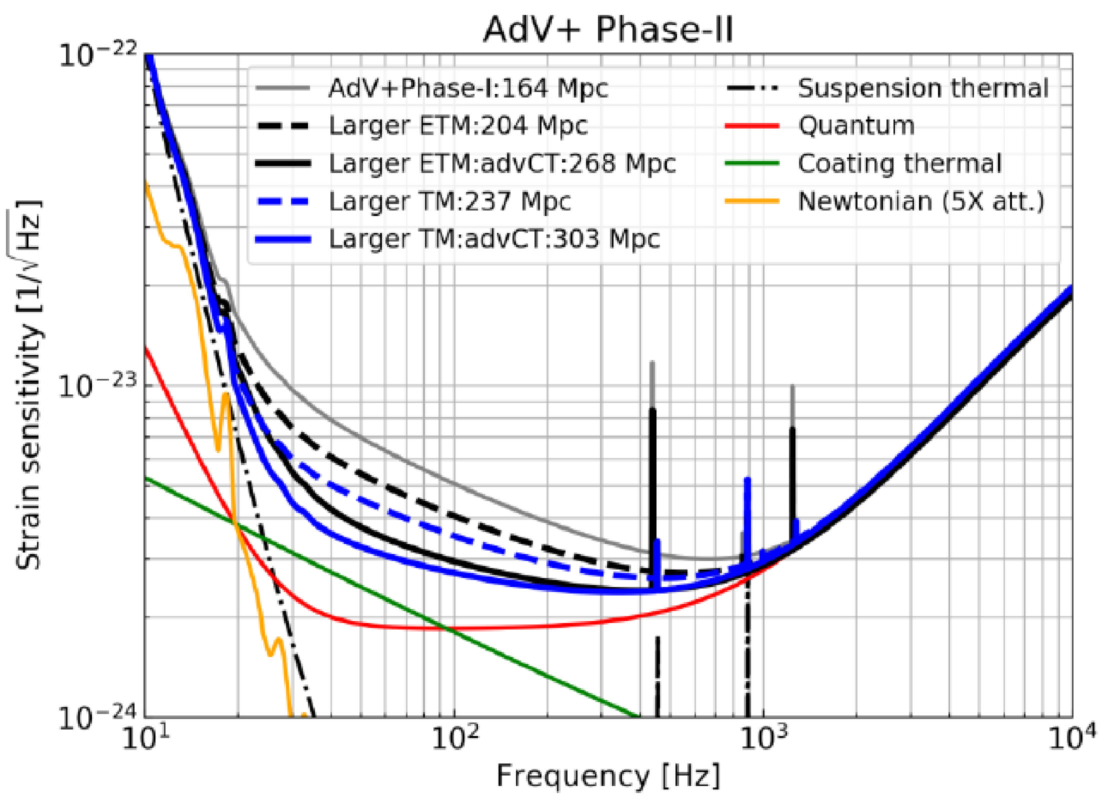
Grand Coater upgrade

Many activities

Vacuum, infrastructure

Payloads and superattenuators

Aberration control



FDS Conceptual Design Report

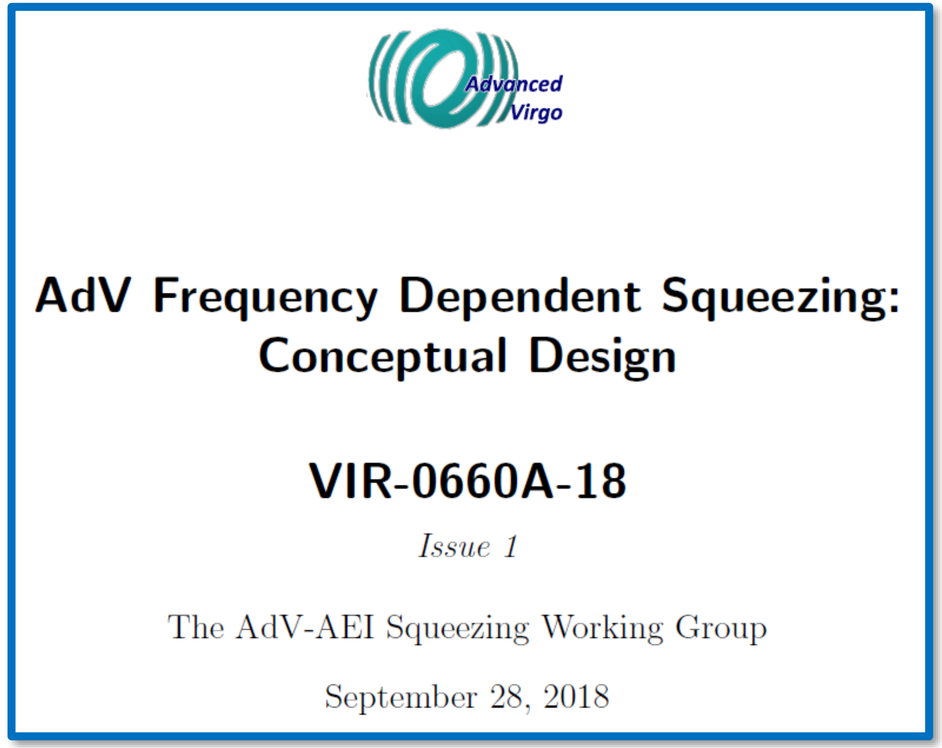
The AdV – AEI Squeezing Working Group prepared a Conceptual Design (transverse activity)

Optical loss, injection losses, noise tolerances
- Technical noise and phase noise
- Filter cavity: cavity length and finesse
- Stray light considerations

Infrastructure
- Overall layout
- Minitower and control microtower locations
- Cavity mirrors locations

Suspensions
- Optical benches and mirrors suspensions

Optics, optical layout, filter cavity mirrors
- OPO location
- Filter cavity control schemes
- Suspended bench optical links
- General layout
- In-air squeezed light source operation
- In-vacuum squeezed light source operation


Advanced Virgo

AdV Frequency Dependent Squeezing: Conceptual Design

VIR-0660A-18

Issue 1

The AdV-AEI Squeezing Working Group

September 28, 2018

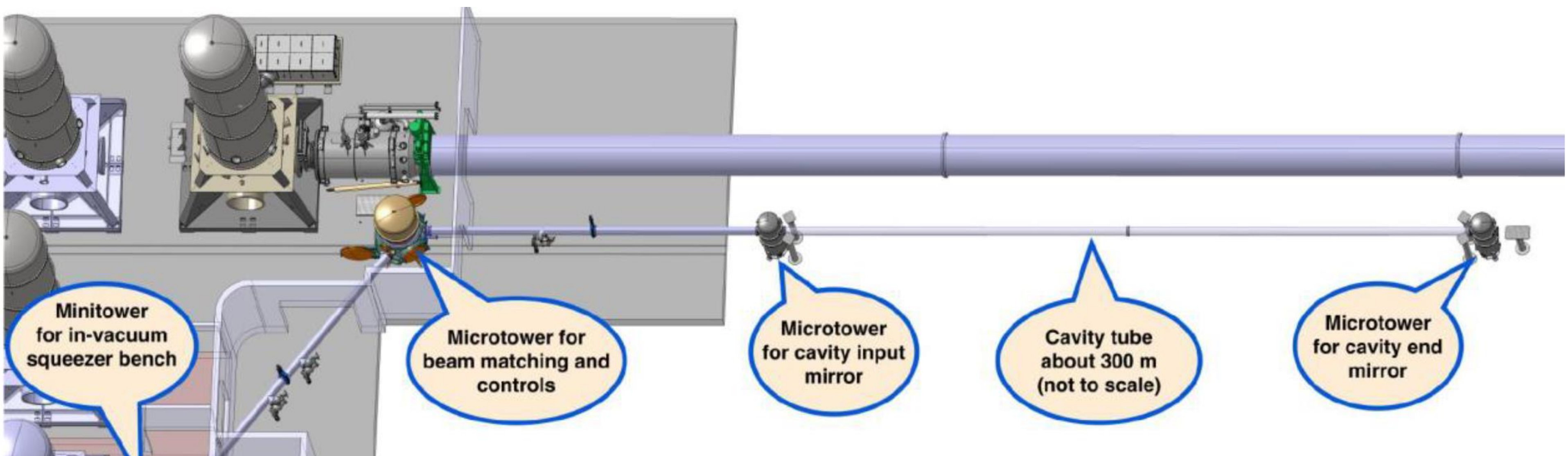
Frequency dependent squeezing in the post-O4 era: EPR-entanglement

FDS Project Breakdown Structure

PBS follows the hardware components (not a WBS)

Responsibilities for construction of items for AdV+ have been allocated

a) Optical design and preparations for FDS ongoing
b) Smart infrastructure (HVAC) for NNC: under discussion

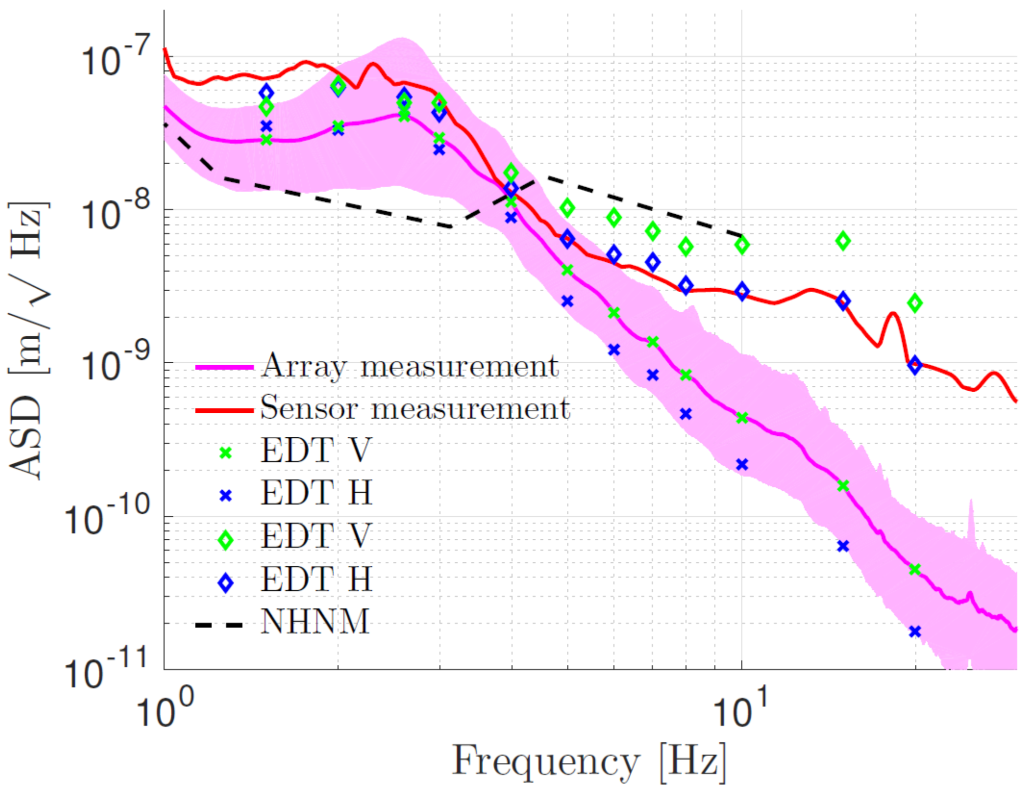


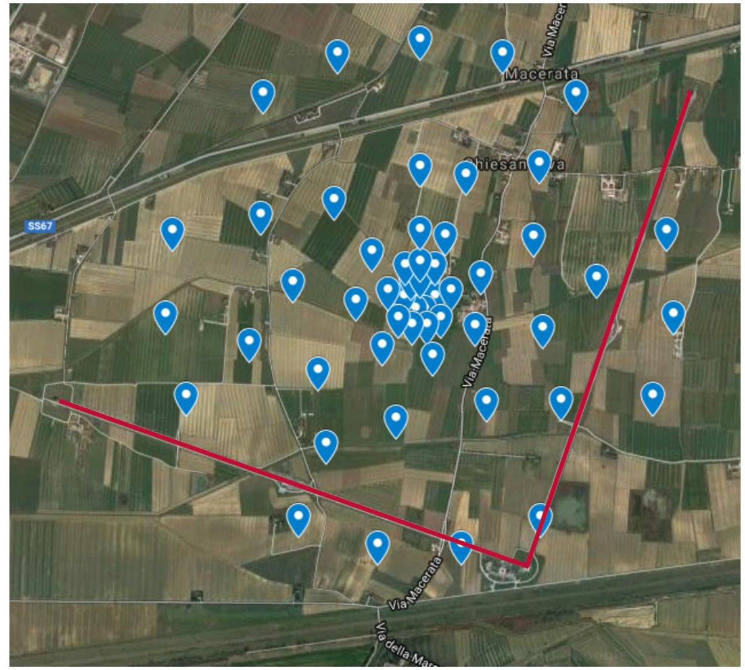
Virgo squeezer from AEI Hannover

Newtonian Noise Cancellation

Improvements to the infrastructure are expected to have a large impact

Noise at Central Building is about an order of magnitude higher than the noise in the vicinity of Virgo



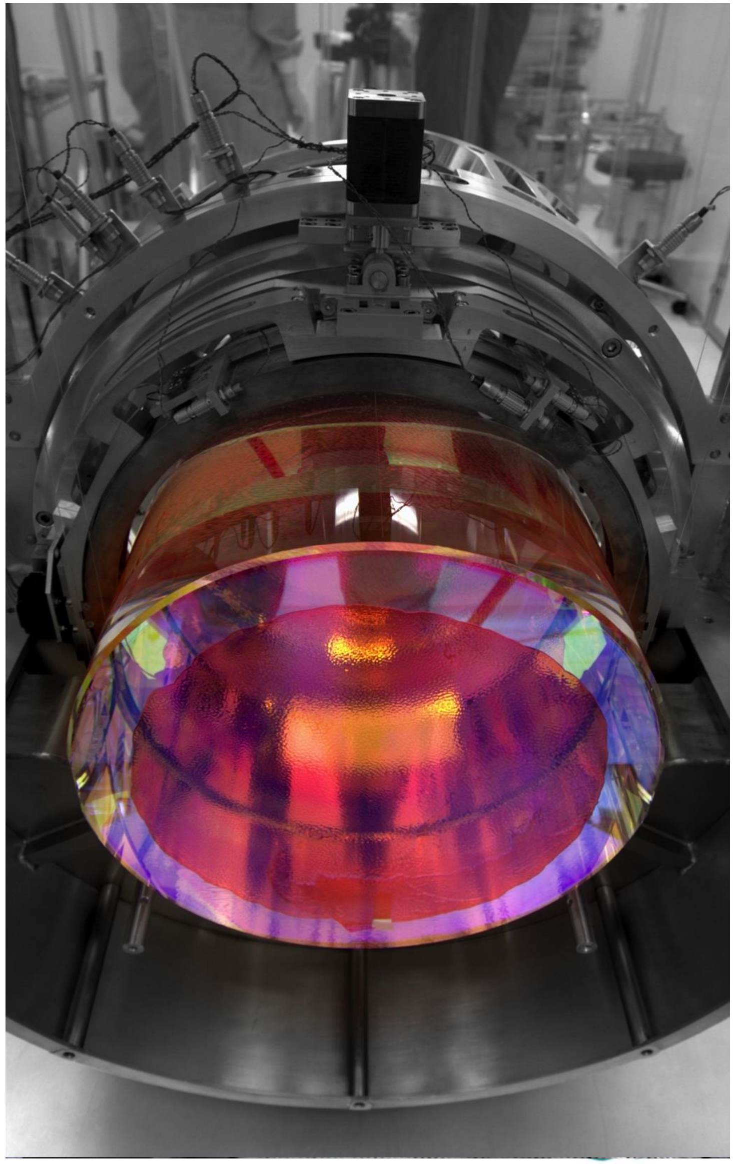


Need for emphasis on smart infrastructure for gravitational wave observatories

- Smart infrastructure design
- Newtonian noise modeling of infrastructure noise
- HVAC modification

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

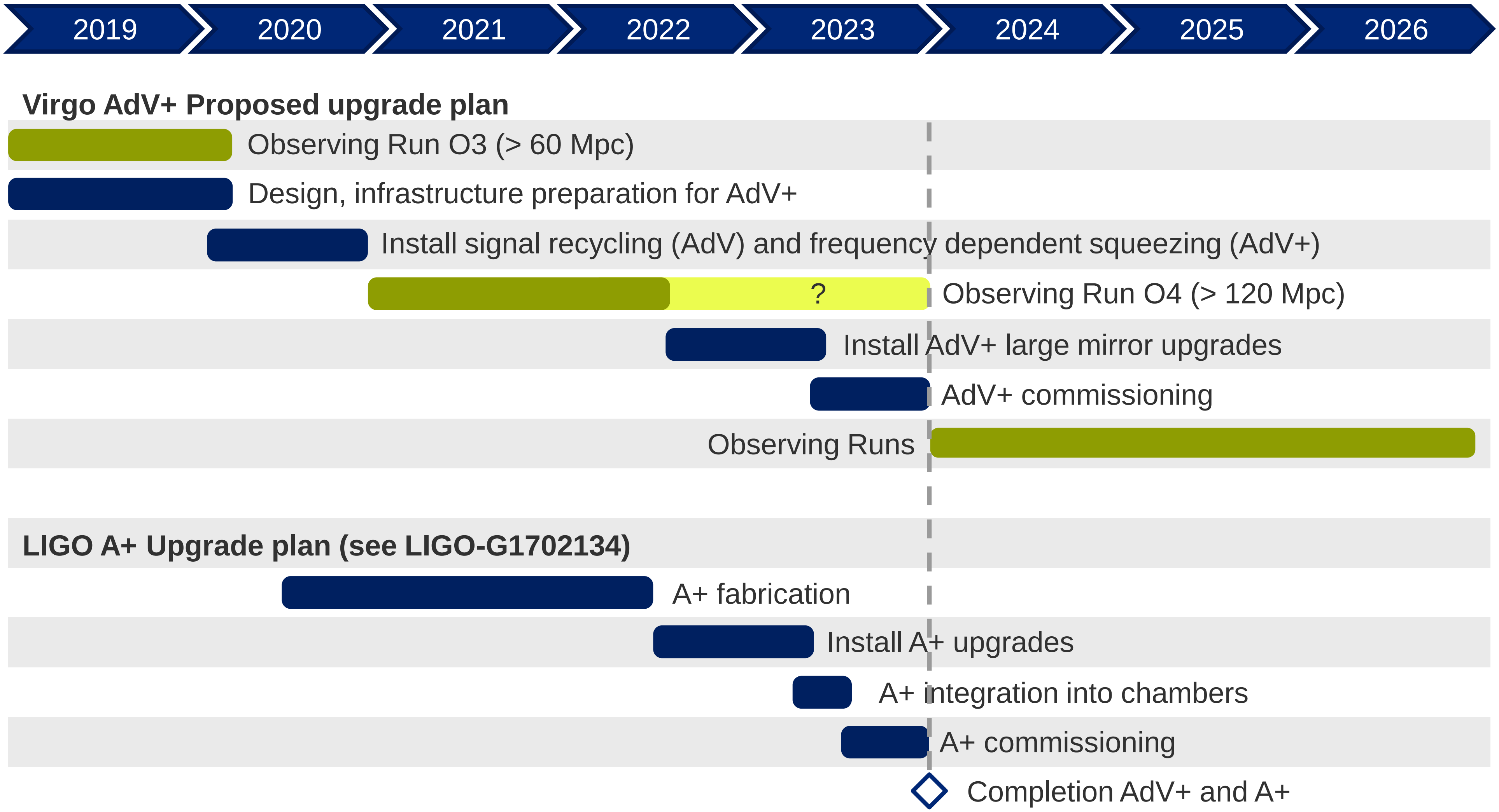
- Flatness < 0.5 nm rms over central 160 mm of mirrors by using ion beam polishing (robotic silica deposition was investigated)
- Ti:Ta_2O_5 and SiO_2 stacks with optical absorption about 0.3 ppm

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

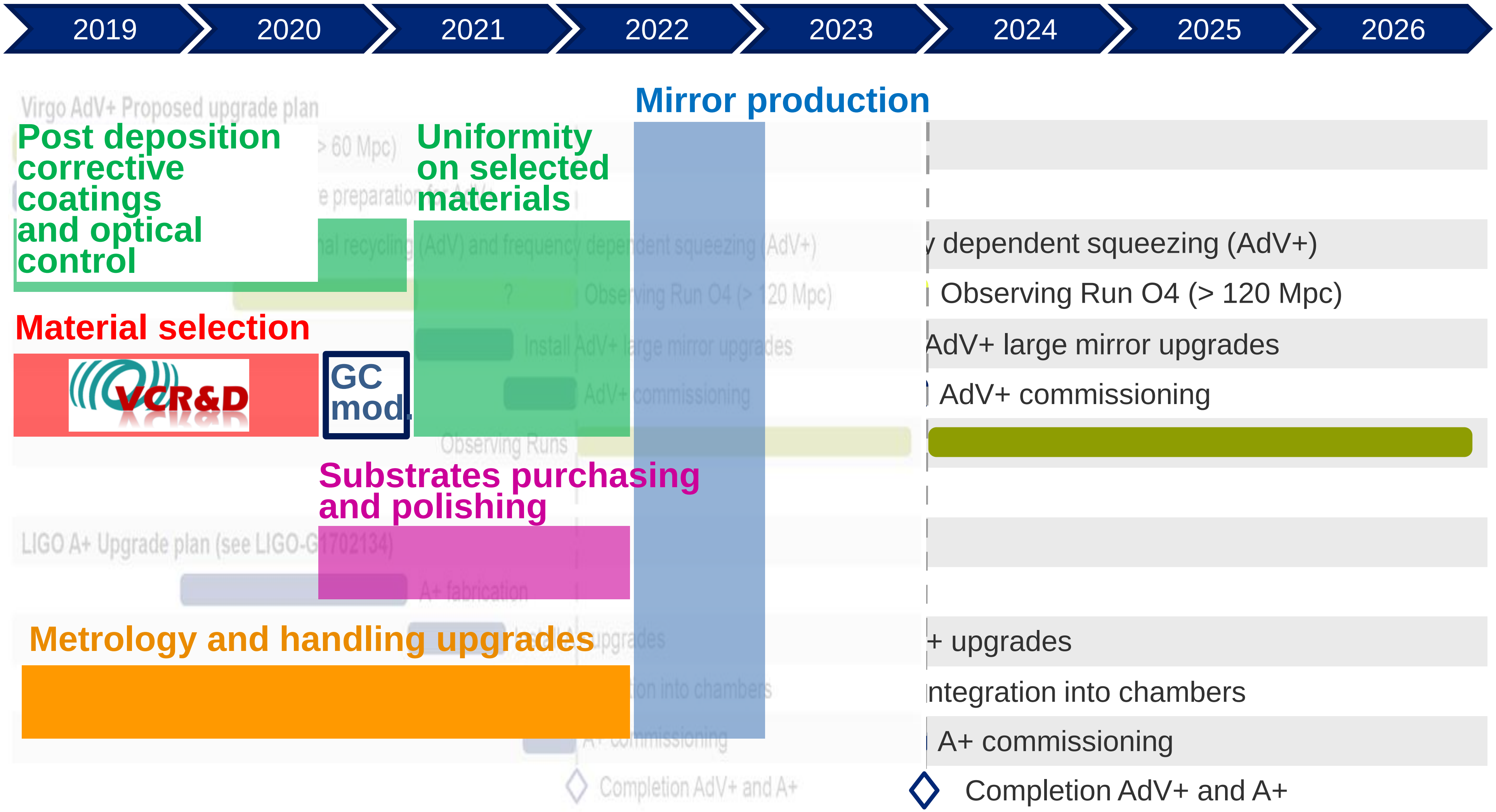


Note: duration of O4 has not been decided at this moment

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

Virgo’s coating R&D secures LMA’s relevance in future GW science

Five year plan for observational runs, commissioning and upgrades



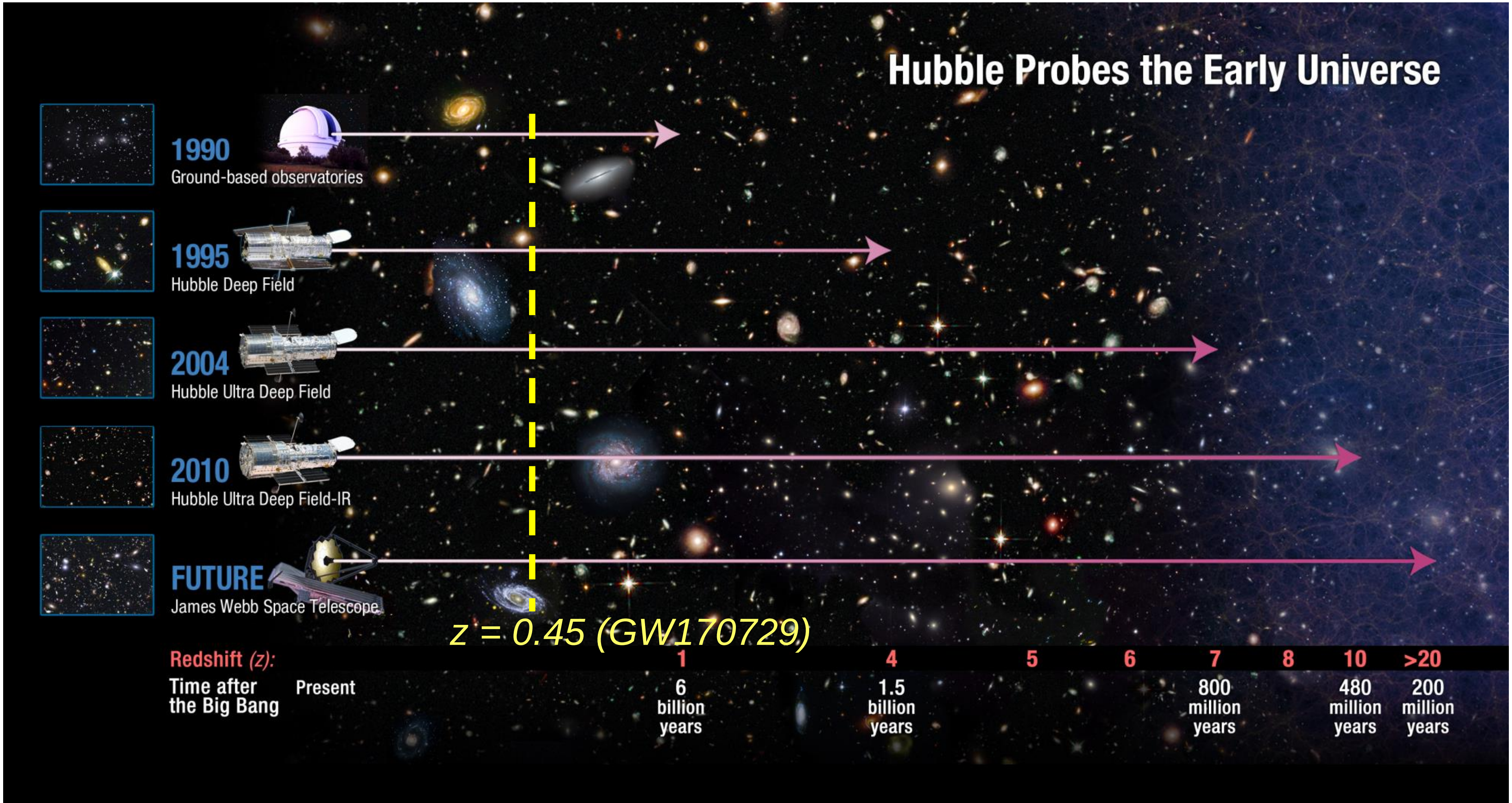
Note: duration of O4 has not been decided at this moment

3G: observing all mergers in the Universe

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

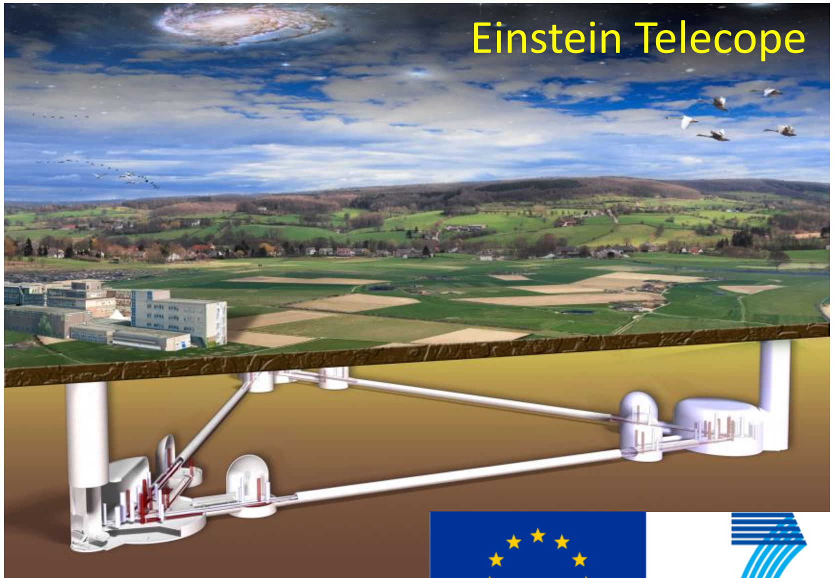
We want to collect high statistics (*e.g.* millions of BBH events), high SNR, distributed over a large z-range (*z < 20*)

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

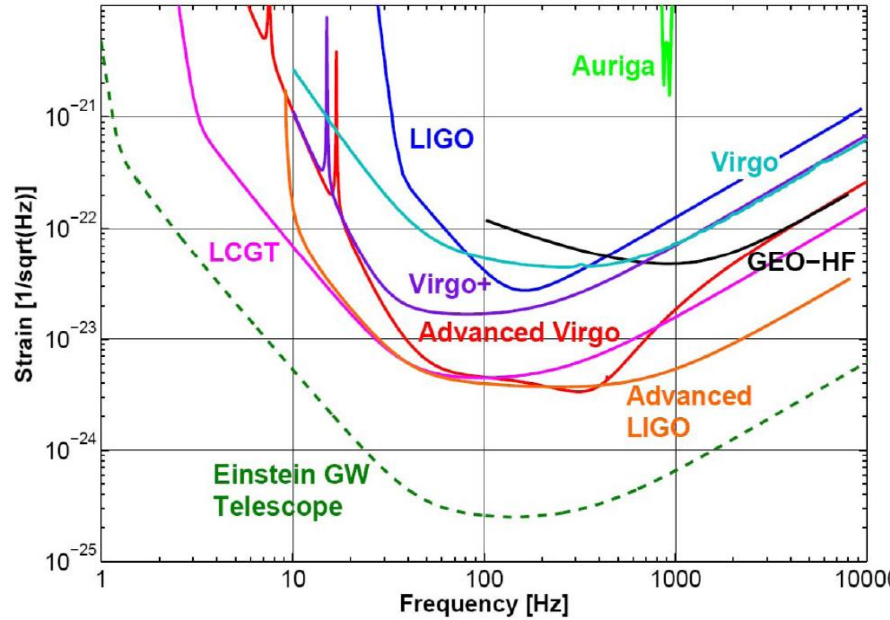


ET and CE

Realizing the next gravitational wave observatories is a coordinated effort to create a worldwide 3G network

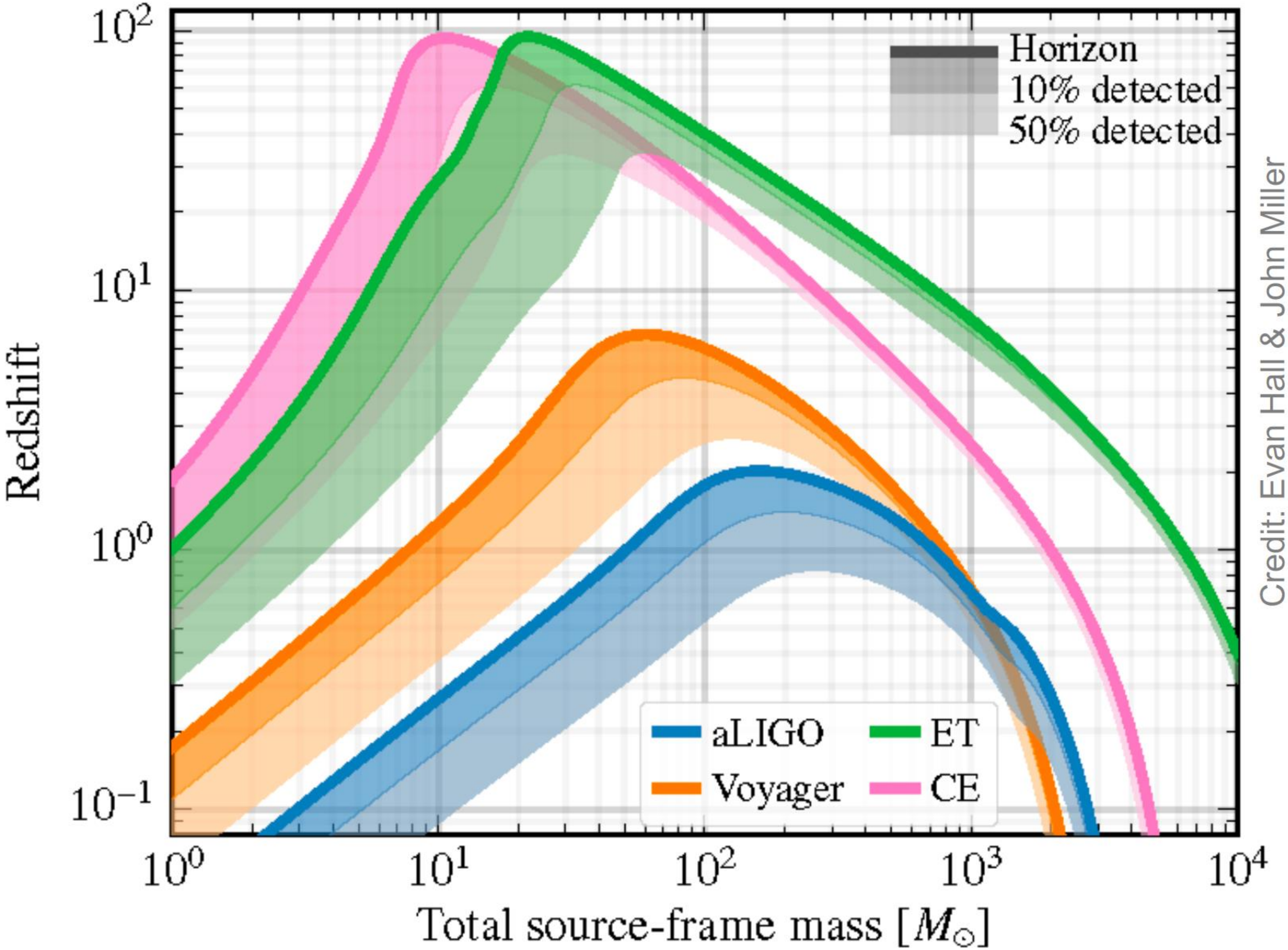


SEVENTH FRAMEWORK PROGRAMME



Einstein Telescope has excellent sensitivity

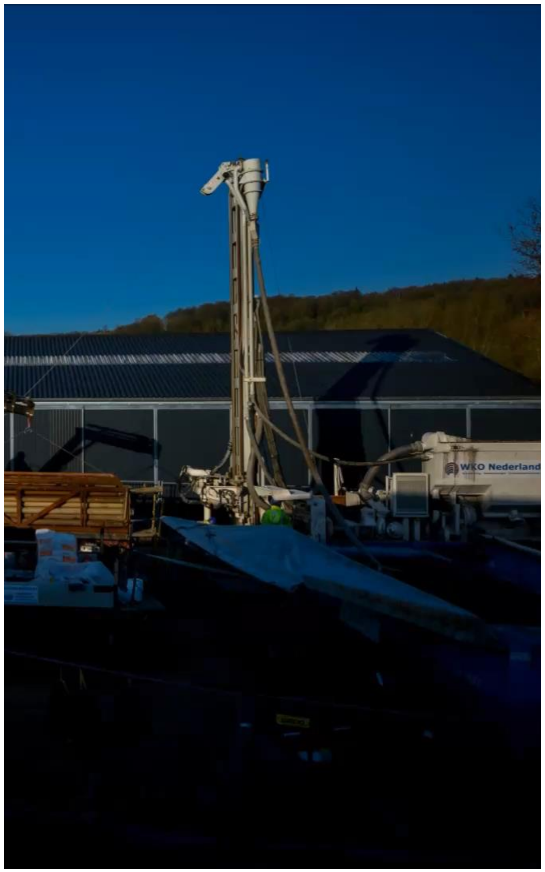
Einstein Telescope and Cosmic Explorer can observe the entire universe



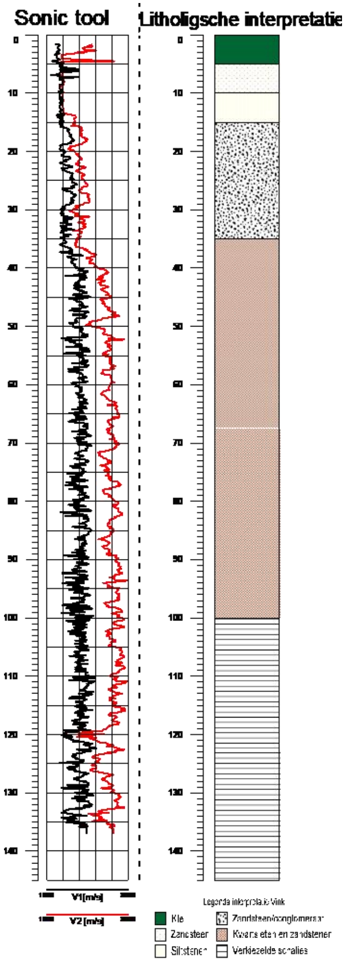
Studies of quality at potential sites in Sardinia and B-G-NL

The geology of the B-G-NL 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

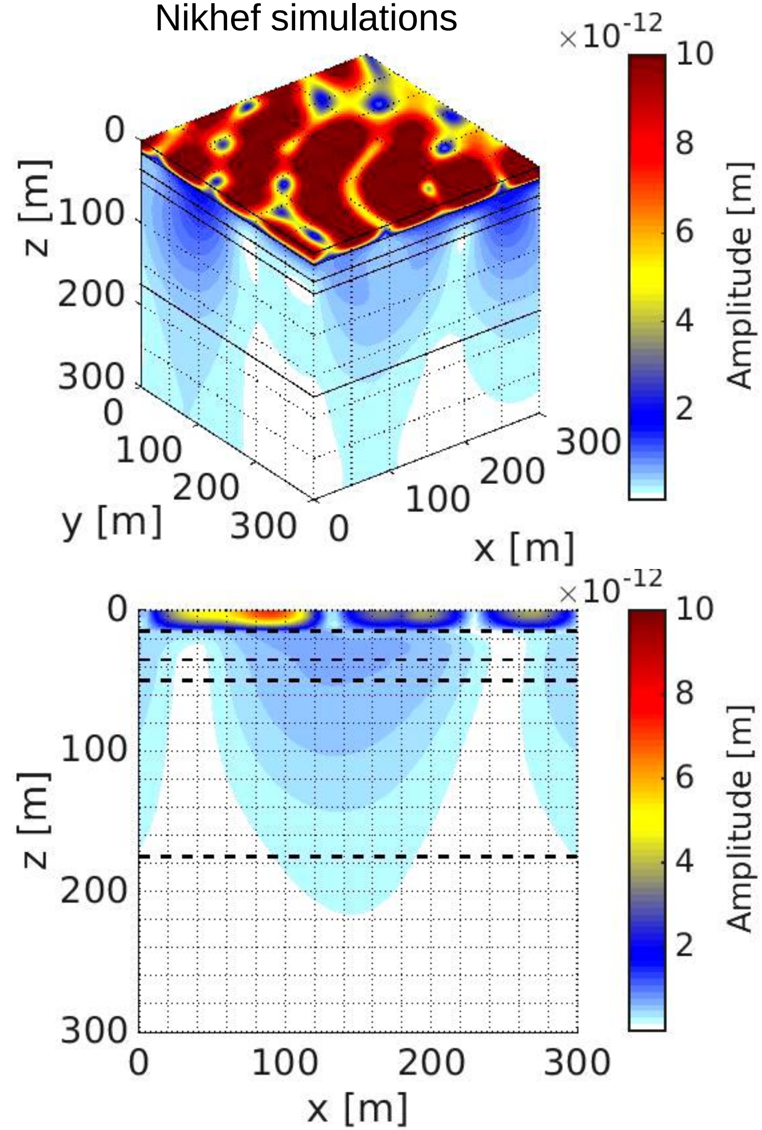
Antea borehole



Deltares research



Nikhef simulations



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

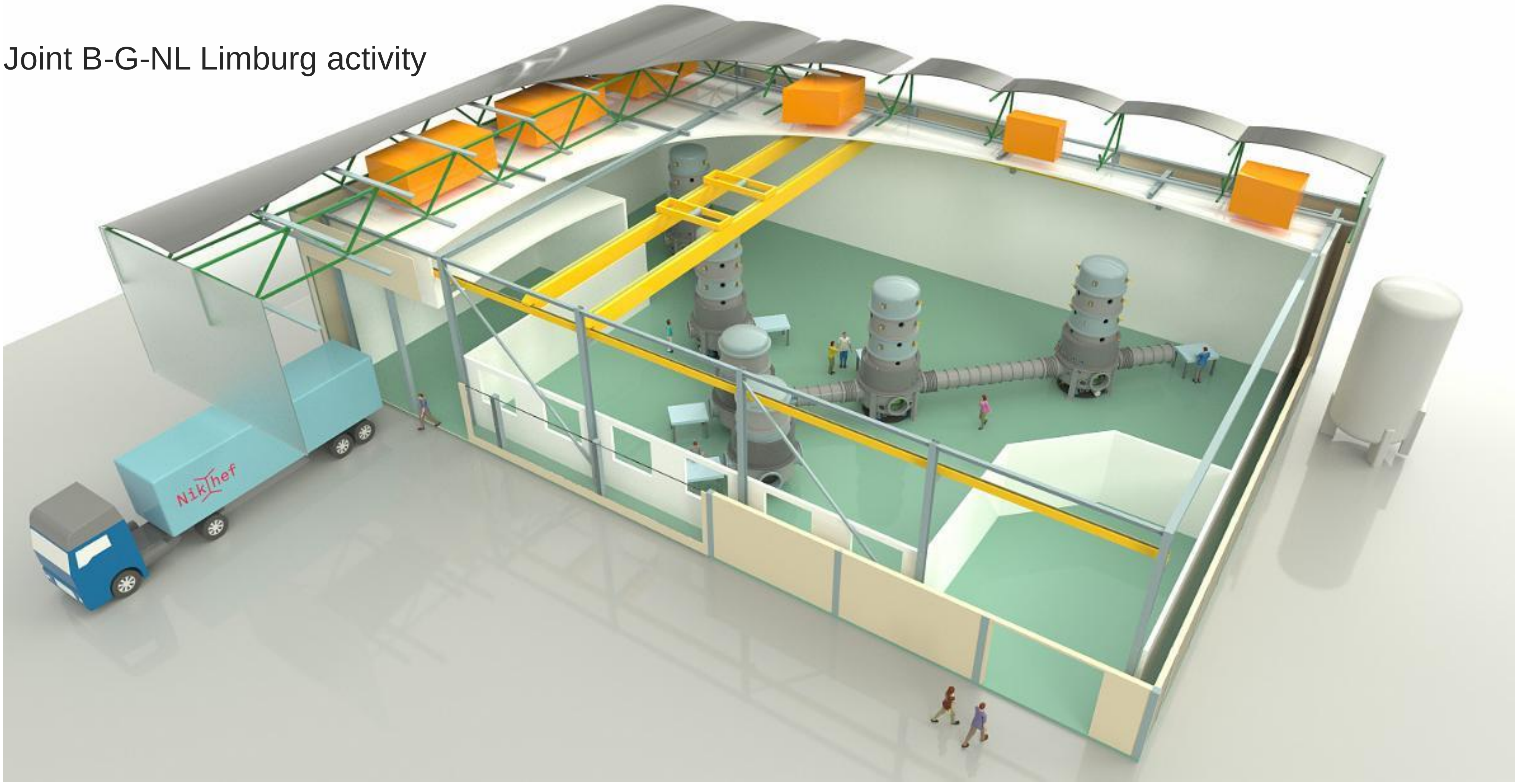
Plans for detailed geological studies of B-G-NL site are under development in Belgium

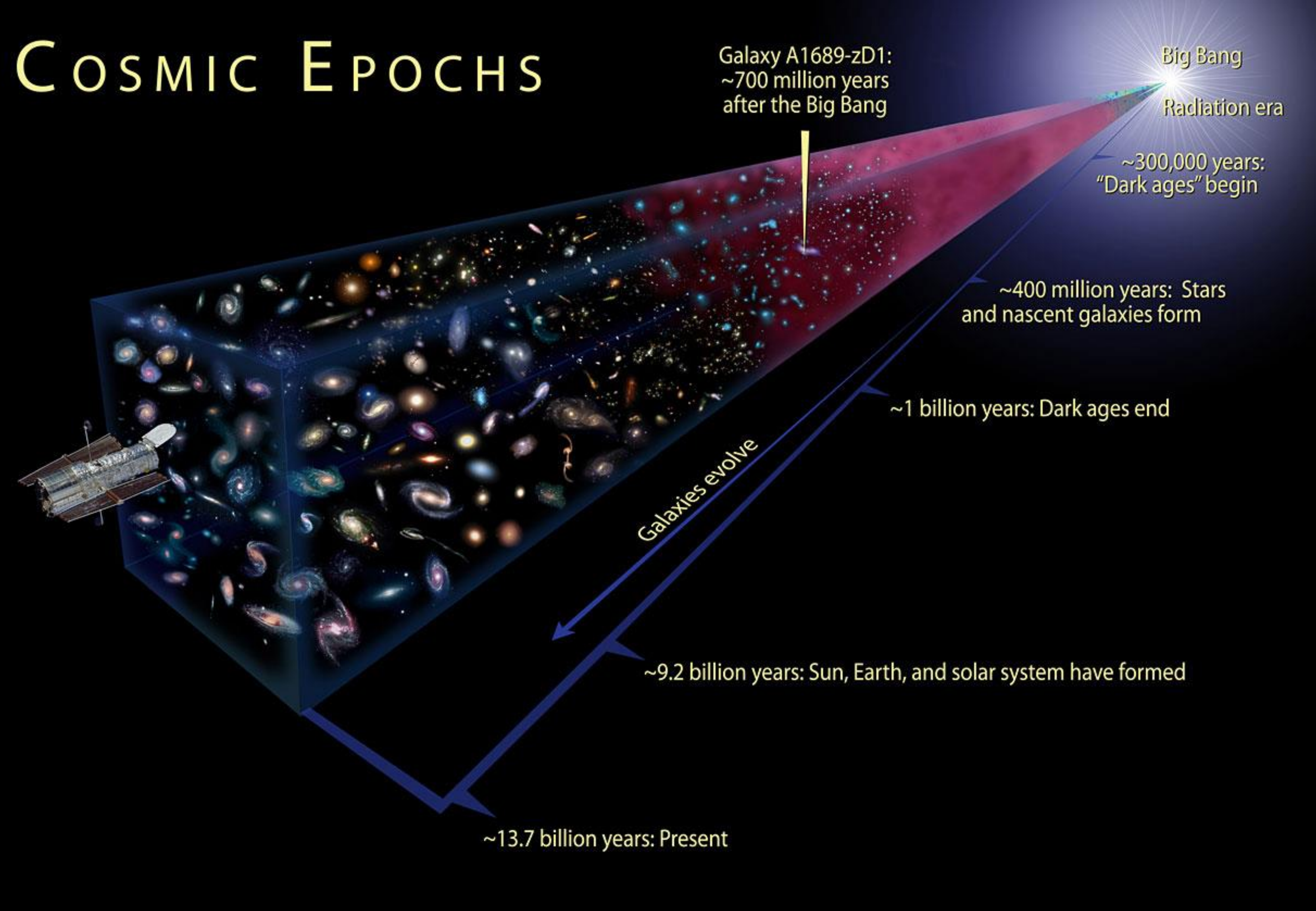
Development of a local 3G Excellence Center

Realization of a realistic test facility is under discussion. This will allow de-risking of key technologies such as large scale cryogenic test masses, sensor development, new laser technology, controls, …
Also industry will be involved

Opportunity for training on GW instrumentation

Joint B-G-NL Limburg activity





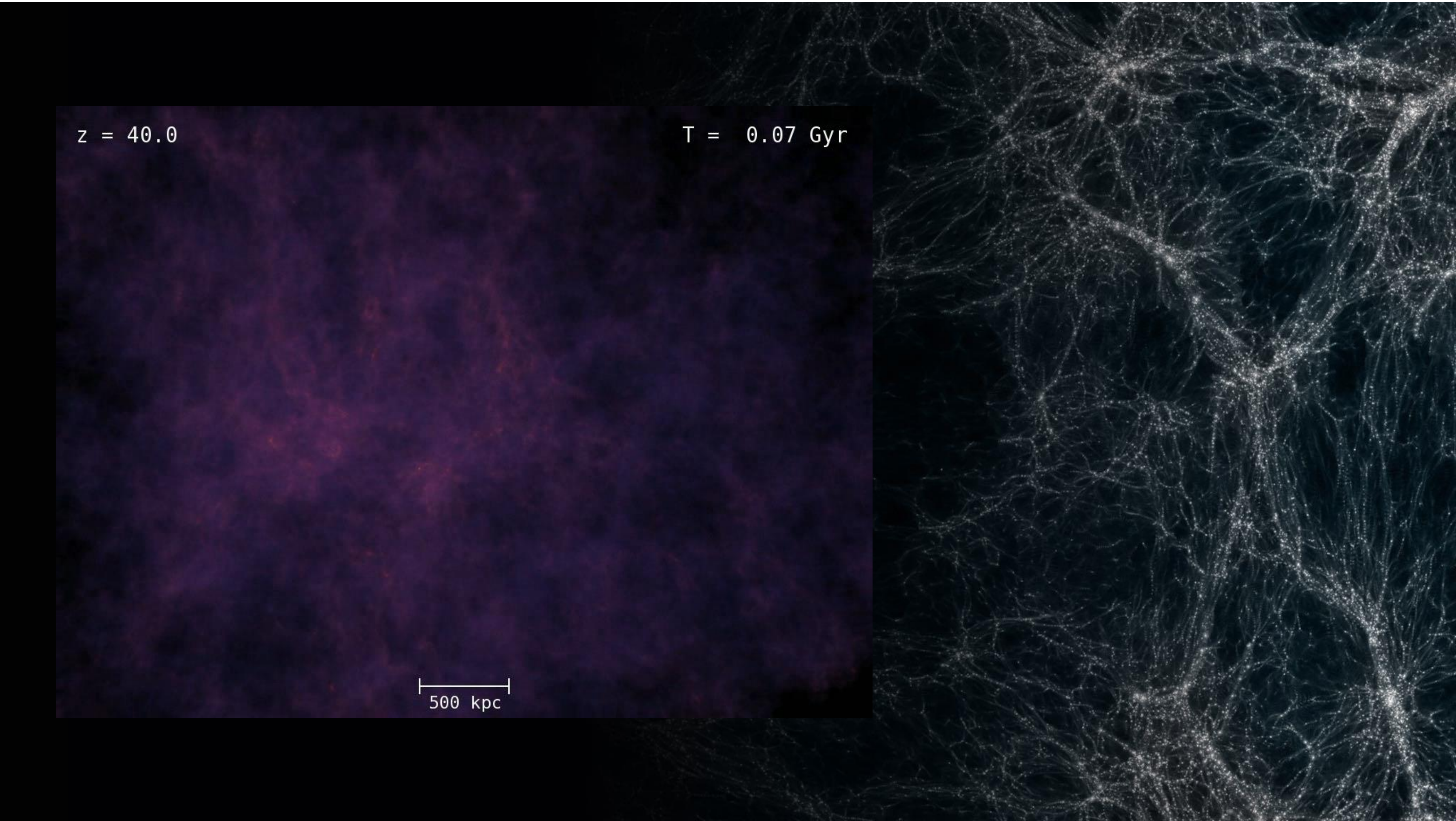
COSMIC EPOCHS
Galaxy A1689-zD1: ~700 million years after the Big Bang
Big Bang
Radiation era
~300,000 years: "Dark ages" begin
~400 million years: Stars and nascent galaxies form
~1 billion years: Dark ages end
Galaxies evolve
~9.2 billion years: Sun, Earth, and solar system have formed
~13.7 billion years: Present

Einstein Telescope

Einstein Telescope can observe BBH mergers to a redshift more than 20. This allows a new approach to cosmography. Study primordial black holes, BH from population III stars (first metal producers), *etc*.

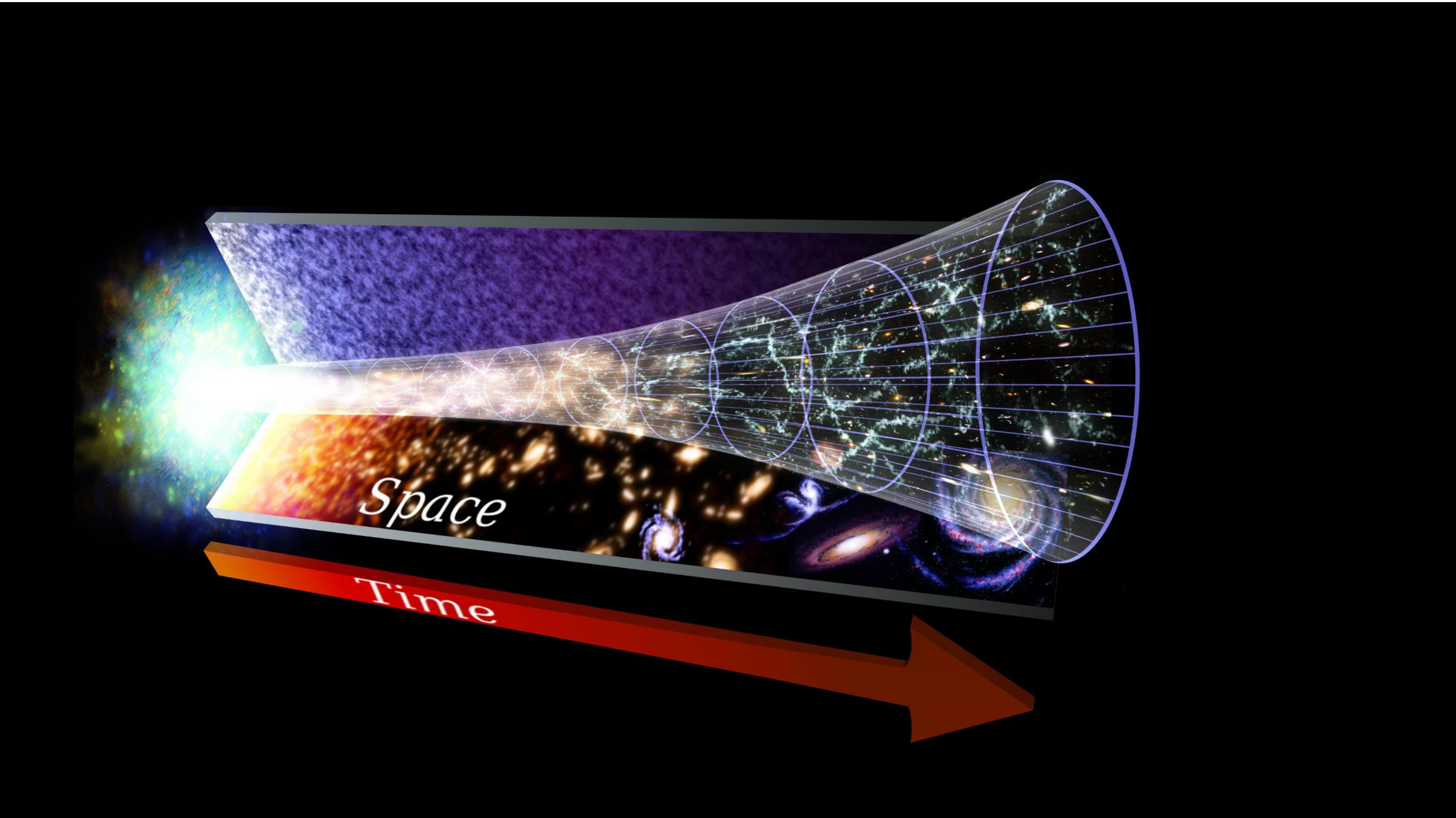
Einstein Telescope

Einstein Telescope can observe BBH mergers to a redshift more than 20. This allows a new approach to cosmography. Study primordial black holes, BH from population III stars (first metal producers), *etc*.



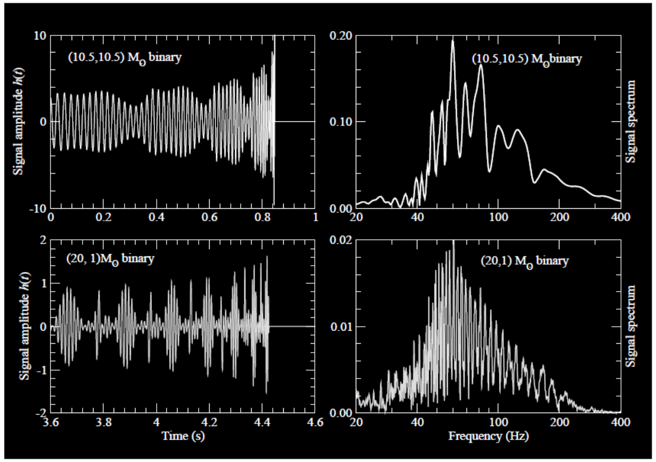
Dark energy: what is ripping the universe apart?

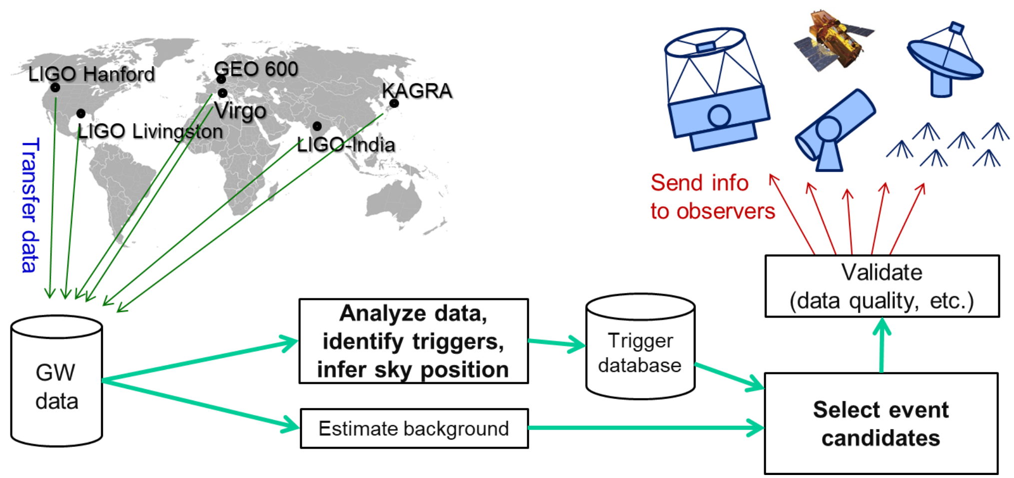
Einstein Telescope will use CBC events as standard “sirens”. This allows a new type of cosmography. Moreover the equation of state parameter for Dark Energy can be measured

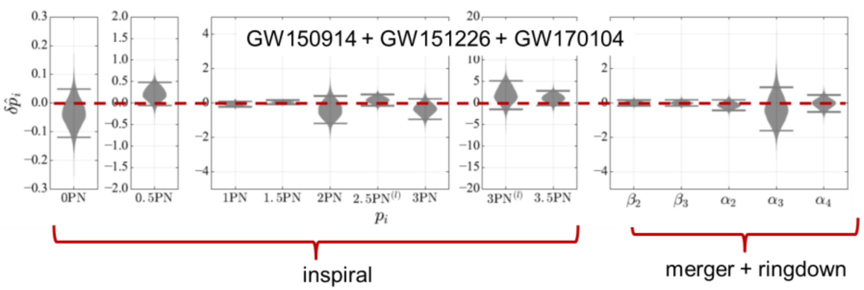


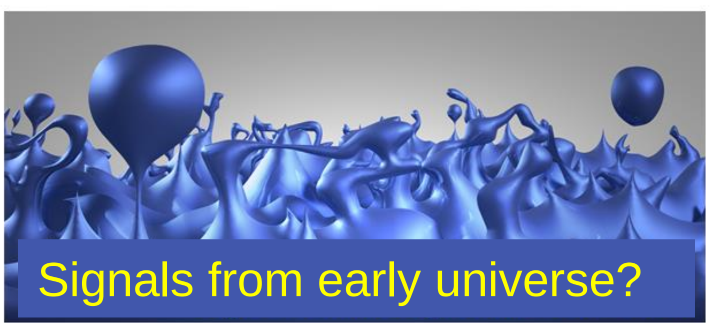
3G science

Detailed studies of gravity, near black holes. Early warning to EM follow-up community. Precision tests of detailed aspects of CBC. Cross correlation of the largest data sets. Access to early Universe









Bright future for gravitational wave research

LIGO and Virgo are operational. KAGRA in Japan next year, LIGO-India is now under construction. ESA launches LISA in 2034. Einstein Telescope and CE CDRs financed, strong support by APPEC

Gravitational wave research

- LIGO and Virgo operational
- KAGRA to join next year
- LIGO-India under construction (2025)
- ESA selects LISA, NASA rejoins
- Pulsar Timing Arrays, such as EPTA and SKA
- Cosmic Microwave Background radiation

Einstein Telescope and Cosmic Explorer

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

Next steps for 3G

- Organize the community and prepare a credible plan for EU funding agencies
- ESFRI Roadmap (2020)
- Support 3G: http://www.et-gw.eu/index.php/letter-of-intent