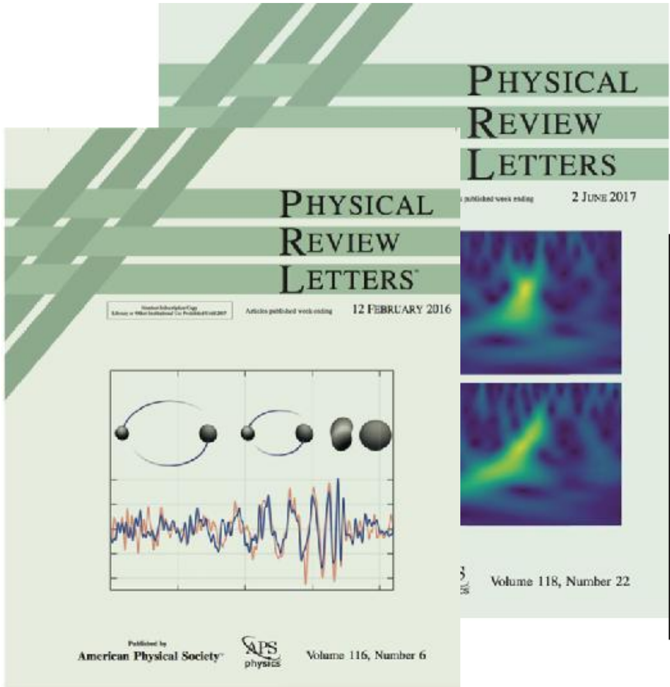
The future of ground-based gravitational wave observatories

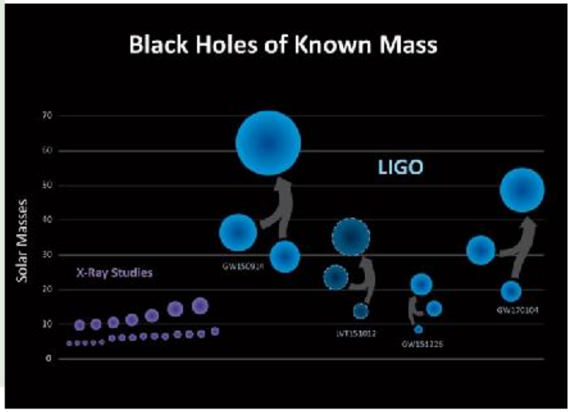
Sheila Rowan

University of Glasgow
GWIC Chair
Amaldi 2017

Plans for the coming era of gravitational wave astronomy and astrophysics

- 2015 to now:
  - start of the era of gravitational wave astronomy and astrophysics!
  - Work of many 100s of people over several decades now paying off
  - Long term thinking has been a hallmark of the field

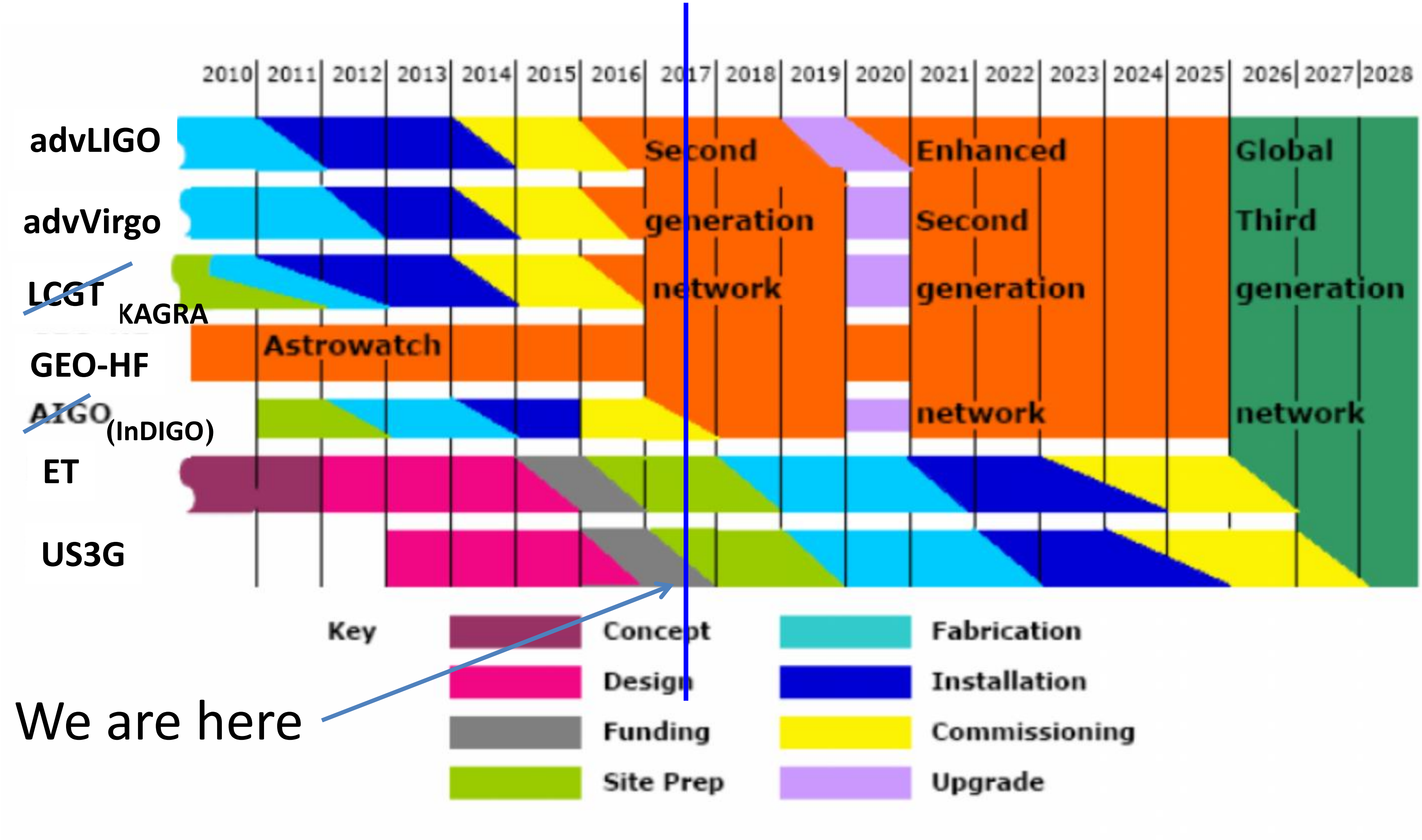




- In 2007/8 the international GW community formed a vision for the future of the field;
  - 2009 Gravitational Wave International Committee (GWIC) Roadmap: https://gwic.ligo.org/roadmap.
  - Perspective: to optimize the global science in the field
  - 30-year horizon
  - Global advanced detector network envisioned

GWIC
Gravitational Wave International Committee

The global GW roadmap Circa 2009

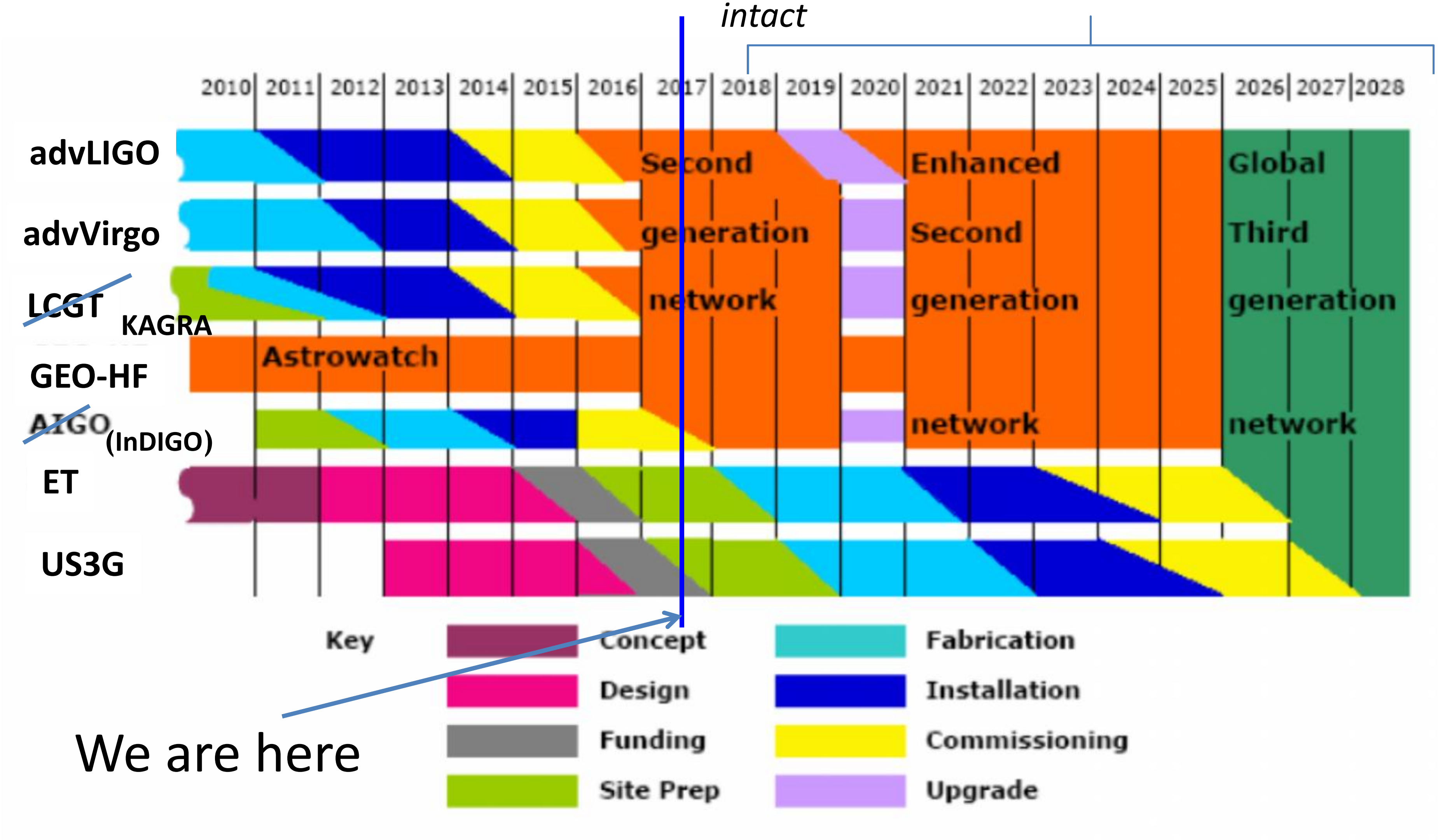


From the Gravitational Wave International Committee (GWIC roadmap - available at: http://gwic.ligo.org/roadmap/)

The global GW roadmap

GWIC
Gravitational Wave International Committee

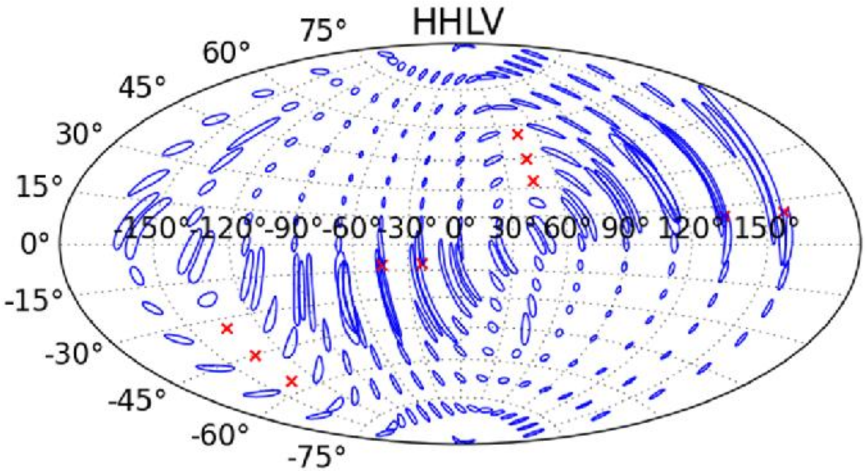
Some timescales need revised but vision remains intact



From the Gravitational Wave International Committee (GWIC roadmap - available at: http://gwic.ligo.org/roadmap/)

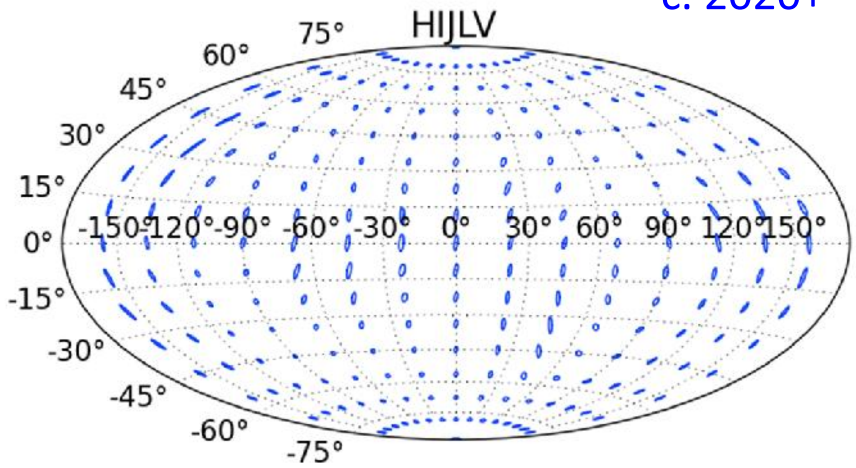
Completing the advanced detector network

Sky localization with 3 sites …



… and with 5 sites

c. 2020+

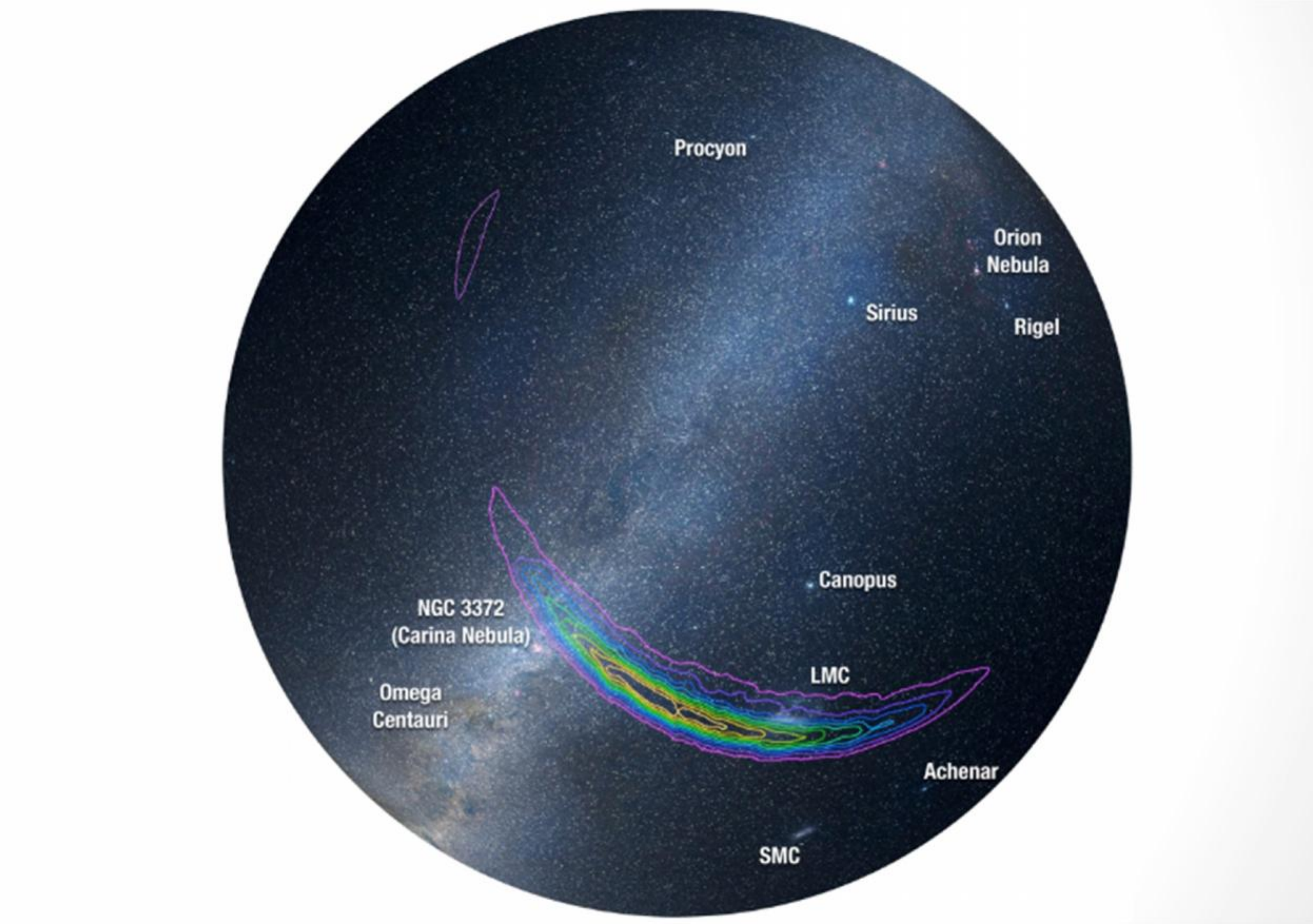


Typical 90% error box areas for Neutron Star-Neutron Star binaries

- median > 20 sq deg

Fairhurst, CQG 28 105021 (2011)

GW150914 Sky Location estimate



Credit: Shane Larson, Northwestern University; Roy Williams, Caltech; Thomas Boch, CDS Strasbourg

Completing the advanced detector network

- LIGO-India

LIGO-India 'in principle' Approval

By Indian Union cabinet on Feb 17, 2016

Press Information Bureau
Government of India
Cabinet

17-February-2016 14:55 IST

Cabinet grants 'in-principle' approval to the LIGO-India mega science proposal

The Union Cabinet chaired by the Prime Minister Shri Narendra Modi has given its 'in principle' approval to the LIGO-India mega science proposal for research on gravitational waves. The proposal, known as LIGO-India project (Laser Interferometer Gravitational-wave Observatory in India) is piloted by Department of Atomic Energy and Department of Science and Technology (DST). The approval coincides with the historic detection of gravitational waves a few days ago that opened up of a new window on the universe to unravel some of its greatest mysteries.

The LIGO-India project will establish a state-of-the-art gravitational wave observatory in India in collaboration with the LIGO Laboratory in the U.S. run by Caltech and MIT.

The project will bring unprecedented opportunities for scientists and engineers to dig deeper into the realm of gravitational wave and take global leadership in this new astronomical frontier.

LIGO-India will also bring considerable opportunities in cutting edge technology for the Indian industry which will be engaged in the construction of eight kilometre long beam tube at ultra-high vacuum on a levelled terrain.

The project will motivate Indian students and young scientists to explore newer frontiers of knowledge, and will add further impetus to scientific research in the country.

… on a positive note with a BIG BANG !!!!

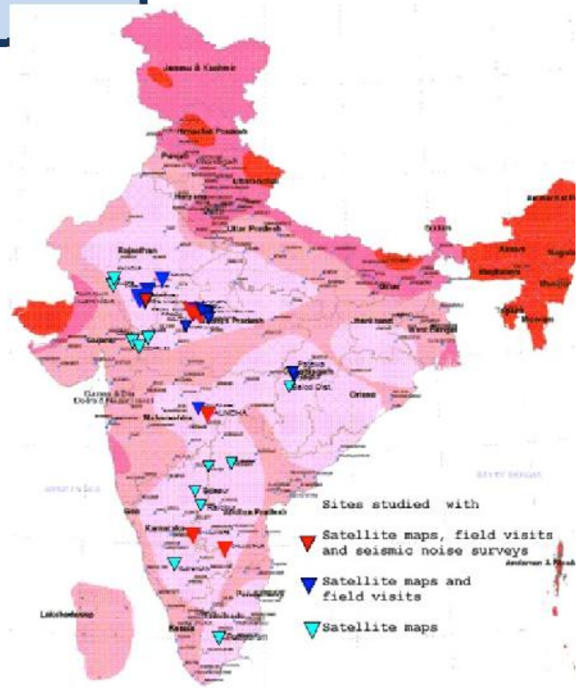
LIGO-India: Indo-US MoU signed

Indo-US MOU between
Department of Atomic Energy &
Department of Science &Tech., India
and
National Science Foundation, USA
signed on March 31, 2016
at Washington DC
in the personal presence of
Hon. Prime Minister of India

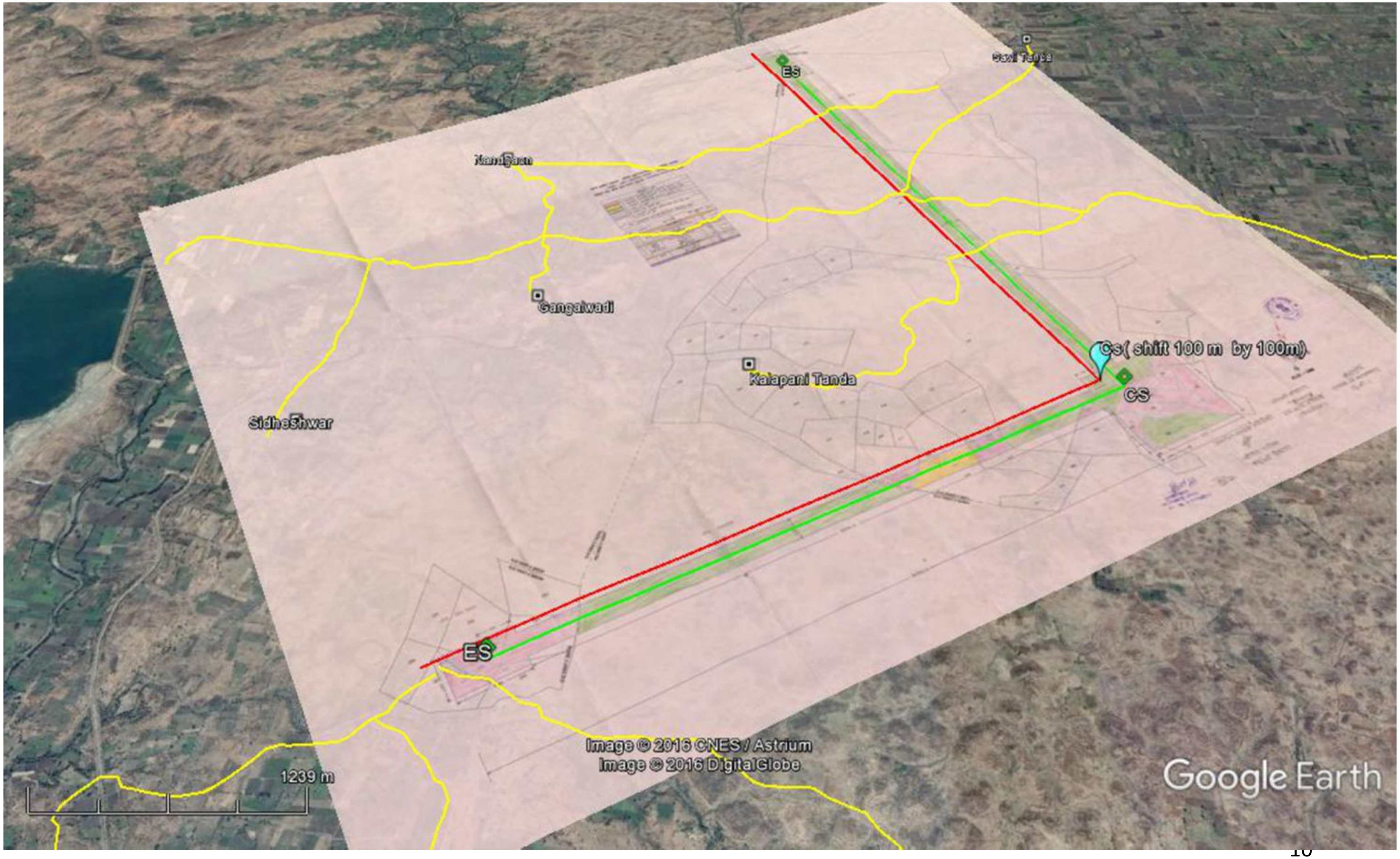
LIGO-India Site search

Led by IUCAA

LIGO-India selection
39 site leads followed up
(since Sept 2011)
Recommendation for primary and backup site
Jul 2016



LIGO-India ‘preferred’ site



Maharashtra, India

LIGO-India: site acquisition

Important Steps undertaken :

- Formal letter from Secretary, DAE to State chief Secretary for Special project status : **expected soon**
- Joint Measurement survey completed in **Feb 2017**
- Restricted development zones 5km, 10km, 15km around LIGO-India implemented in district development plans
- Payment of fees for initiating land acquisition procedure
- Identification of land for LIGO-India campuses in neighbouring towns

Buildup of Science

- LIGO–India construction, installation and commissioning involve number of scientific issues
  - Meeting stringent noise budgets in construction of infrastructure with regard to foundation, building design, installation of allied facilities.
  - Scientific oversight of design, fabrication & installation of vacuum infrastructure
  - Trained manpower for installation, commissioning, detector characterisation. Structured training program with LIGO USA & LSC.
  - R&D to Advanced LIGO+ configuration in 2024.
  - LIGO-India is expected to start in a much more advanced configuration than the advanced LIGO of 2015 or even 2018.

- Creating a sizable science community commensurate with scale of LIGO-India megascience
- Meeting LIGO–India promise for Indian S&T impetus.

See talk by Sanjit Mitra for more details

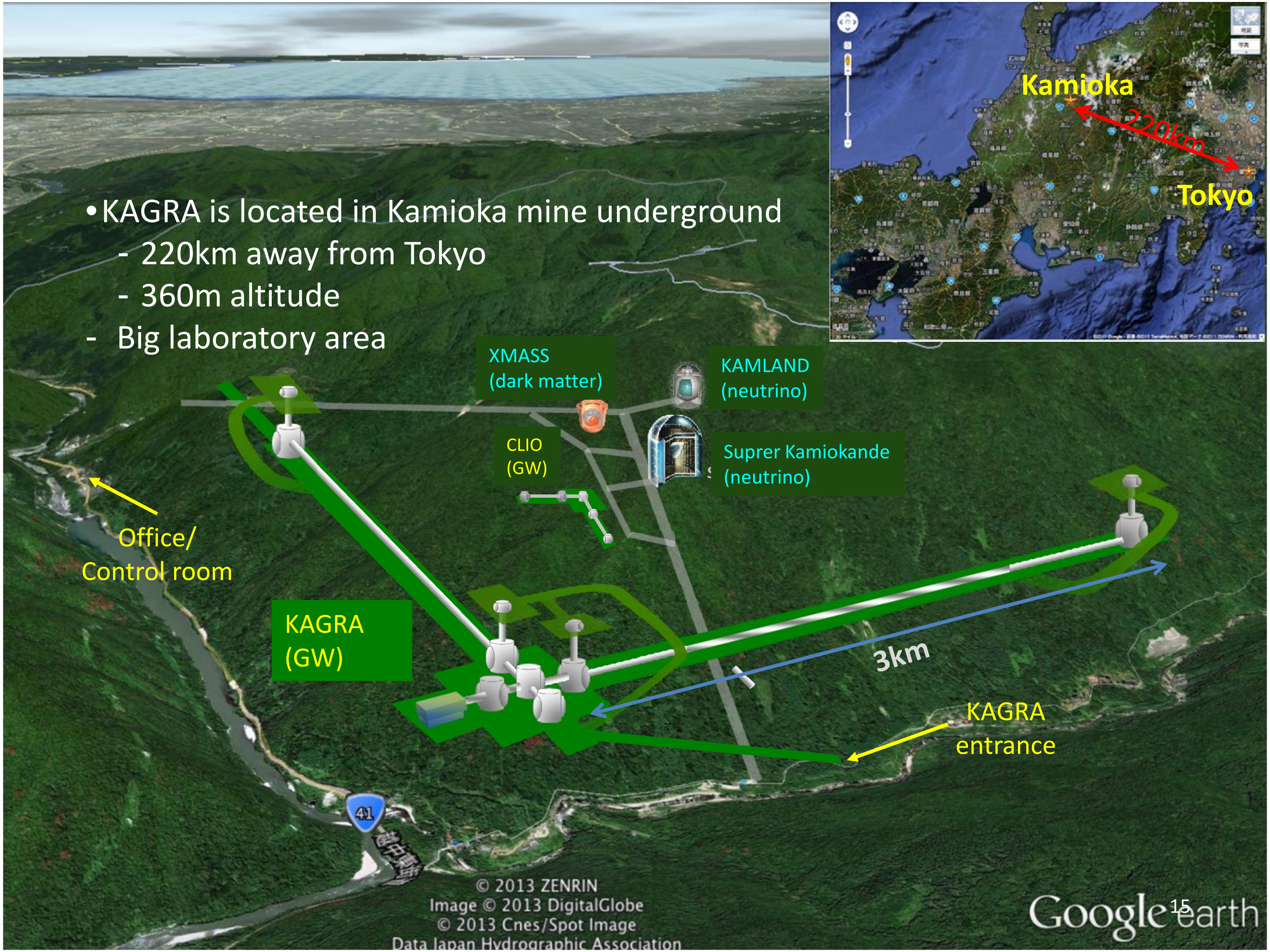
Completing the advanced detector network

- LIGO-India
- KAGRA

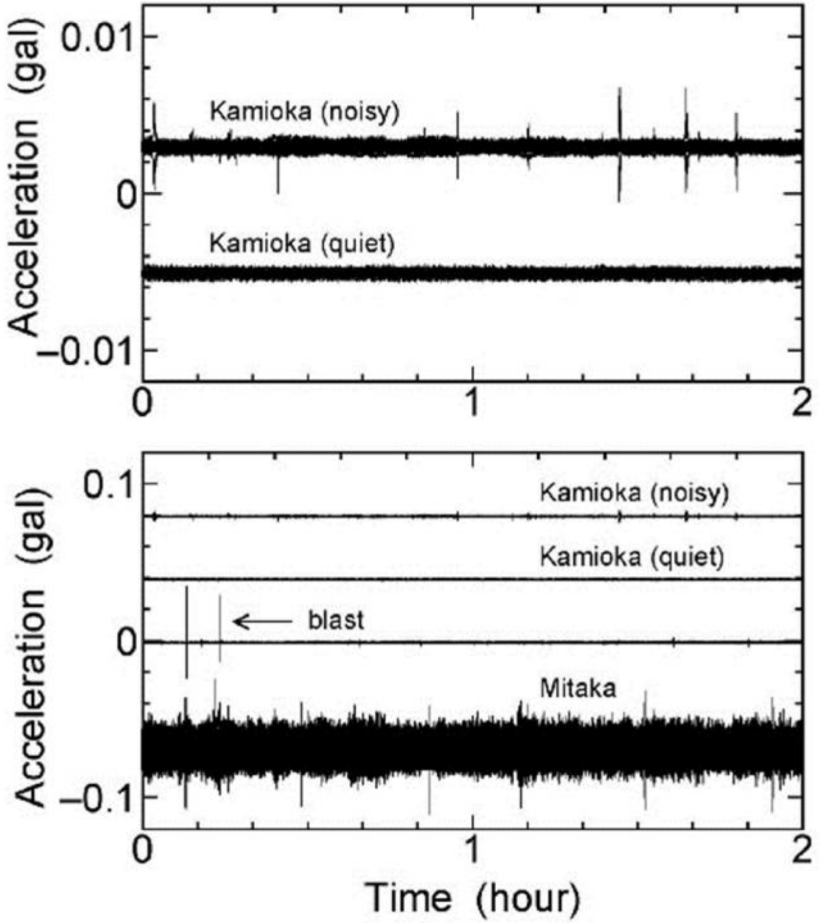
KAGRA Project

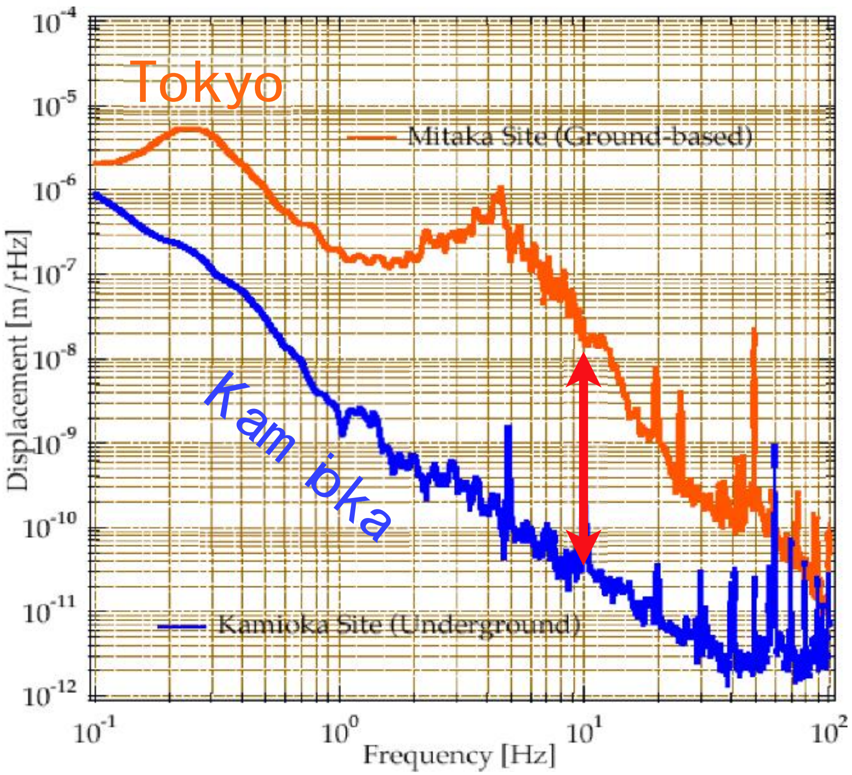
- Host: ICRR UTokyo, Co-host: KEK, NAOJ
- 300+ collaborators from 90+ institutes
- Constructed in Kamioka mine
- Underground and cryogenic

- KAGRA is located in Kamioka mine underground
  - 220km away from Tokyo
  - 360m altitude
- Big laboratory area



Quiet underground site

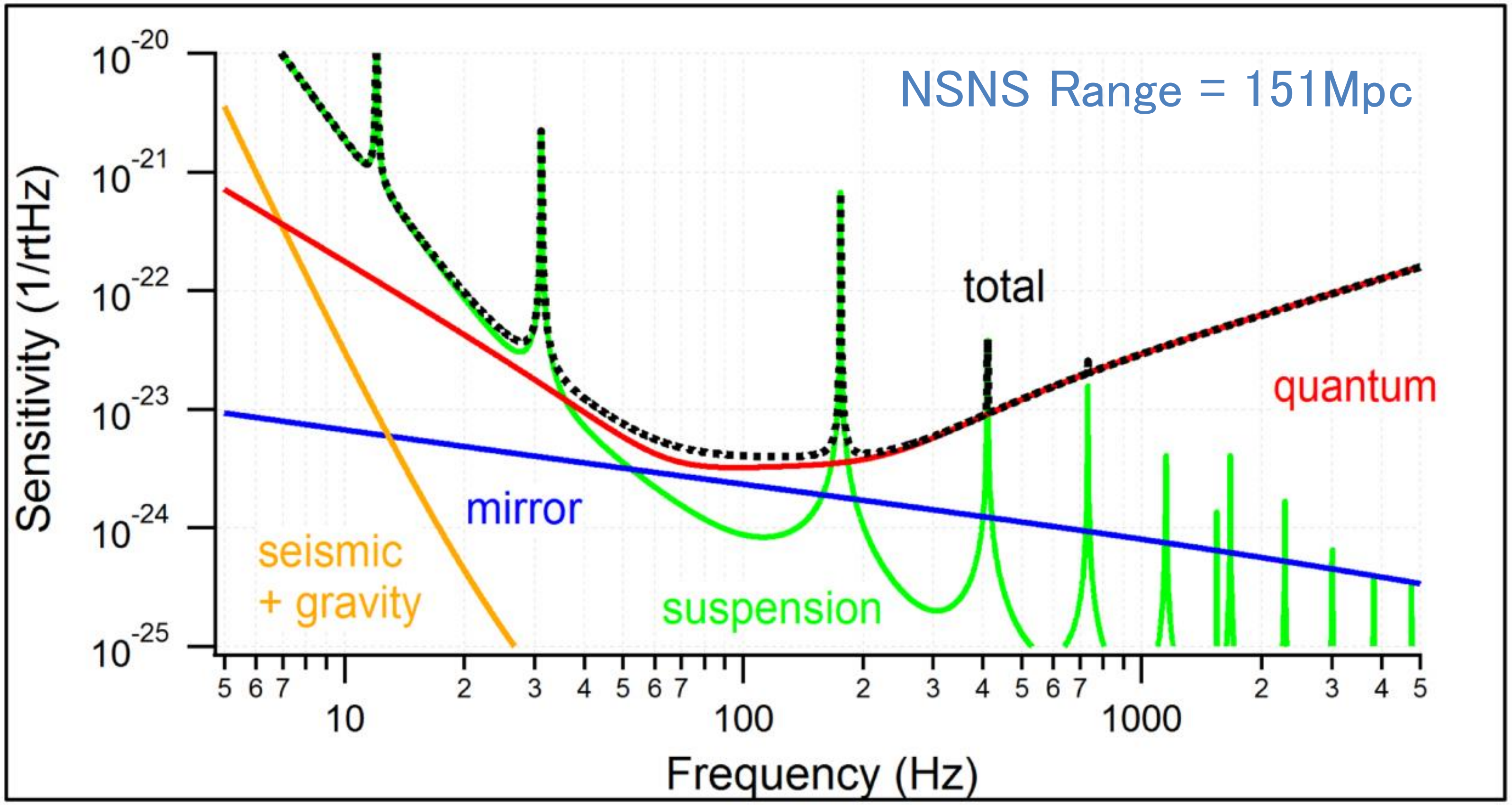




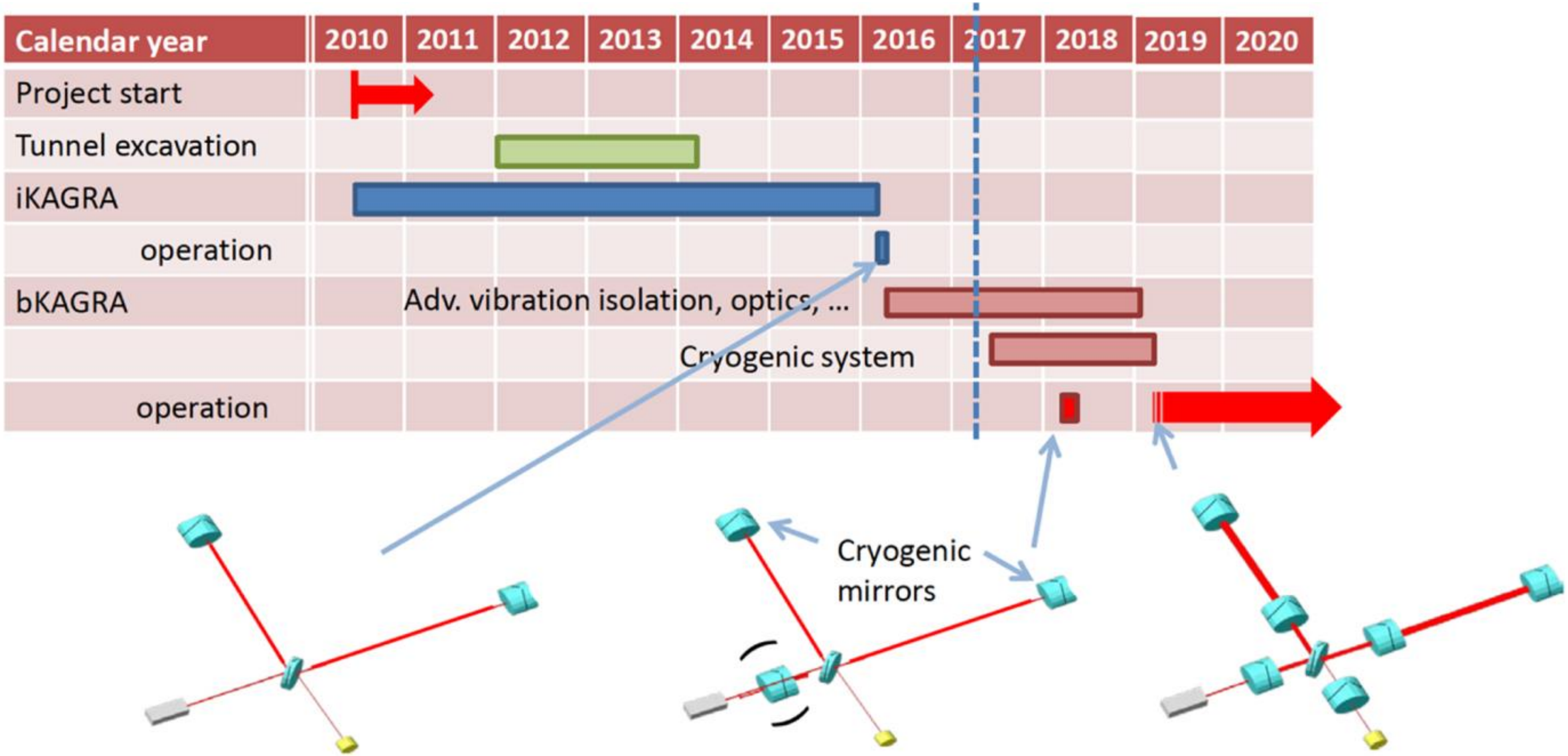
Amplitude of seismic motion

- Surrounded by hard rock (Hida-gneiss)
  - 5 km/sec sound speed

KAGRA Baseline Sensitivity



Overall plan



iKAGRA

bKAGRA

Initial KAGRA
Michelson at room temp.

Phase 1
Michelson with two cryogenic mirrors.

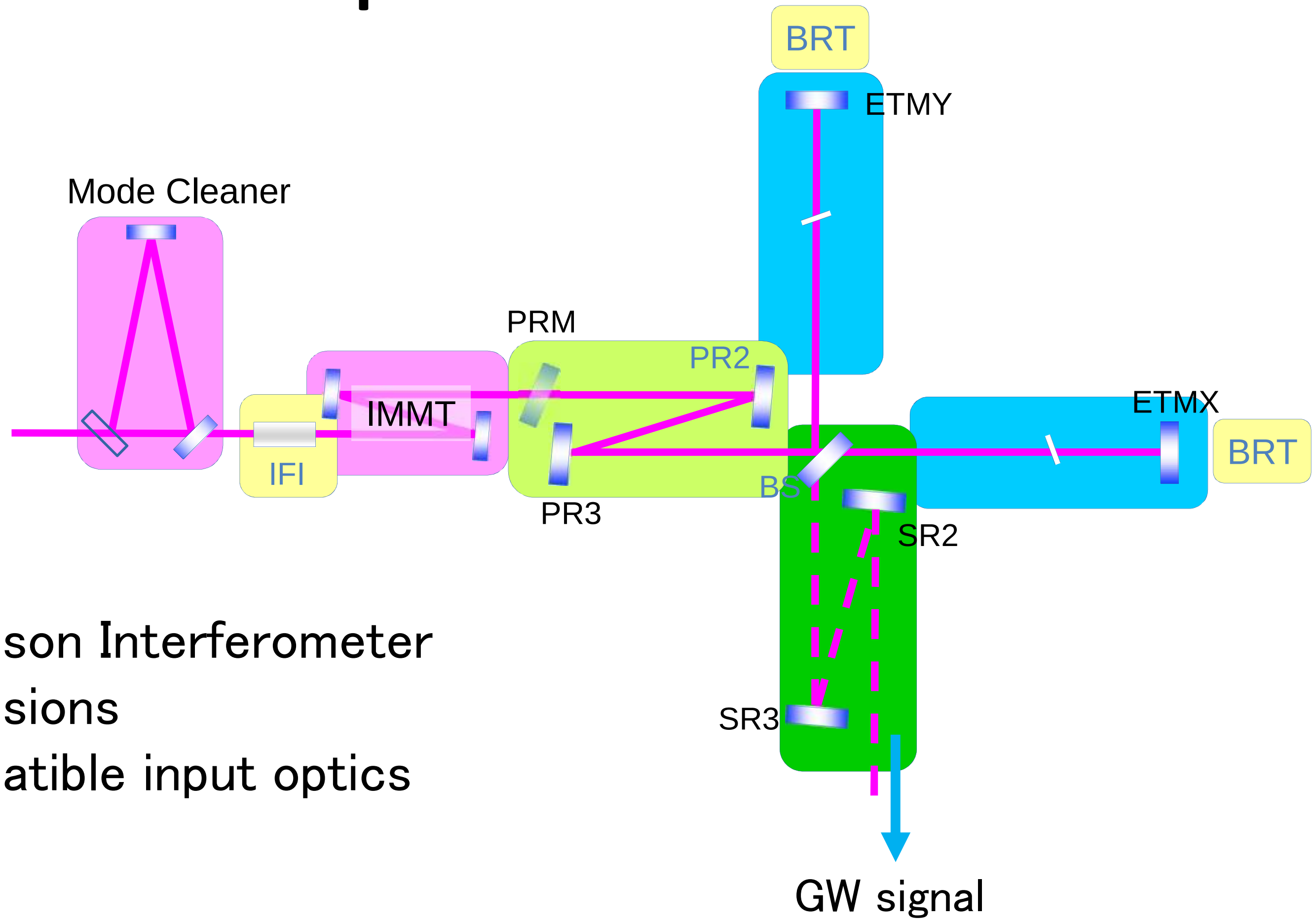
Phase 2
Four cryogenic mirrors.

Phase 3
DRFPMI with four cryogenic mirrors. Observation run

iKAGRA Test Run in 2016

- Period: March 25 to 31 and April 11 to 25
- obtain experiences of the management and operation of the km-class interferometer
- test controls, data transfer, observation shift, etc.

bKAGRA phase 1

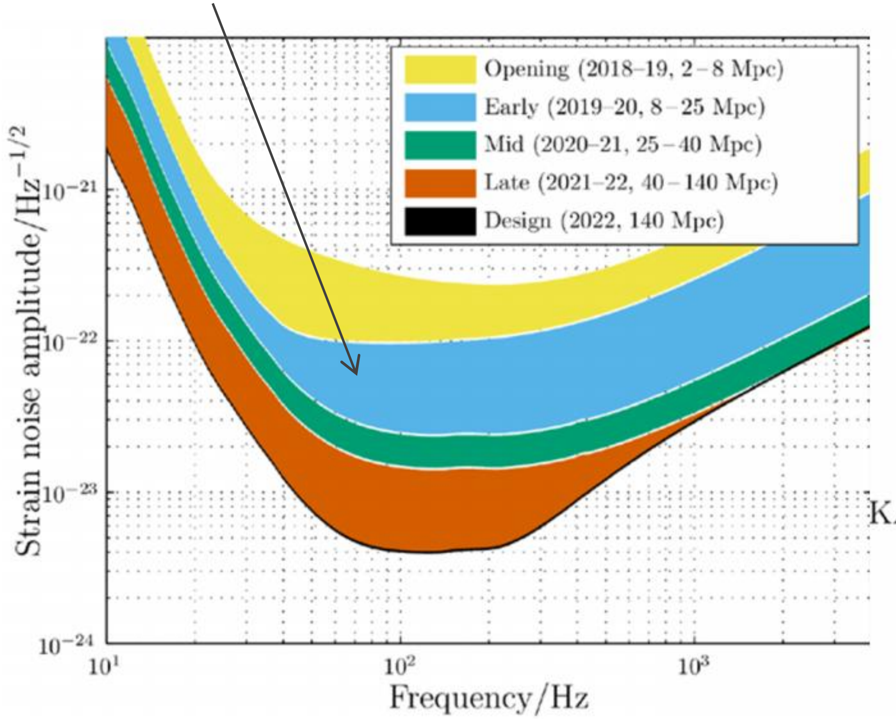


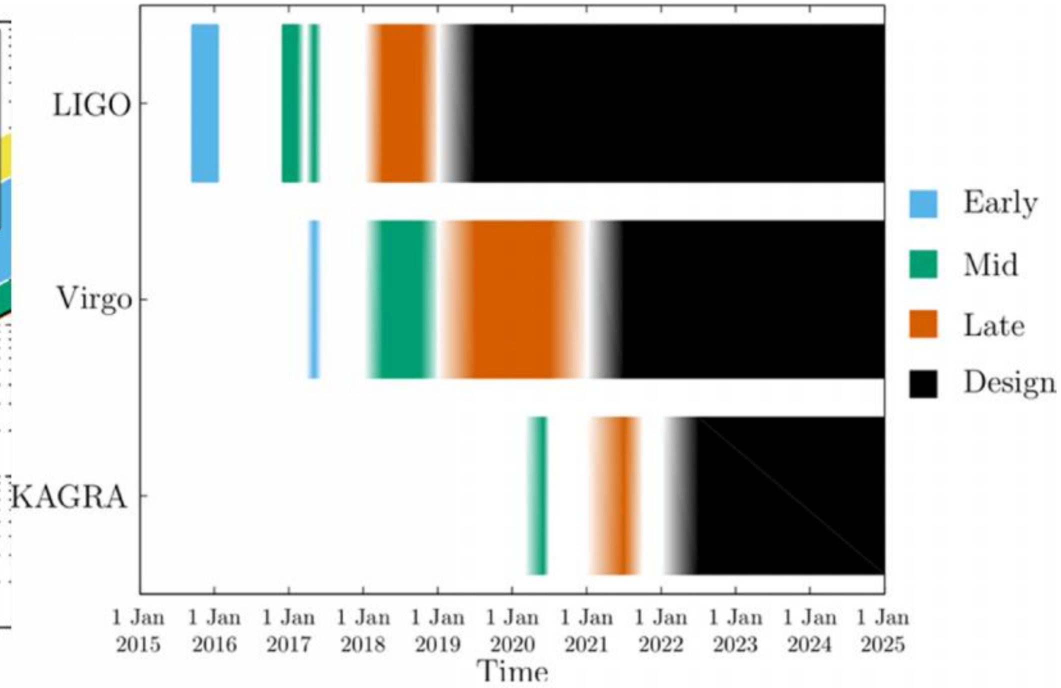
- Cryogenic Michelson Interferometer
- Full scale suspensions
- High power compatible input optics

Start operation by the end of **March 2018**

Observation Scenario (Under discussion)

bKAGRA Phase 3





- Binary neutron-star range:

  25-40 Mpc in 2020,
  40-140 Mpc in 2021

Summary – KAGRA planning

- iKAGRA: Initial 3km test run successfully done with very limited resources.
  - Room temperature, simple Michelson, only one KAGRA style isolation system.
- bKAGRA Phase 1 : The first cryogenic test run is planned in March 2018.
  - Simple Michelson, two low temperature mirrors.
  - Schedule is tight due to installations of KAGRA style isolation system.
- bKAGRA Phase 2 : Two more cryogenic mirrors.
- bKAGRA Phase 3: The first observation run in ~2020

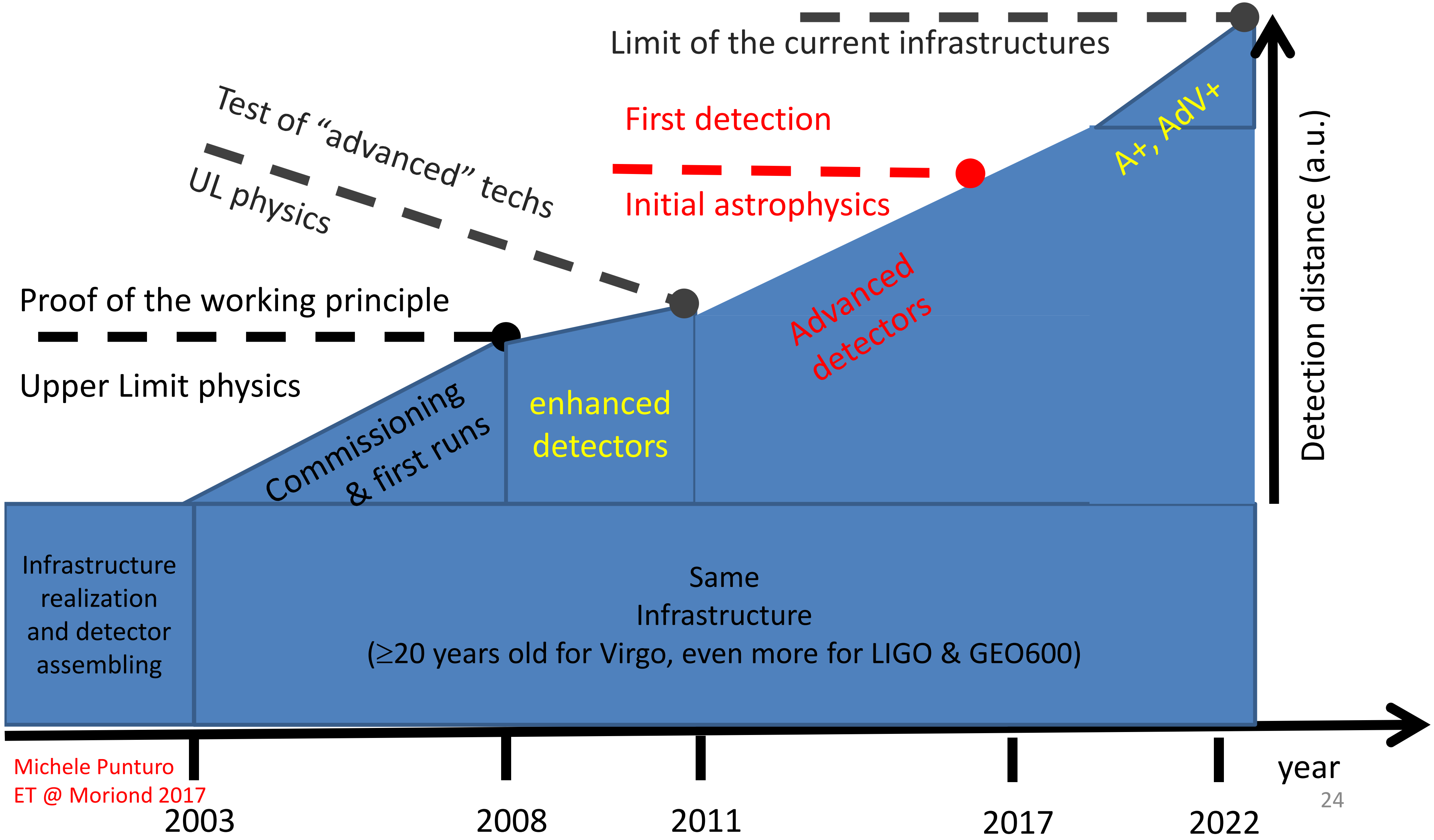
See talk by Seiji Kawamura for news

What Next?

Upgrades to Advanced detectors (keeping the current infrastructure)

A bit of history

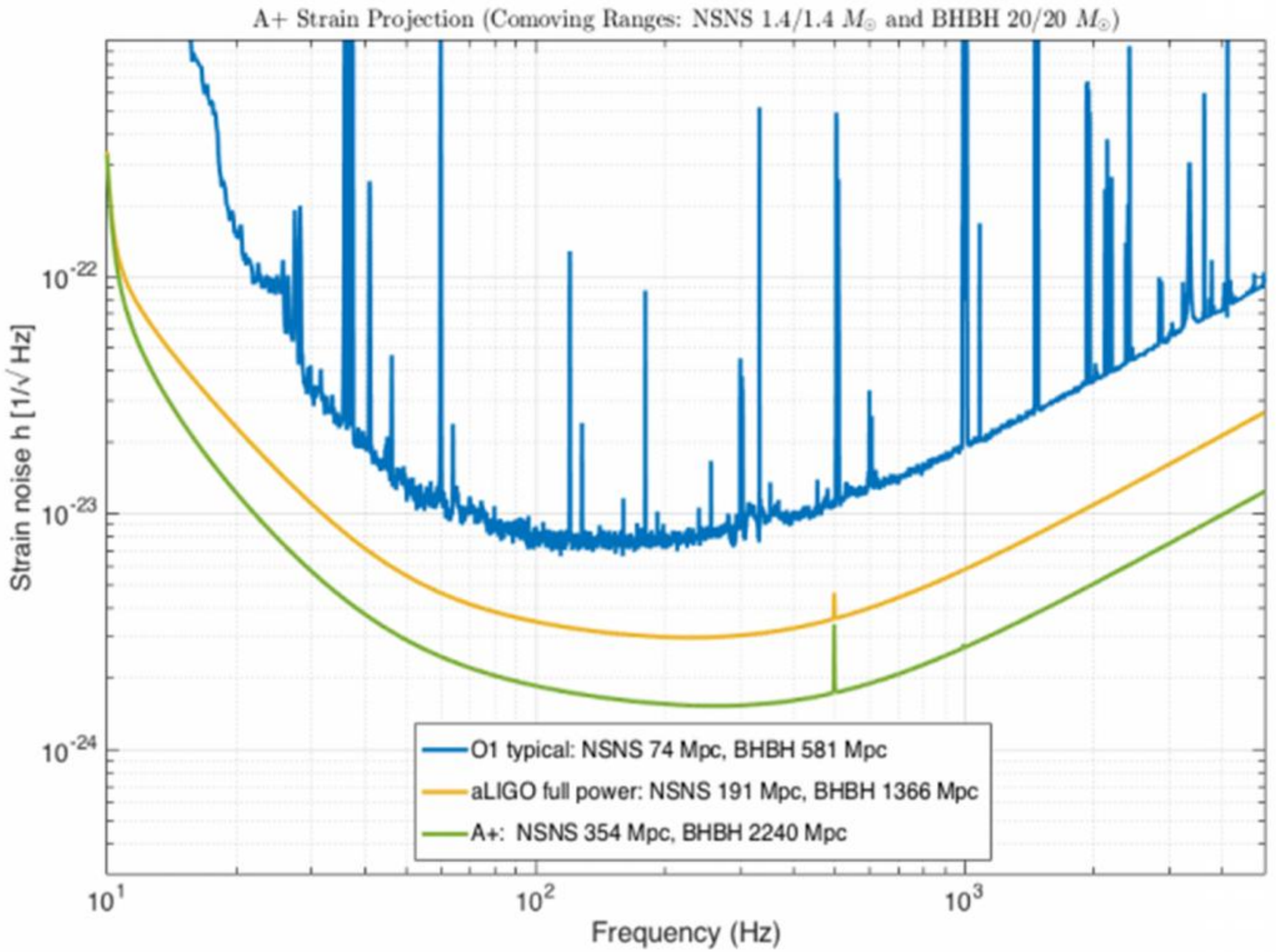
- Evolution of the GW detectors:



Michele Punturo
ET @ Moriond 2017

A+ Strain Sensitivity Projection

(Advanced LIGO +)



Key hardware improvements

A+ key parameters:

12dB injected squeezin
15% readout loss
100 m filter cavity
20 ppm RT FC loss
CTN half of aLIGO

LIGO-G1600769-v5

Similar hardware features incorporated into LIGO-india, Advanced Virgo to give A+ global network

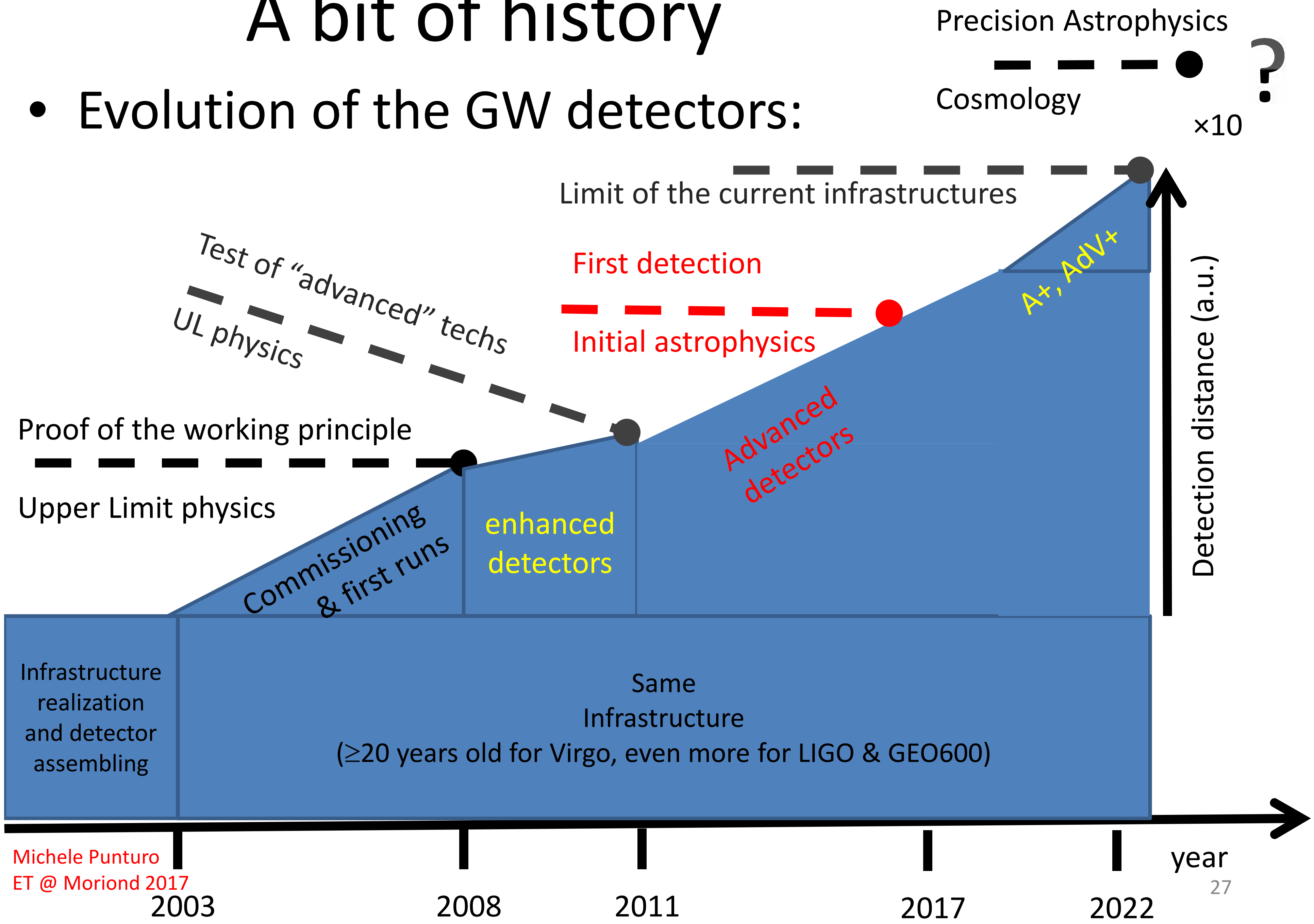
A+ Rationale

- An incremental upgrade to aLIGO that leverages existing technology and infrastructure, with minimal new investment and moderate risk
- Target: factor of 1.7* increase in range over aLIGO
  - ➔ About a factor of 5 greater CCB event rate
- Stepping stone to future 3G detector technologies
- Link to future GW astrophysics, cosmology, nuclear physics
- Could be observing within < 6 years (2022)
  - with prompt funding (FY'19 or earlier)
- "Scientific breakeven" within 1/2 year of operation
- Incremental cost: *a small fraction of aLIGO*

*BBH 20/20 $M_\odot$: 1.64x
*BNS 1.4/1.4 $M_\odot$: 1.85x

A bit of history

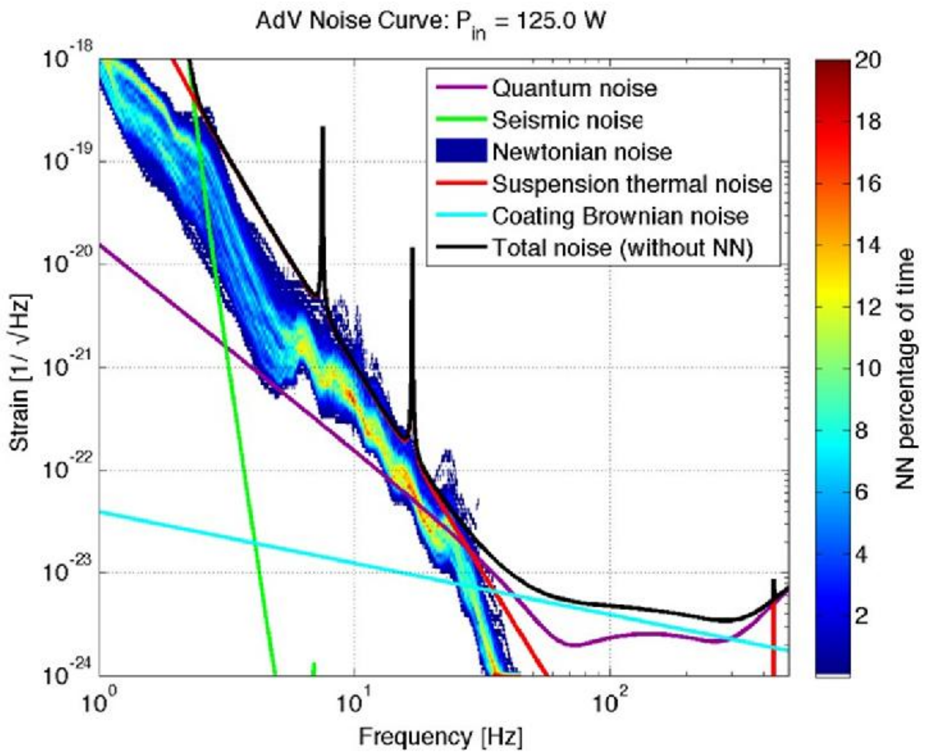
- Evolution of the GW detectors:



Michele Punturo
ET @ Moriond 2017

Limits of the Infrastructures?

- Obsolescence
- Length of the arms
- Low frequency:
  - Seismic and Newtonian noise
  - Cryogenic apparatuses
- Medium frequency:
  - Size of the beam (thermal noise)
- High/medium frequency:
  - Long filtering cavities (squeezing)
- Additional DoF:
  - New geometries or topologies
  - Multiple interferometers



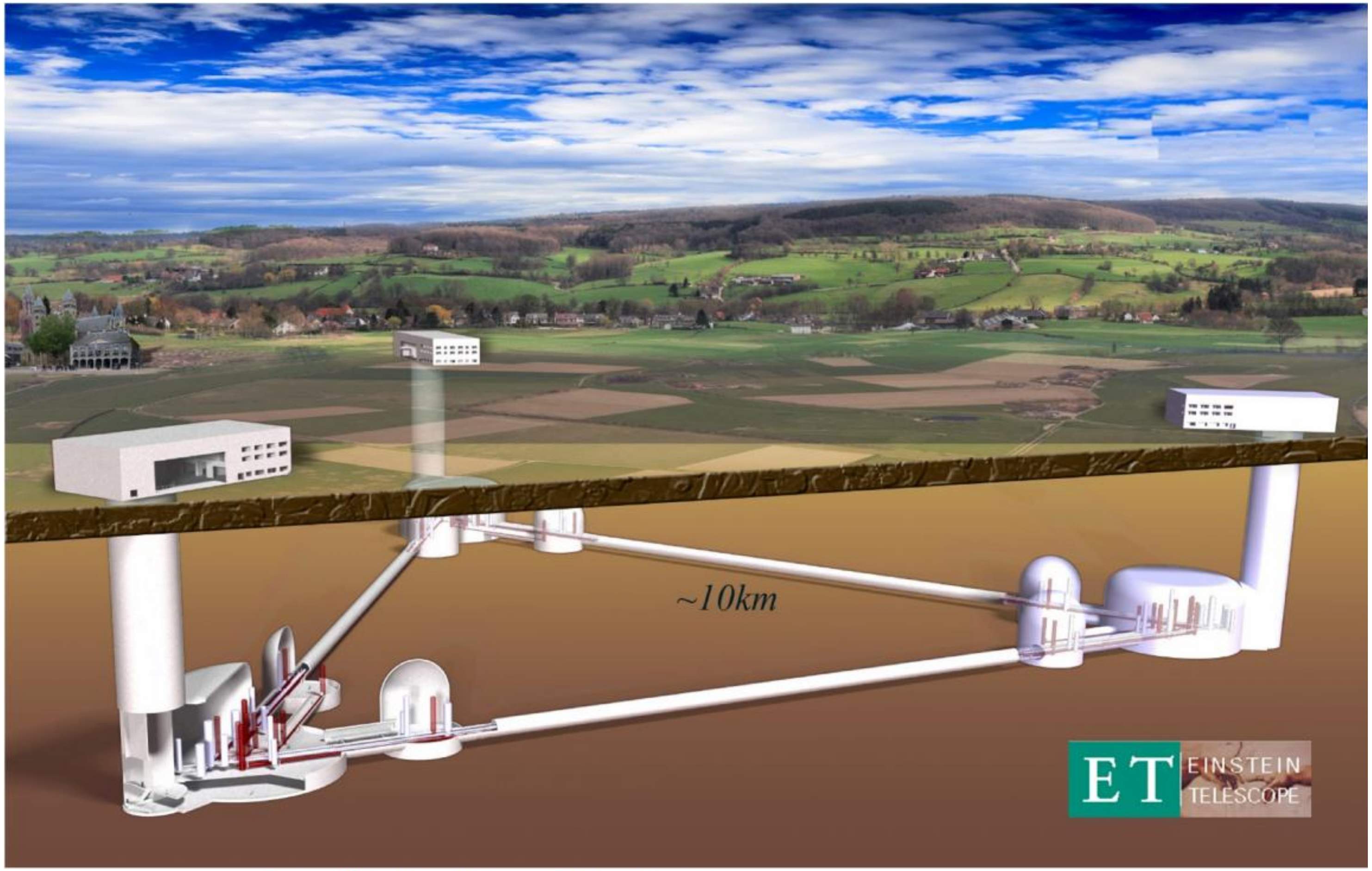
The Einstein Telescope design study

- The "what next" question has been posed since 2004:
  - ESF funded in 2005 an "Exploratory Workshop" on 3G GW observatories
    - Design Study idea
- Design study funded by the EC in FP7 (2008-2011)
  - Involving France, Germany, Italy, the Netherlands, UK
- Now the ET community includes also Hungary, Poland and Spain
- Project included in sectorial roadmaps (GWIC, APPEC, OECD,. …) and worldwide recognized as leading 3G project

The 3G/ET idea

- To realise a 3G new GW observatory
  - 3G: Factor 10 better than advanced (2G) detectors
  - New:
    - We need new infrastructure because
      - Current infrastructures will limit the sensitivity of future upgrades
      - In 2030 current infrastructures may be tending towards obsolescence
  - Observatory:
    - Wide frequency, with special attention to low frequency (few HZ)
      - Stellar mass Black Holes
    - Capable to work alone (characteristic to be evaluated)
      - Localization capability
      - Polarisations
      - High duty cycle: redundancy
    - 50-years lifetime of the infrastructure
      - Capable to host the upgrades of the hosted detectors

The Einstein Telescope



Scientific objectives of Einstein Telescope

Sathyaprakash, B. and Ajith, P. and Corsi, A. and Favata, M. and Harms, J. and Ott, C. D. and Santamaría, L. (2012) *Scientific objectives of Einstein Telescope.* Classical and Qua

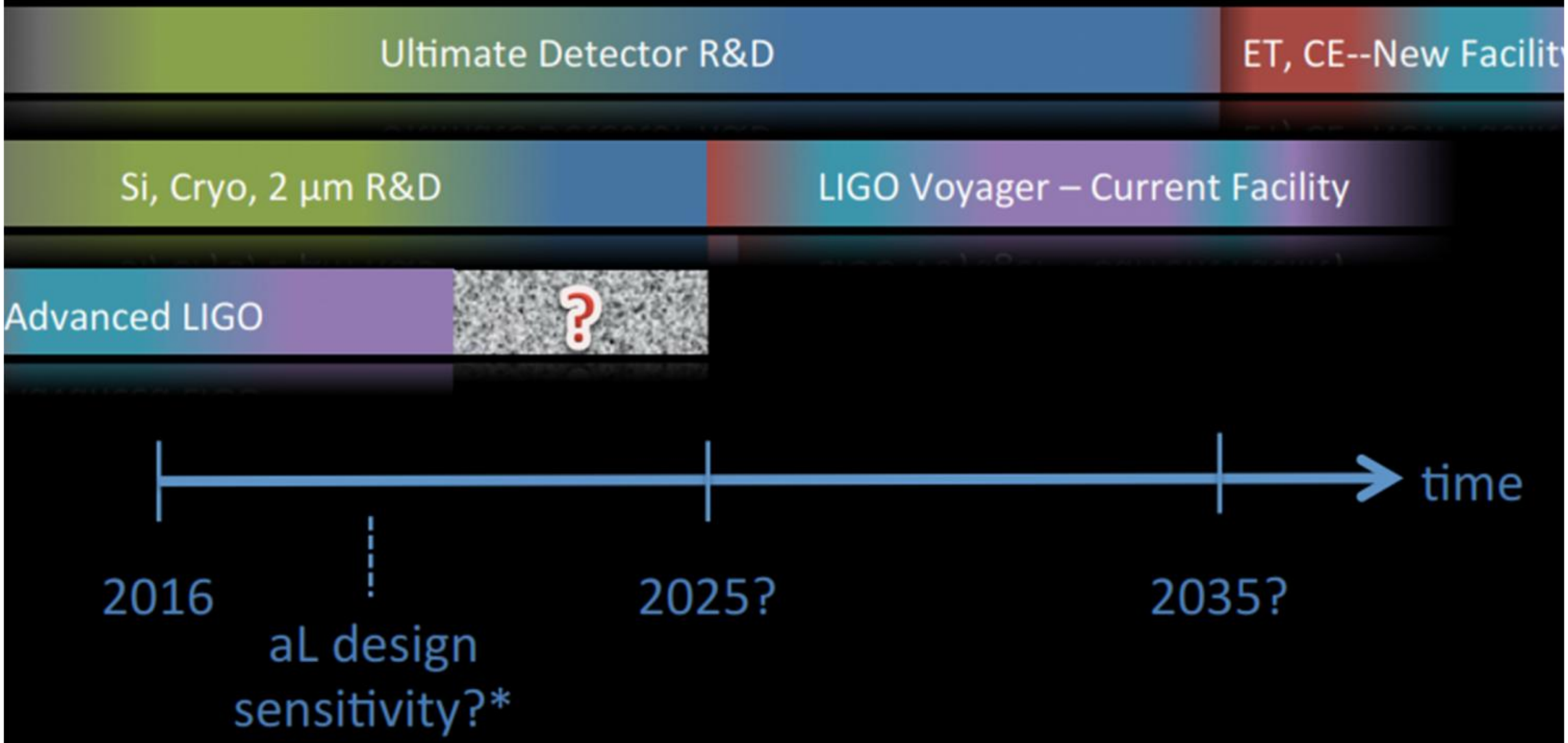
Abstract

The advanced interferometer network will herald a new era in observational astronomy. There is a very strong science case to go beyond the advanced detector network and build detectors that operate in a frequency range from 1 Hz to 10 kHz, with sensitivity a factor 10 better in amplitude. Such detectors will be able to probe a range of topics in nuclear physics, astronomy, cosmology and fundamental physics, providing insights into many unsolved problems in these areas.

Concept Roadmap: Bridging the Gap

(adapted from G1401081)

The path to 3G – adding in planning in the US



GWIC 3G sub-committee

- GWIC is conscious of the relevance of the global approach to 3G matters
- A sub-committee has been formed to deal with this subject:
  - Co-chairs: Dave Reitze, Michele Punturo

  Members:
  - Federico Ferrini - EGO Director/interface to Virgo related organisations
  - Takaaki Kajita - KAGRA Director
  - Harald Lueck - interface to German agencies
  - Jay Marx - Big Project Expertise
  - David McClelland - interface to Australian agencies
  - Michele Punturo - ET Design Study Lead
  - David Reitze - LIGO Director/interface to NSF
  - Sheila Rowan - GWIC Chair

\+ D. Shoemaker (secretary)

V. Kalogera, B. Sathyaprakash } Expertise in astrophysics/analysis

GWIC 3G sub-committee mandate

WG under composition: chairs V. Kalogera, B. Sathyaprakash

"Examining the path to a future network of observatories / facilities specifically":

1) Science Drivers for 3G detectors:

commission a study of ground-based gravitational wave science from the global scientific community, investigating potential science vs architecture vs. network configuration vs. cost trade-offs, recognizing and taking into account existing studies for 3G projects (such as ET) as well as science overlap with the larger gravitational-wave spectrum.

2) Coordination of the Ground-based GW Community:

develop and facilitate **coordination mechanisms** among the current and future planned and anticipated ground-based GW projects, **including identification of common technologies and R&D activities** as well as comparison of the specific technical approaches to 3G detectors. Possible support for coordination of 2G observing and 3G construction schedules.

3) Networking among Ground-based GW Community:

organize and facilitate links between planned global 3G projects and other relevant scientific communities, including organizing:

- town hall meetings to survey the community **(see later in this meeting)**
- dedicated sessions in scientific conferences dedicated to GW physics and astronomy
- focused topical workshops within the relevant communities

GWIC 3G sub-committee mandate

4) Agency interfacing and advocacy:

identify and establish **a communication channel with funding agencies** who currently or may in the future support ground-based GW detectors; communicate as needed to those agencies officially through GWIC on the scientific needs, desires, and constraints from the communities and 3G projects (collected via 1) – 3) above) structured in a coherent framework; serve as an advocacy group for the communities and 3G projects with the funding agencies.

5) Investigate governance schemes:

by applying knowledge of the diverse structures of the global GW community, propose a sustainable governance model for the management of detector construction and joint working, to support planning of 3rd generation observatories"

- The subcommittee should provide a preliminary report and set of proposed actions recommendations to GWIC no later than the 2017 GWIC meeting.
- Subsequent reports should be delivered future GWIC meetings.

GWAC – Gravitational Wave Agency Correspondents

- GW (“funding”) Agencies Committee
- Promoted by NSF, involving:
  - Australian Research Council (ARC)
  - Canada Foundation for Innovation (CFI)
  - Centre National de la Recherche Scientifique (CNRS)
  - Consejo Nacional de Ciencia y Tecnología (CONACYT)
  - Deutsche Forschungsgemeinschaft (DFG)
  - Istituto Nazionale di Fisica Nucleare (INFN)
  - National Aeronautics and Space Administration (NASA)
  - Science & Technology Facilities Council (STFC)

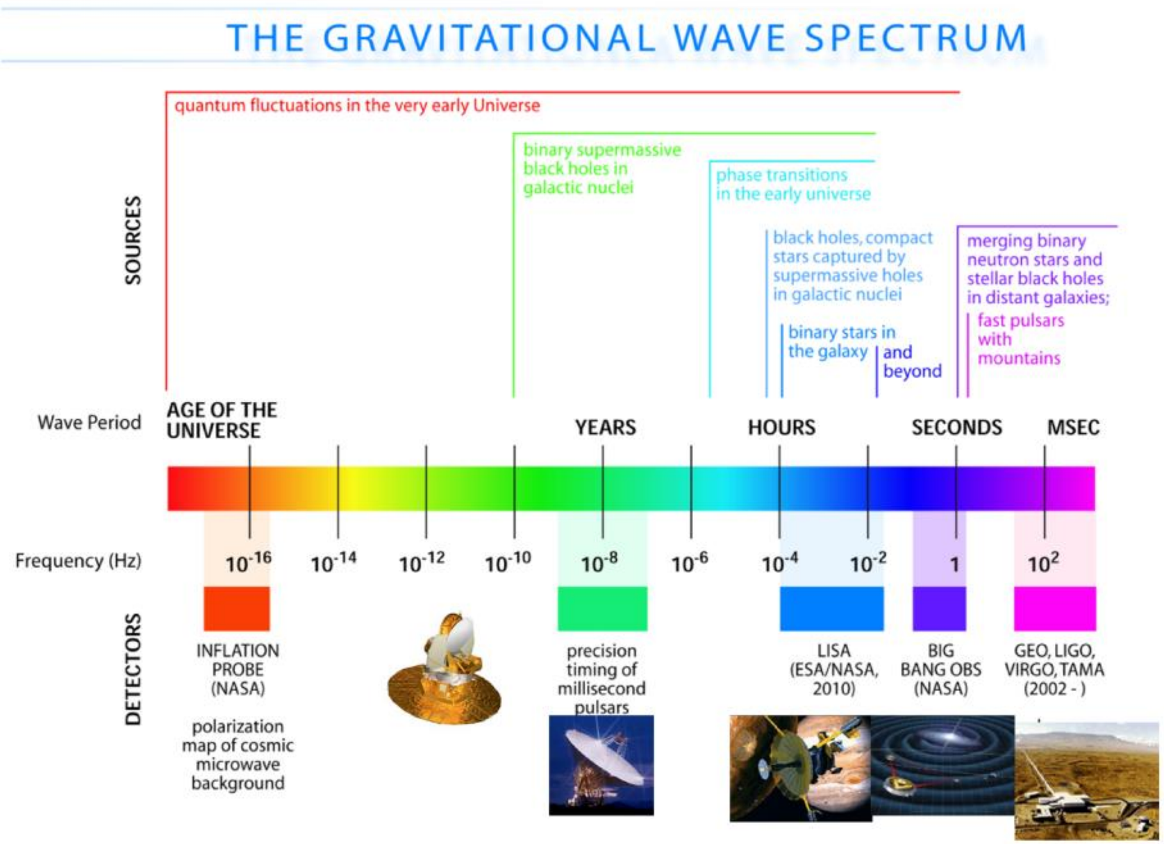
  +++ open invitation to interested agencies

Conclusions

- GW detection is a wonderful achievement, but it is mainly the beginning of the new era of the GW astronomy and astrophysics.

- New instruments will be needed to investigate the universe (across the whole spectrum of gravitational wave sources)

- New technologies and new infrastructures are needed for the future on the ground - and now it is time to articulate the science case, design and build them!



Thanks to Tarun Souradeep, Michele Punturo, Matt Evans, Mike Zucker, Osamu Miyakawa for slides