Gravitational Waves: Advanced-Generation Detectors

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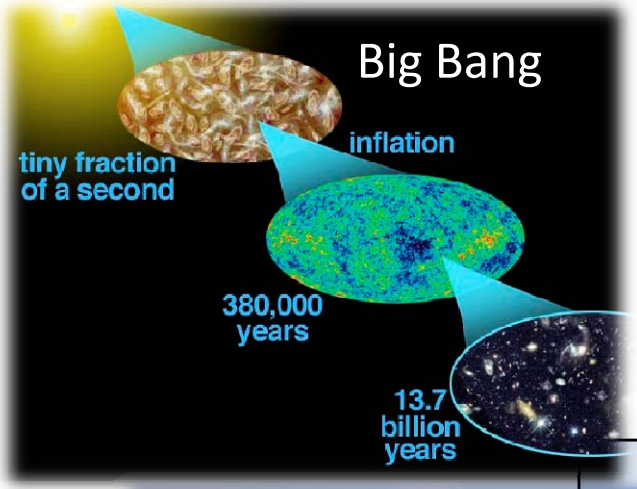
See also; S. Hughes's talk, parallel session talks (GW I and II)

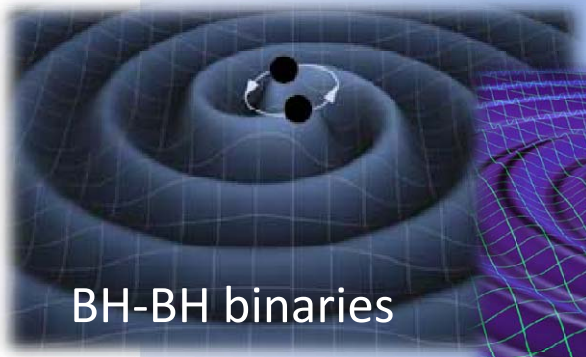
Outline

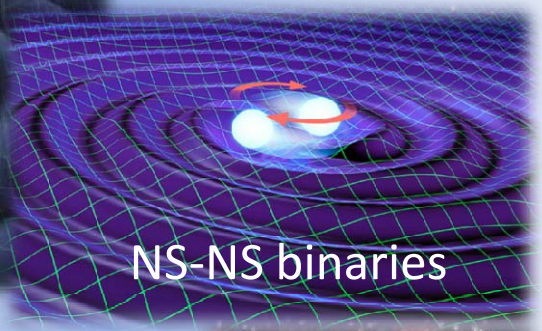
- Introduction
- Advance generation GW detectors
  - Initial to Advanced detectors
    - Advanced LIGO, Advanced Virgo, GEO
  - New advanced detectors
    - KAGRA
    - IndIGO
- Approximate Timeline
- Multi-messenger astronomy
- Beyond “advanced” generation: Einstein telescope (ET)
- Summary

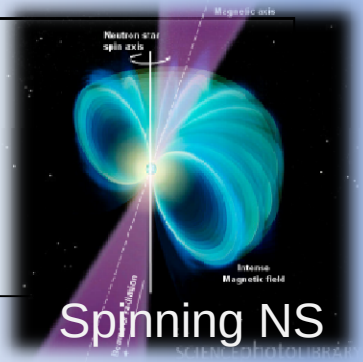
Introduction

Potential GW sources









?

(unexpected)

~1 Hz

Ground based laser interferometers

~1 kHz

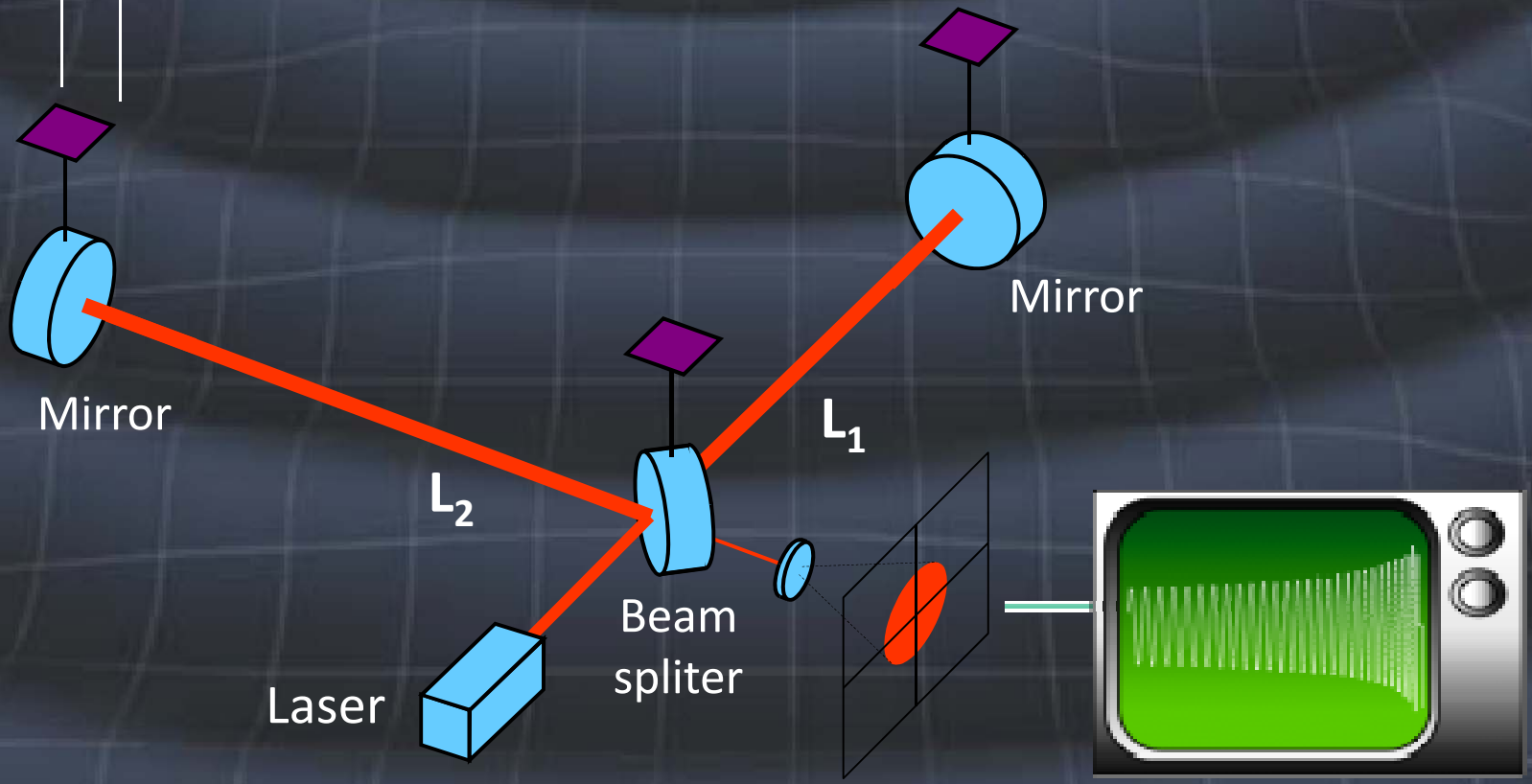
Low frequency

High frequency

Detectors: interferometers

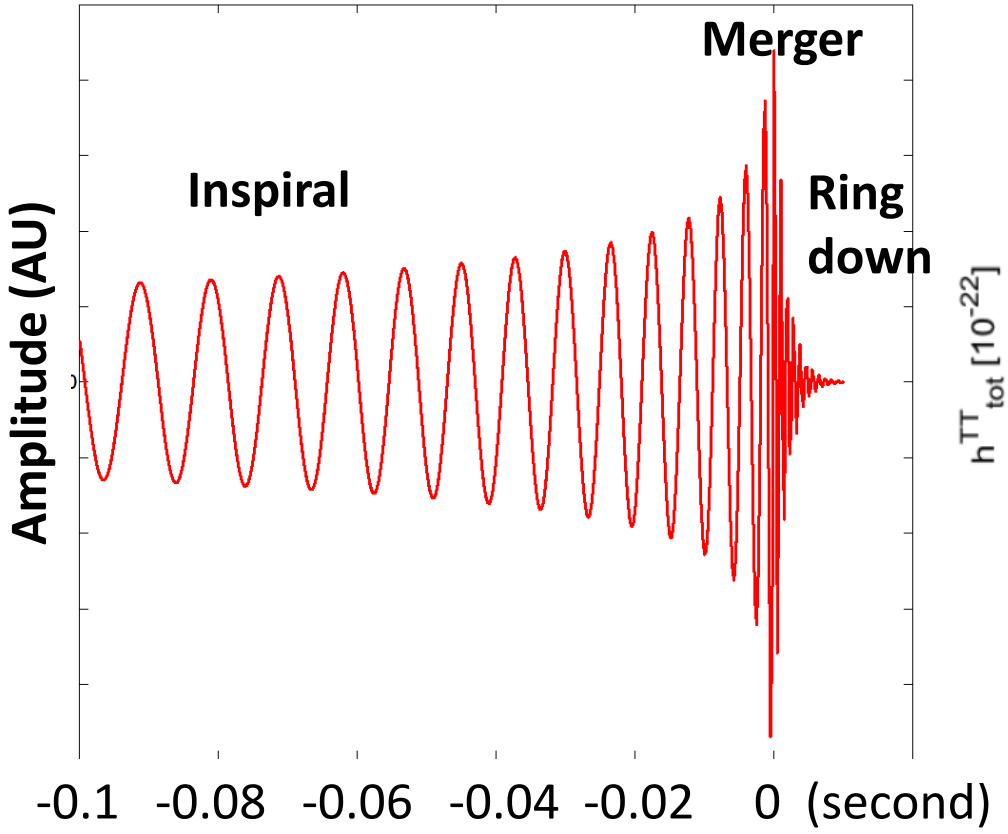
$\Delta L \sim 10^{-(16\sim17)}$ cm (for L = 3–4 km)

$\Delta L/L \sim 10^{-22}$



Expected signal

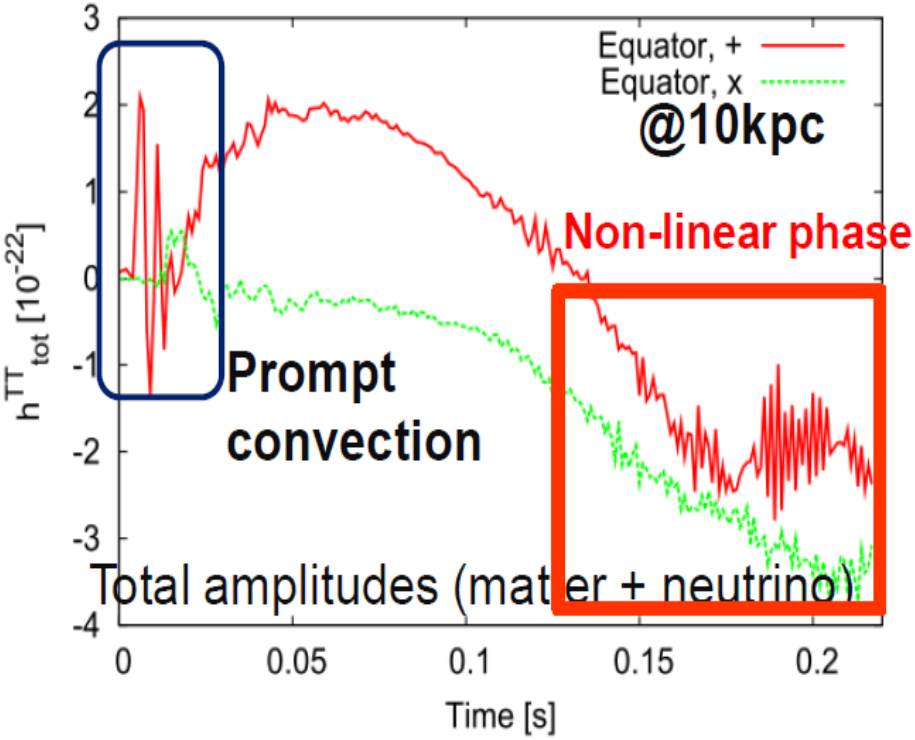
NS-NS merger



Supernova

3D, 11.2 M_{sun}

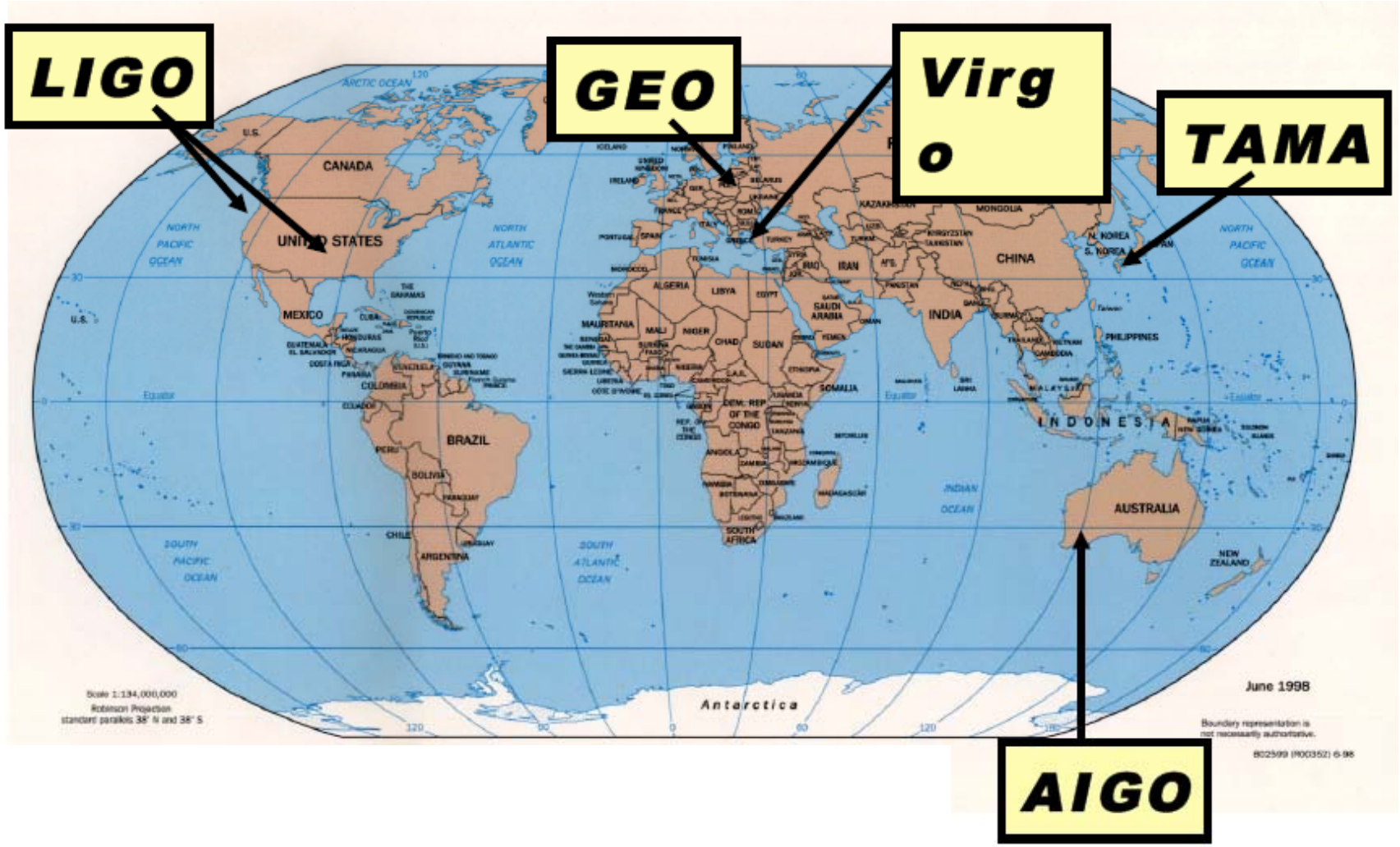
K. Kotake this meeting



(see also H.T. Janka this meeting)

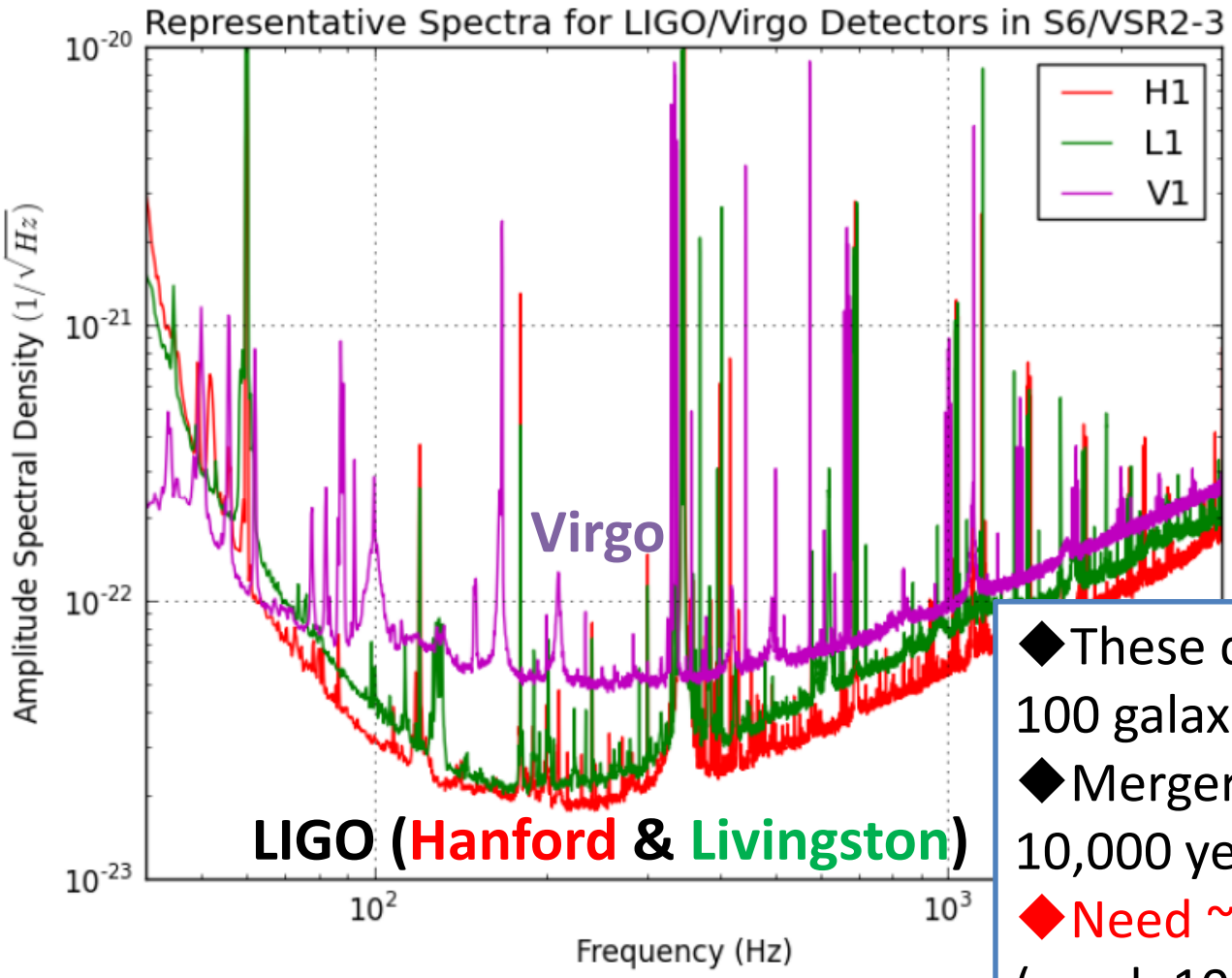
GW detectors 10 years ago

B. Barish TAUP2003



Sensitivity achieved so far (LIGO and Virgo)

LV arXiv:1203.2674

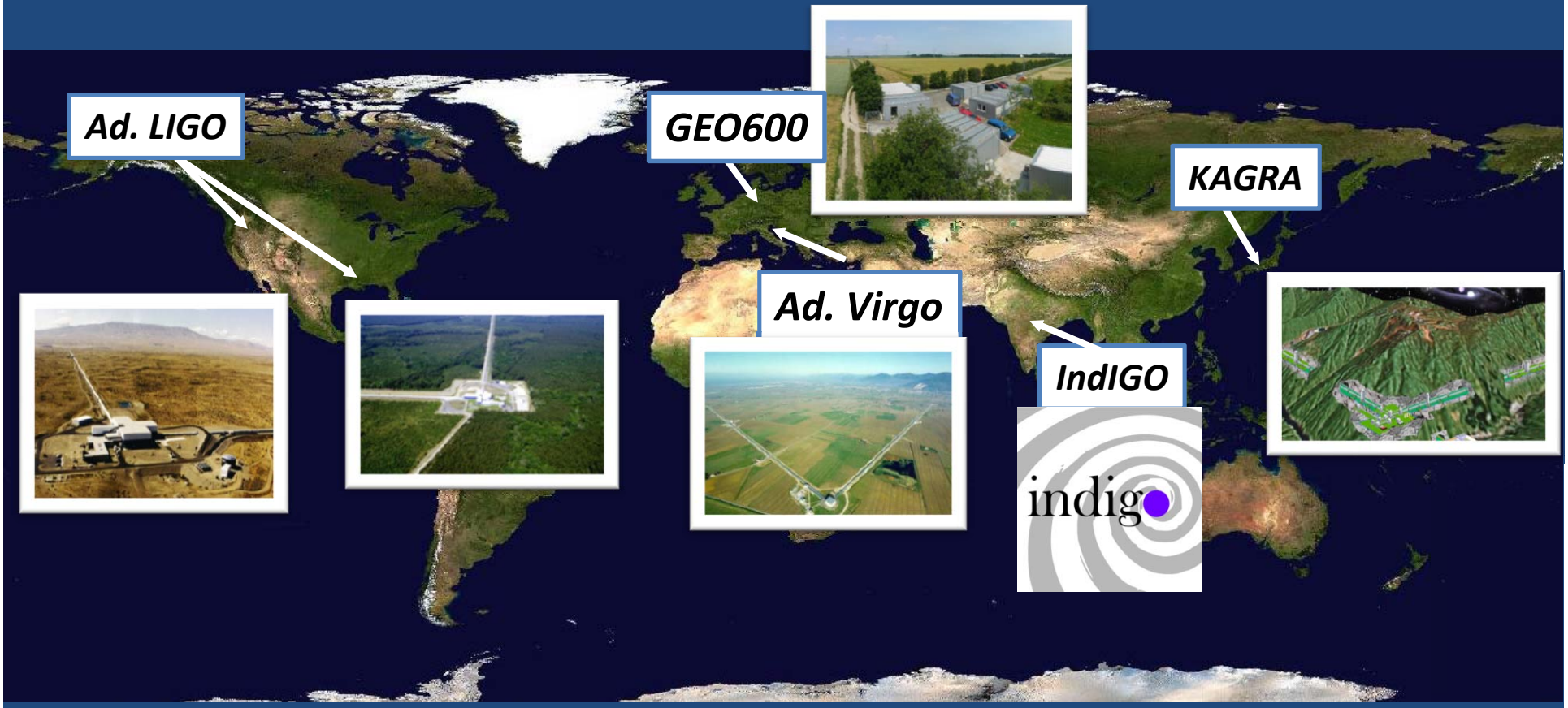


Detection Distance
(NS-NS merger)

~10 Mpc (Virgo)
~20Mpc (LIGO L &H)

◆These detectors reached about 100 galaxies.
◆Merger happens only every 10,000 years per galaxy.
◆Need ~10 better sensitivity (reach 100,000 galaxies).
➔ O(10) mergers per year.

Advanced generation GW detectors



What limits the sensitivity?

Must reduce the seismic noise

→Better seismic attenuation system

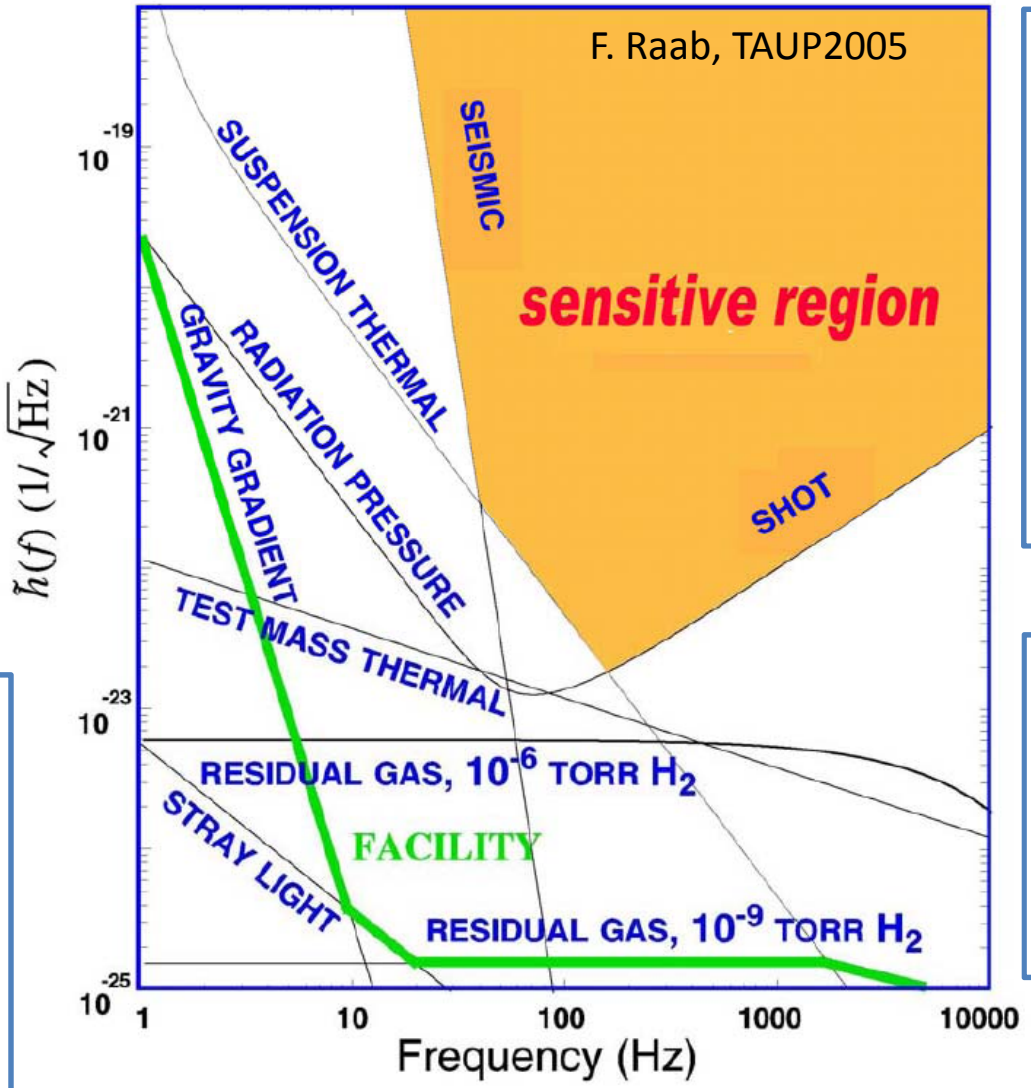
→ locate the interferometer in a much quieter place (underground)

Must reduce the thermal noises

→Better suspension

→ Cryogenic technology

→ …



Must reduce the shot noise

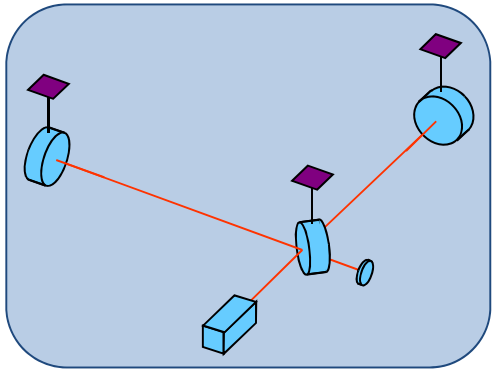
→ Stronger (and stable) laser

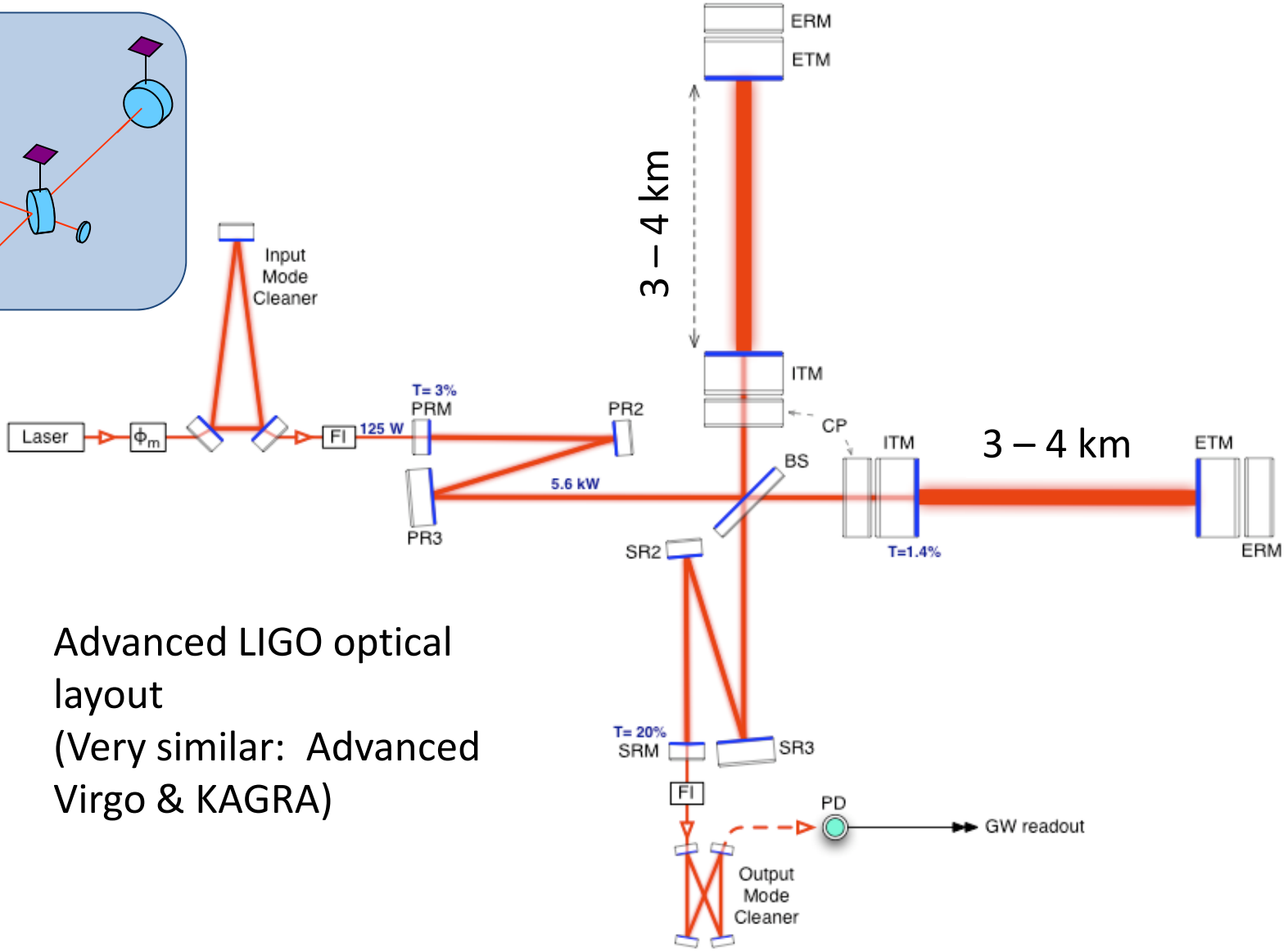
→ advance light source (squeezed light)

Must reduce the radiation pressure noise

→ Heavier test masses

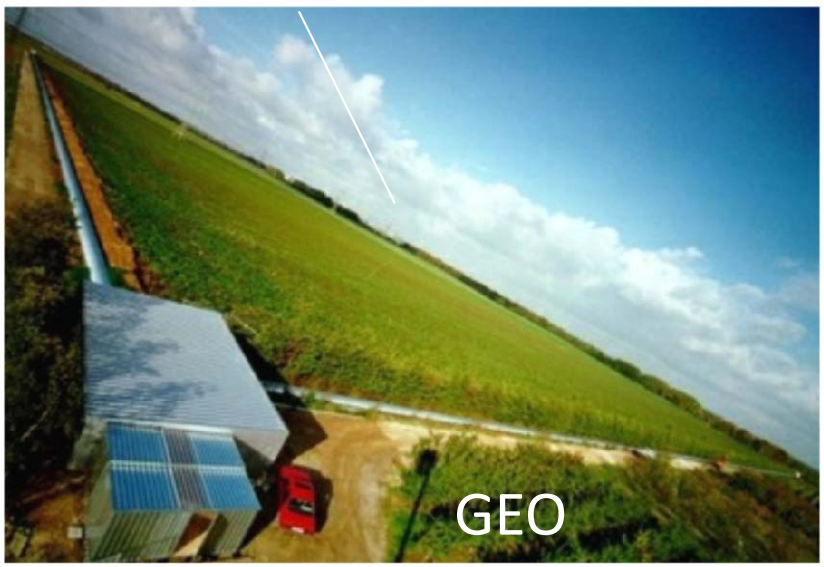
How the advanced detectors look like?



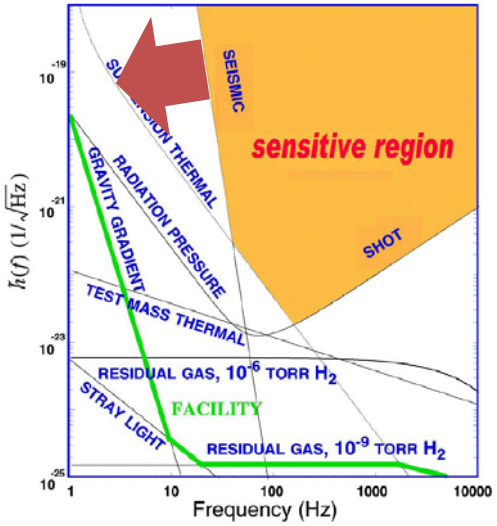


Advanced LIGO optical layout
(Very similar: Advanced Virgo & KAGRA)

Initial to Advanced detectors

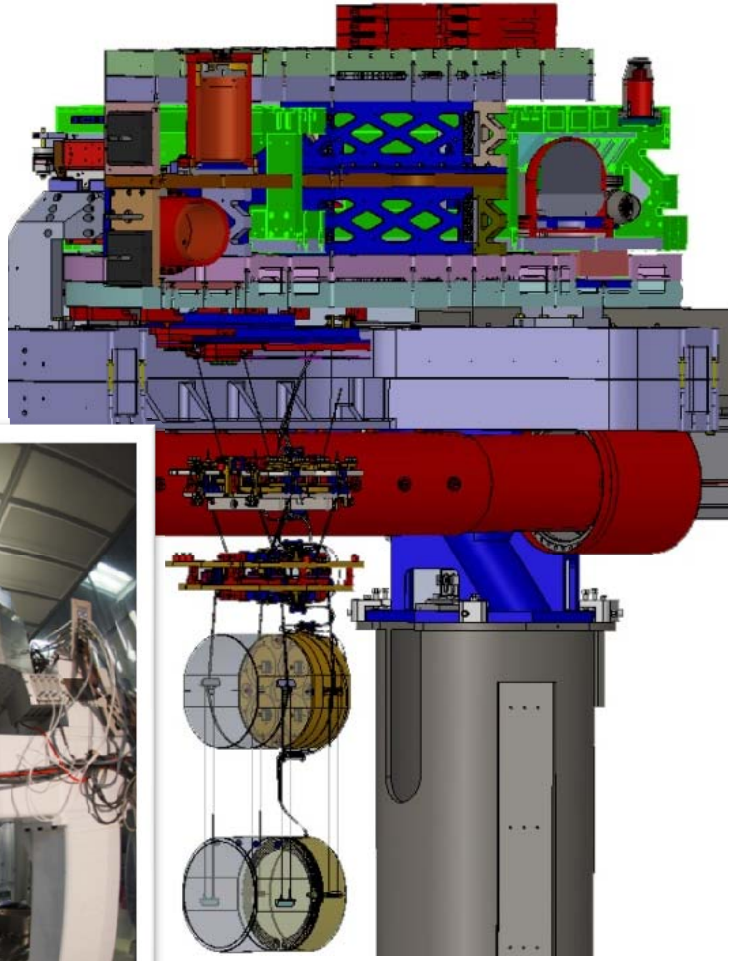


Advanced GW detectors: Seismic Attenuation



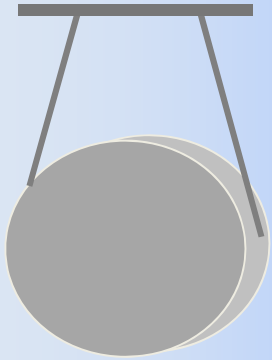
Advanced LIGO

Much more advanced (active, complicated) seismic attenuation and suspension system



Initial LIGO

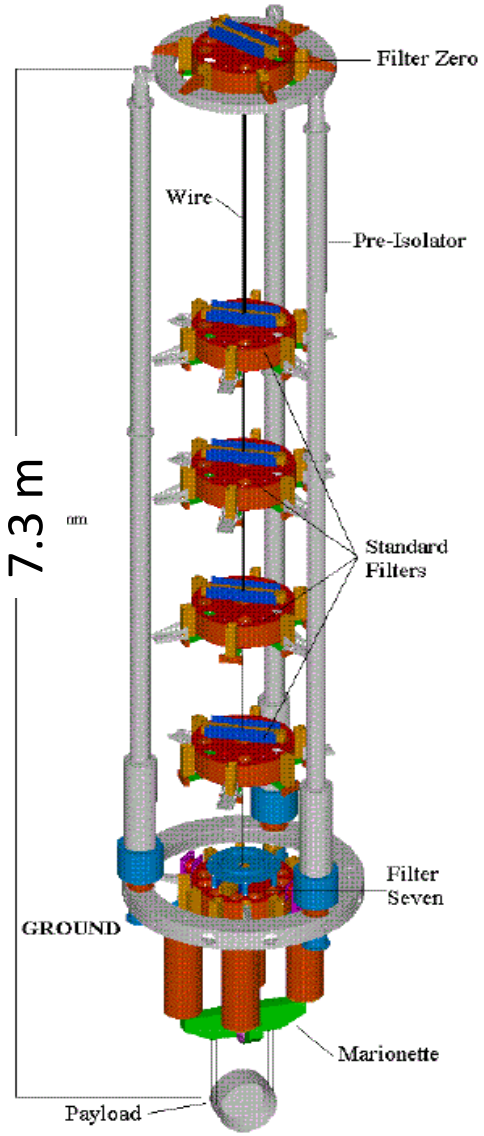
Simple Pendulum

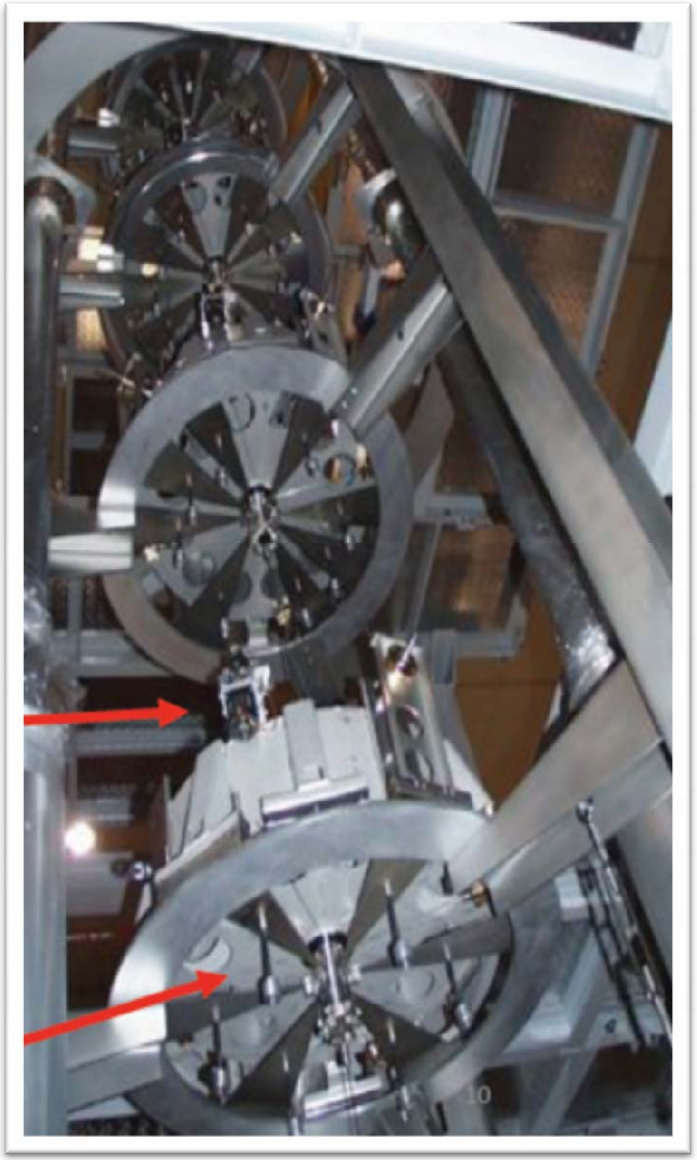


Advanced GW detectors: Seismic Attenuation

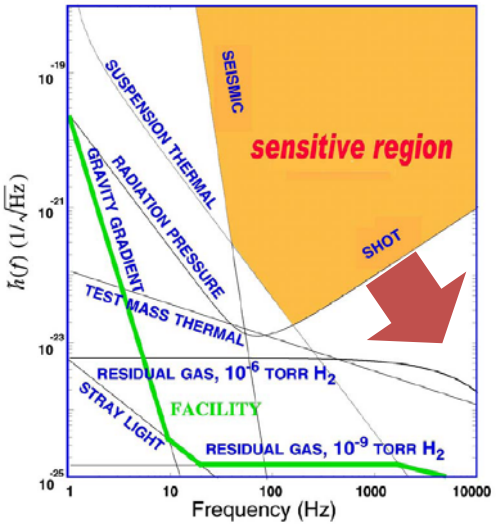
Advance Virgo

Advanced Virgo will use the essentially same *superattenuators* as Virgo.
(Good performance demonstrated)





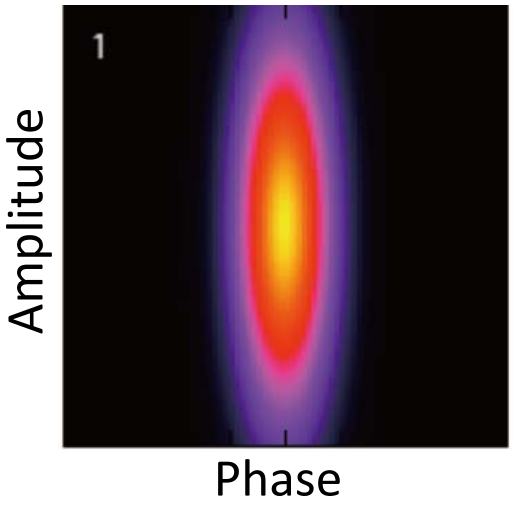
Advanced GW detectors: light source



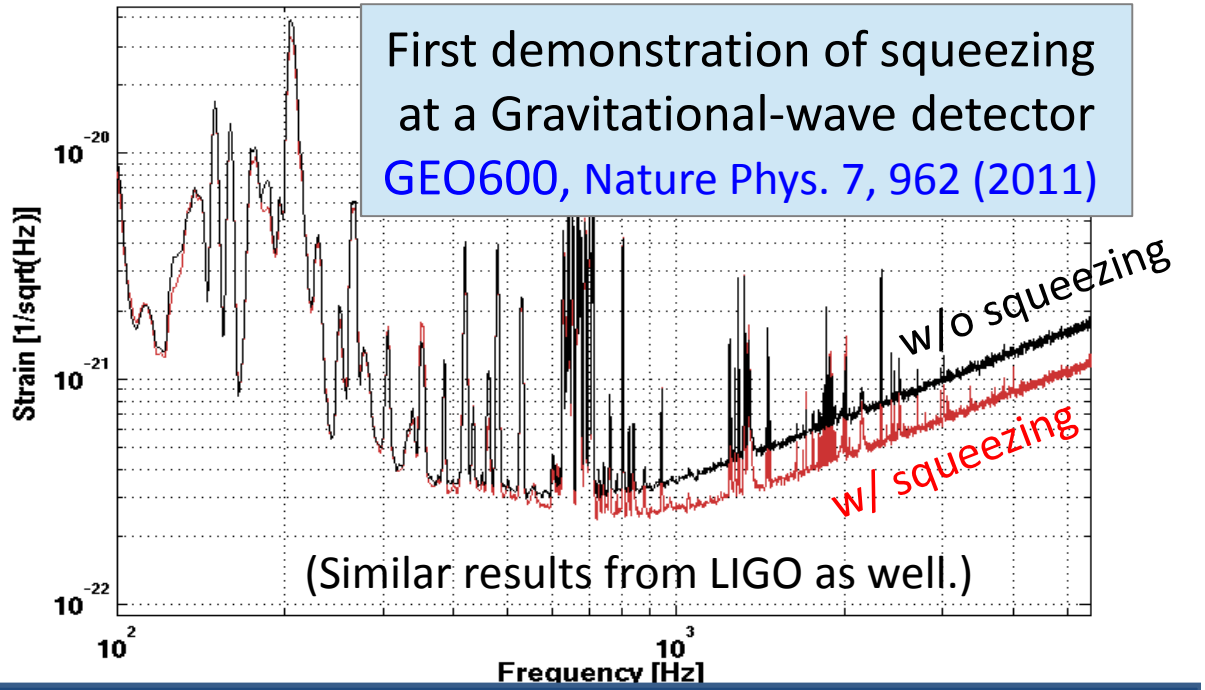
1. Need more photons:
10-40 W class laser →
200 W class laser

Example:
Advance LIGO
laser system

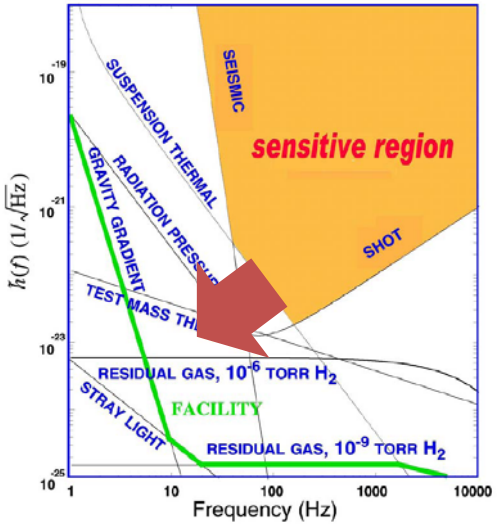
2. and/or squeezed light.

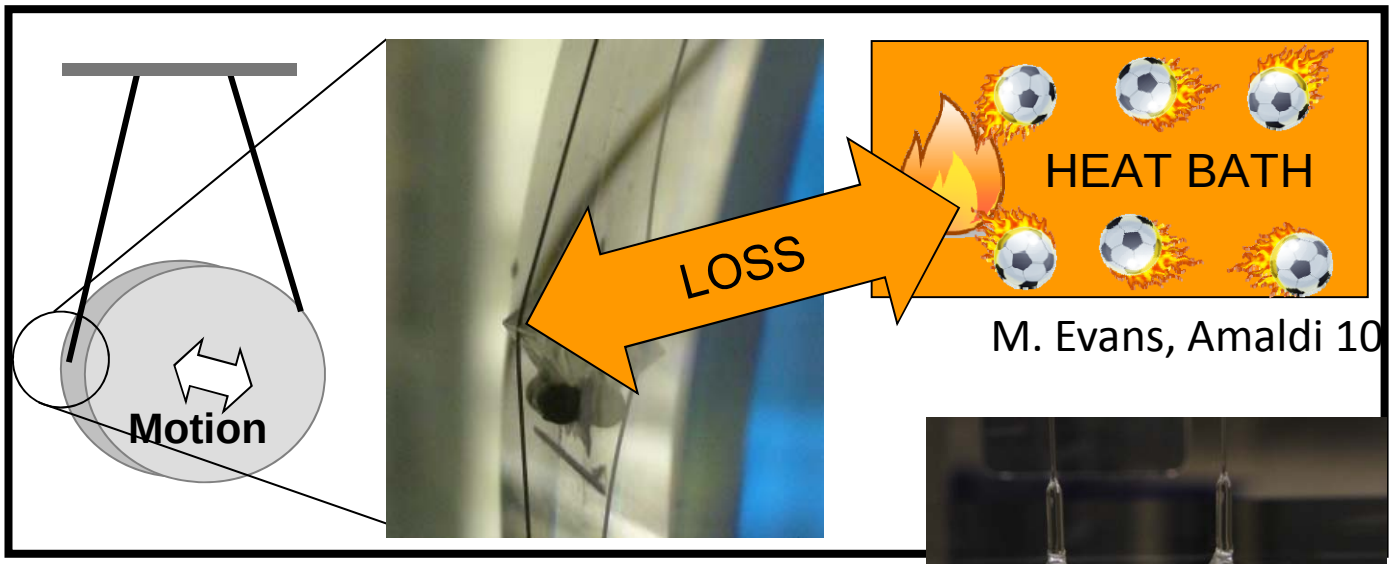


First demonstration of squeezing
at a Gravitational-wave detector
GEO600, Nature Phys. 7, 962 (2011)



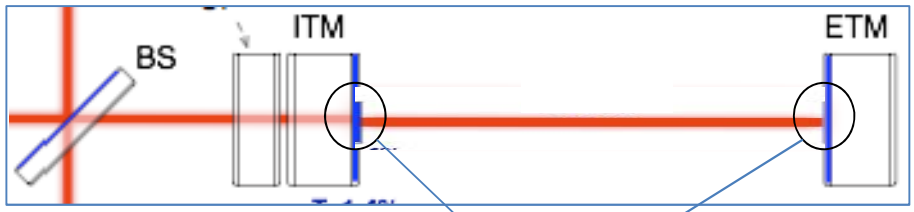
Advanced GW detectors: thermal noise reduction

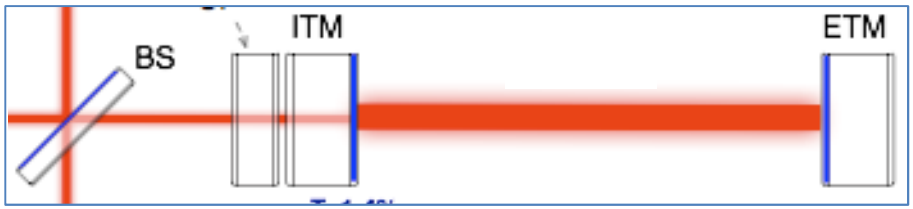




M. Evans, Amaldi 10

Better material with a better mechanical properties are required. Advanced LIGO and Virgo will not use wire suspensions. Instead silica fibers (for the test masses = 4 main mirrors) will be used.

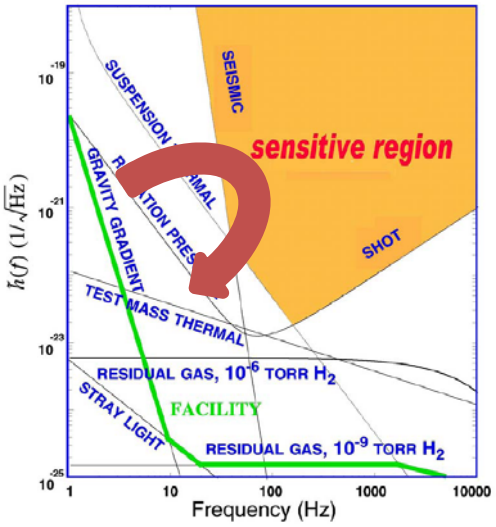


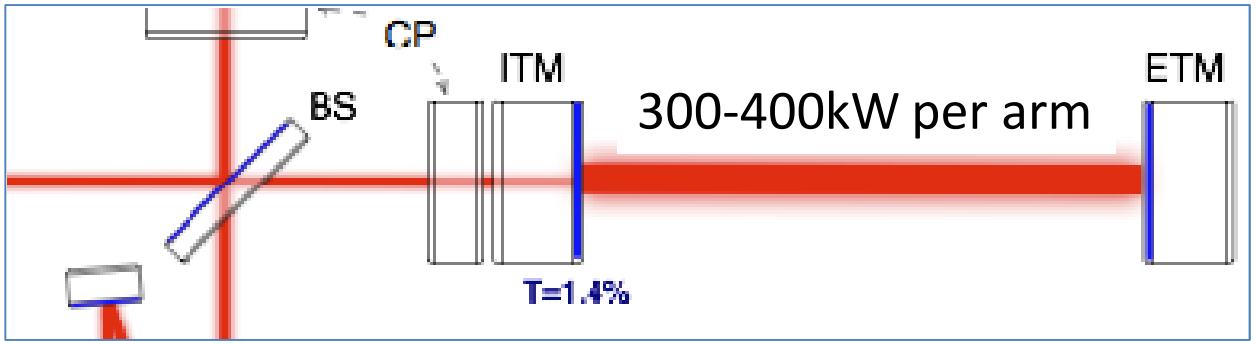


Thermal fluctuation
(Brownian noise)

Wider beam in Advanced detectors

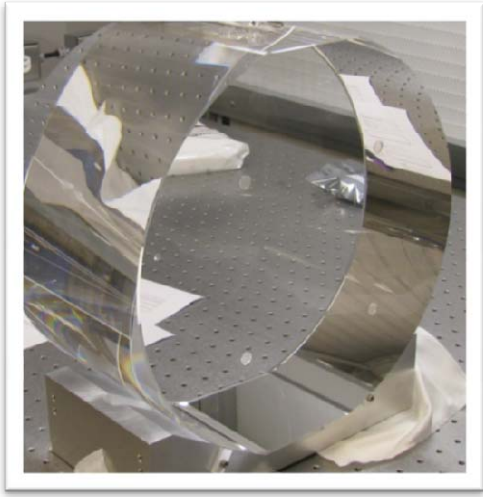
Advanced GW detectors: better and heavier mirrors





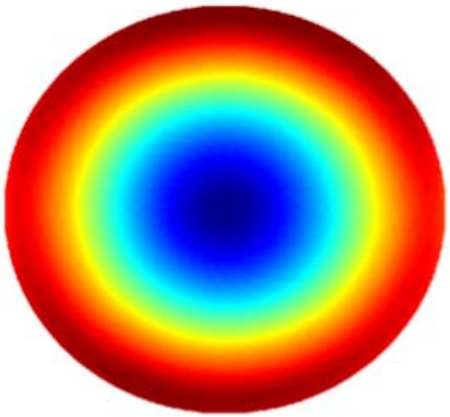
- Both Advanced LIGO and Advanced Virgo will use better and heavier mirrors.
  - ✓LIGO 10kg → Advance LIGO 40kg
  - ✓Virgo 20 kg → Advanced Virgo 42kg

Advanced LIGO

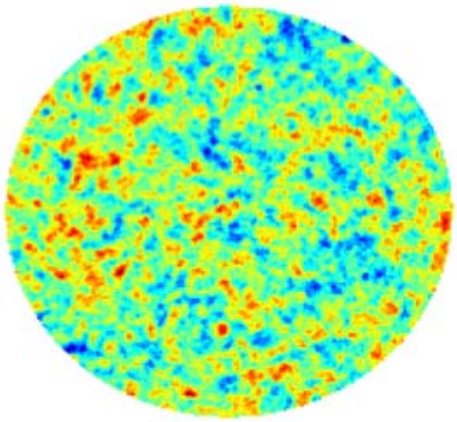


- 0.2 nm rms on 160 mm diameter (Advanced Virgo).

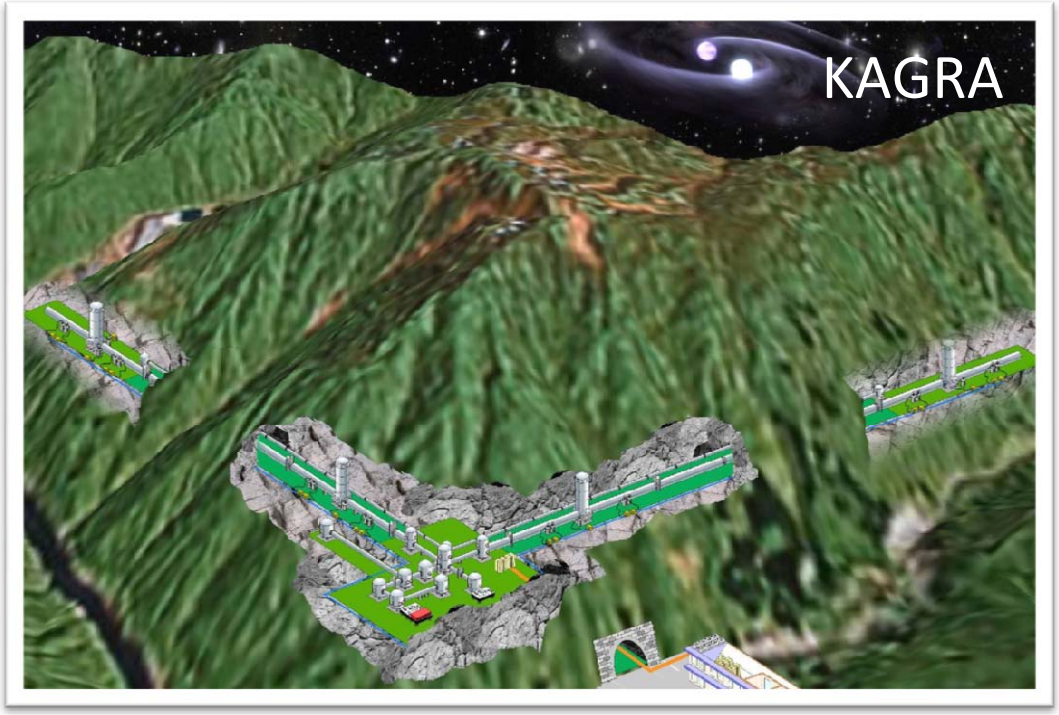
Polished surface



The residual (Ad. Virgo)

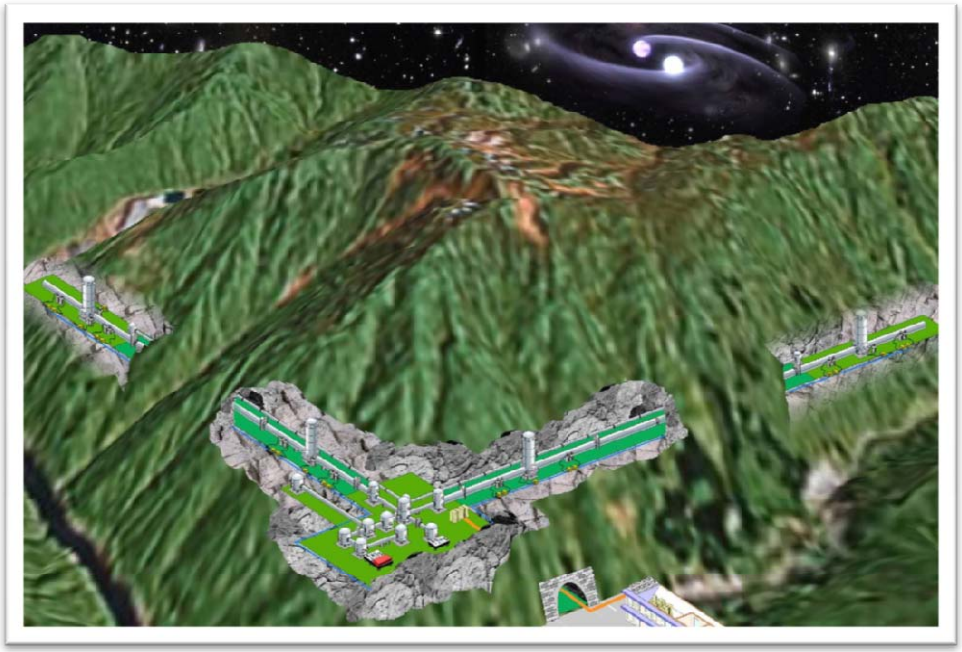


New advanced detectors



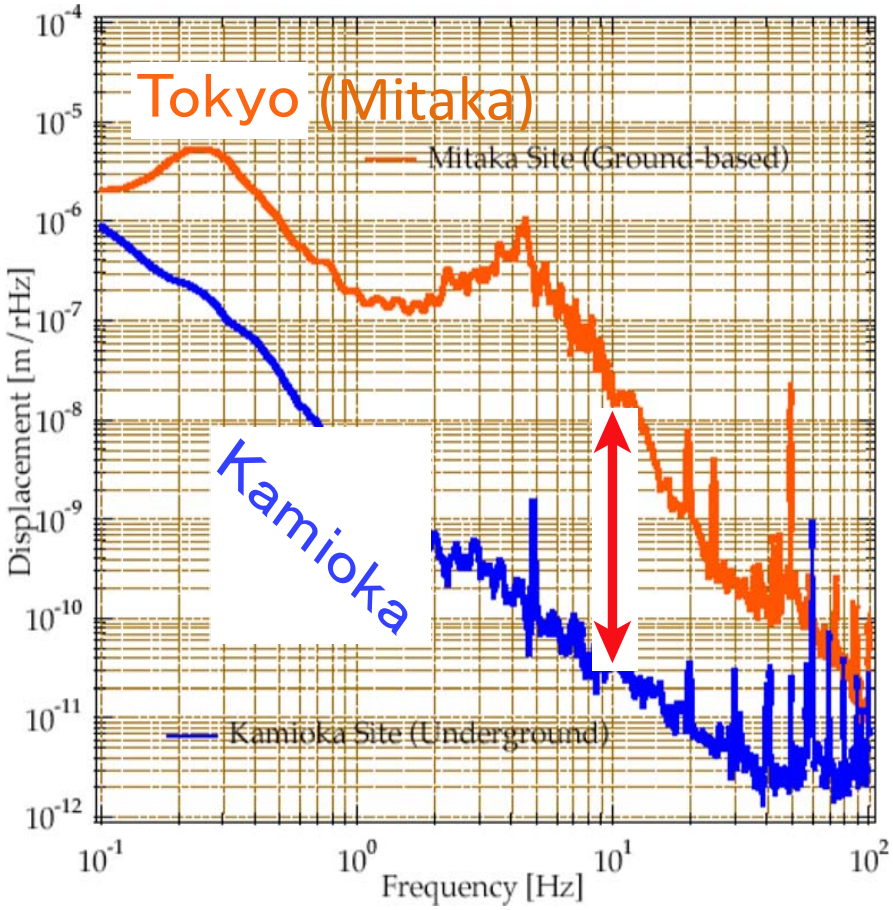
IndIGO (LIGO India)

New advanced detectors: 1. KAGRA



KAGRA is an advanced GW detector with 3km arm lengths. Many features are similar to Ad. LIGO and Ad. Virgo. However, there are 2 noticeable differences;

1) *Located underground,*
2) *Directly reduces the thermal noise using cryogenic mirrors.*



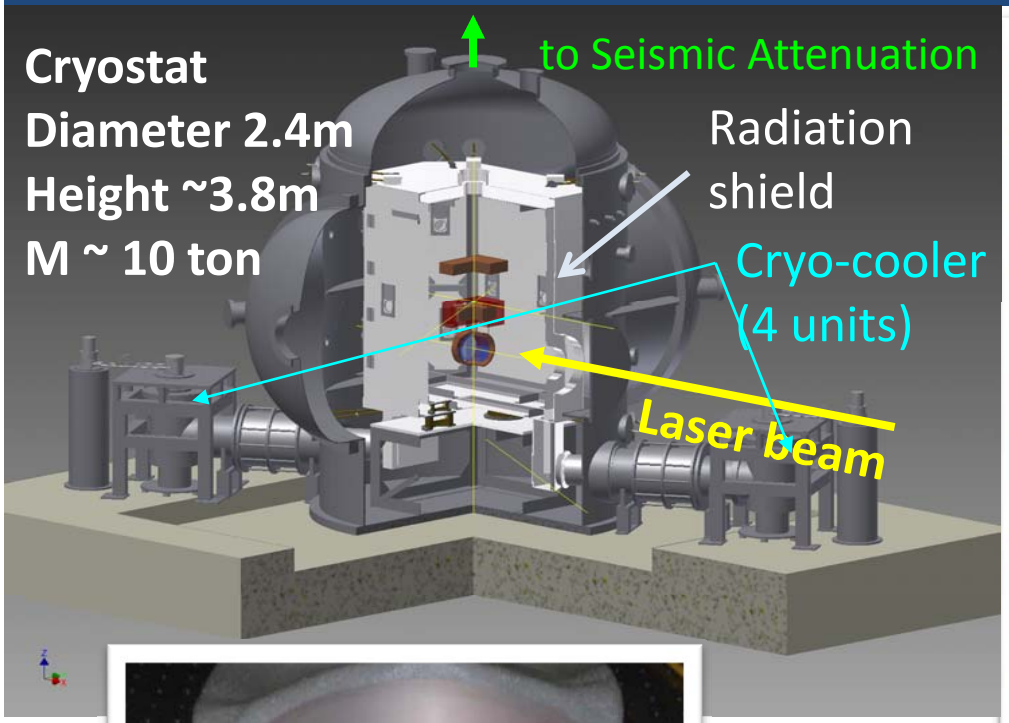
Amplitude of seismic motion

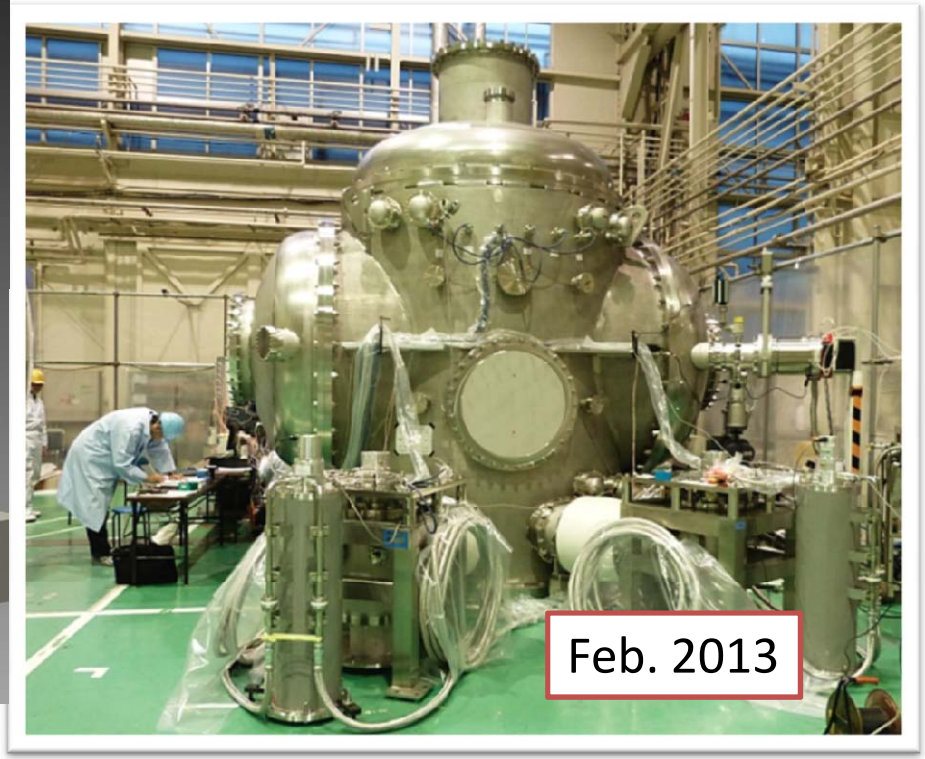
New advanced detectors: 1. KAGRA (Underground)

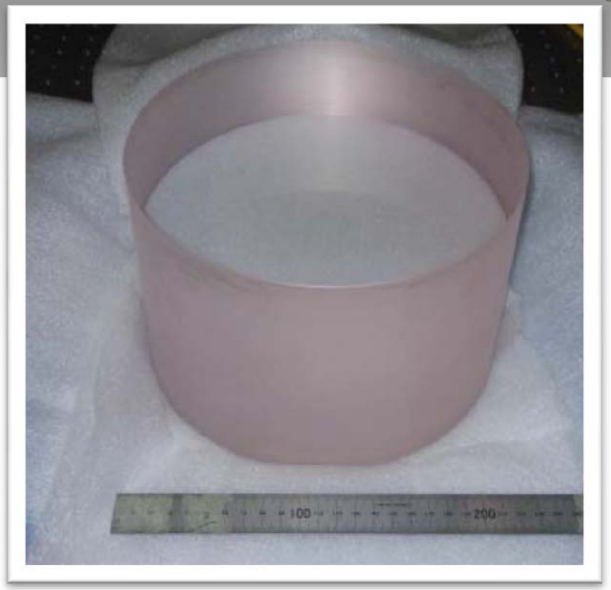
To laser room　　To Y-arm　　To X-arm

- Approximately 2/3 excavated.
  - ✓1.7km/3km of the X-arm excavated.
  - ✓2.35km /3km of the Y-arm excavated.
  - ✓2/3 experimental area excavated.
- Will finish in March 2013.

New advanced detectors: 1. KAGRA (Cryogenic)







- 4 cryostat for the main mirrors were produced and tested.
- Production of sapphire crystals of 23kg (22cm diameter and 15cm thick) started. (The quality yet to be measured. They are not polished yet.)

New advanced detectors: 2. IndIGO (LIGO India)

●***Construction and Operation of a Advanced LIGO Detector in India in collaboration with the LIGO Lab.***

◆hardware components of the Ad. LIGO detector ◆designs and software	◆infrastructure (including the 4+4 km beam tubes, etc) ◆team to build and operate the Observatory
LIGO-USA and its partners.	India

✓August 2012: National Science Board (USA) approved the proposed Advanced LIGO Project change in scope, enabling plans for the relocation of an advanced detector to India.

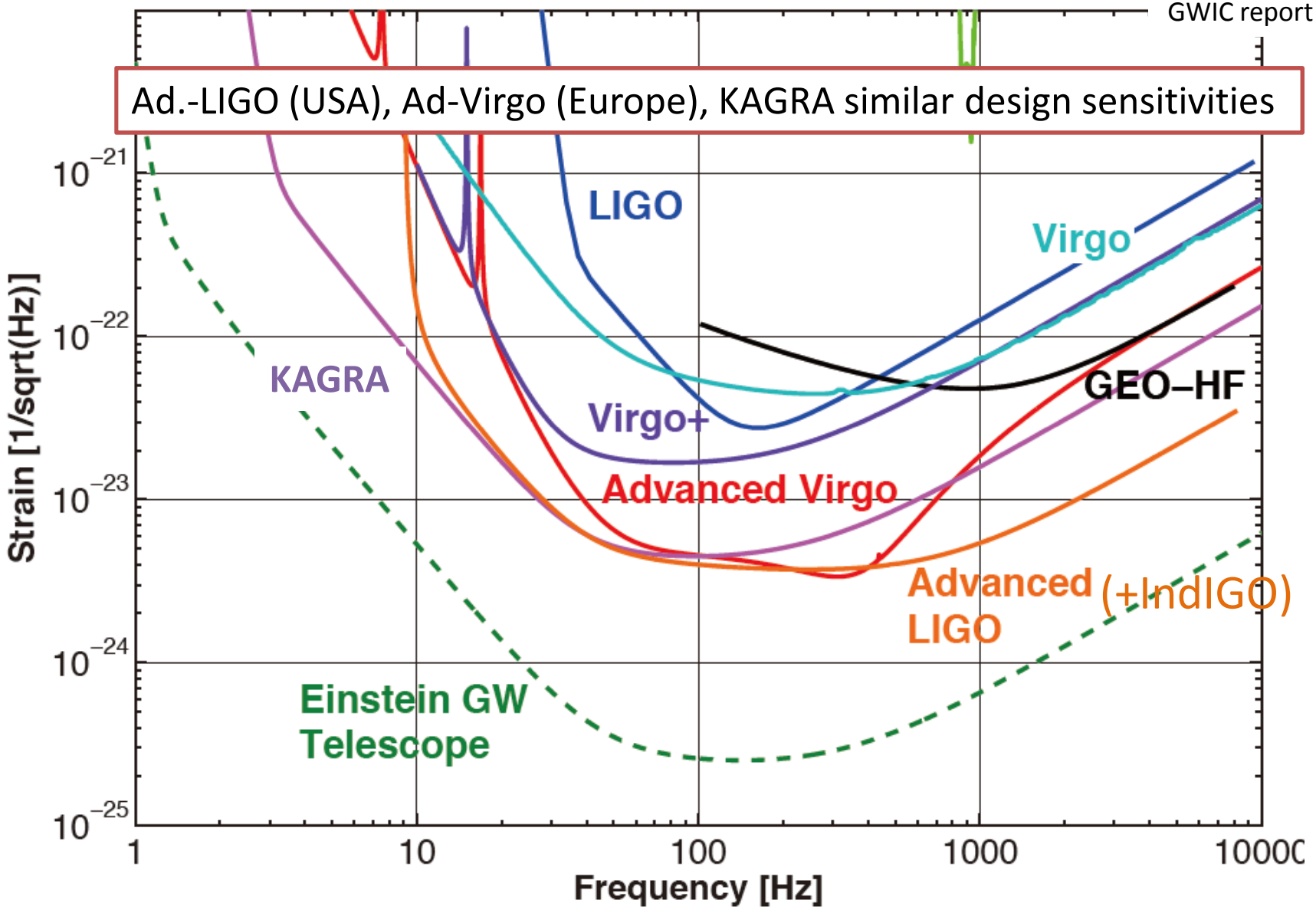
✓Sept 2013: Expected submission of note from Department of Atomic Energy (DAE, India) for Cabinet approval of the LIGO-India Project.

✓***Starting operation by 2020.***

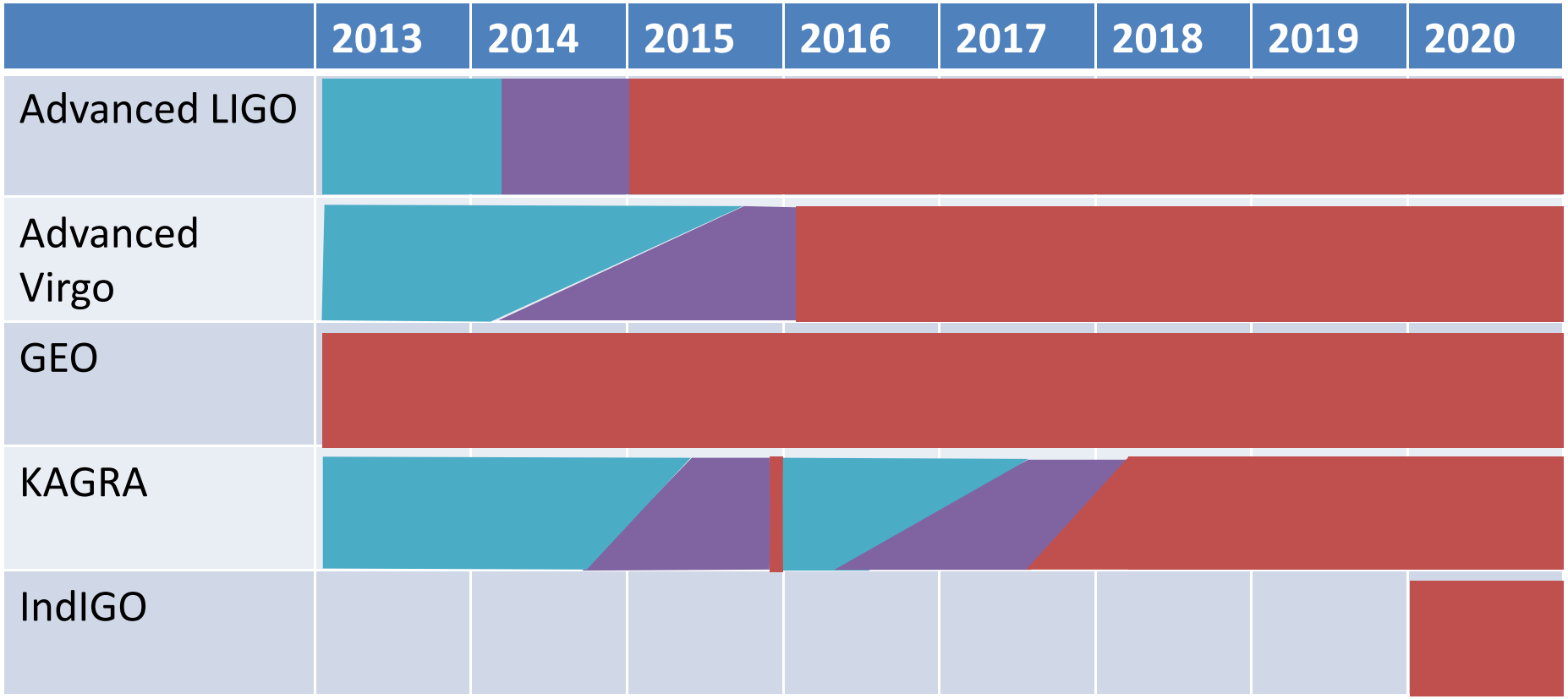
Comparison of sensitivities

GWIC report (2010)

Ad.-LIGO (USA), Ad-Virgo (Europe), KAGRA similar design sensitivities



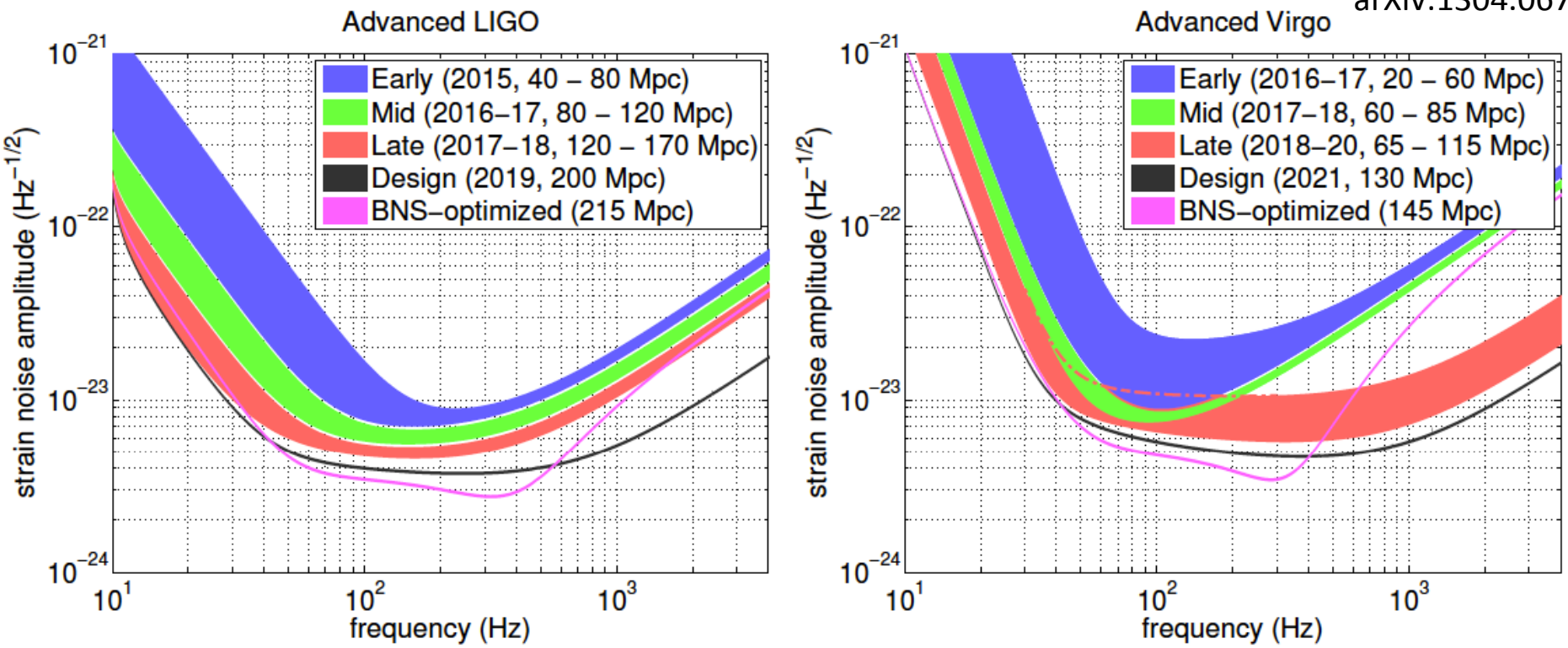
Approximate Time line



Note: the definition for integration and commissioning depends on the project.

Projected sensitivities

arXiv:1304.0670



◆"Likely" detection during the Mid period (2016-2017 Ad. LIGO, 2017-18 Ad. Virgo)

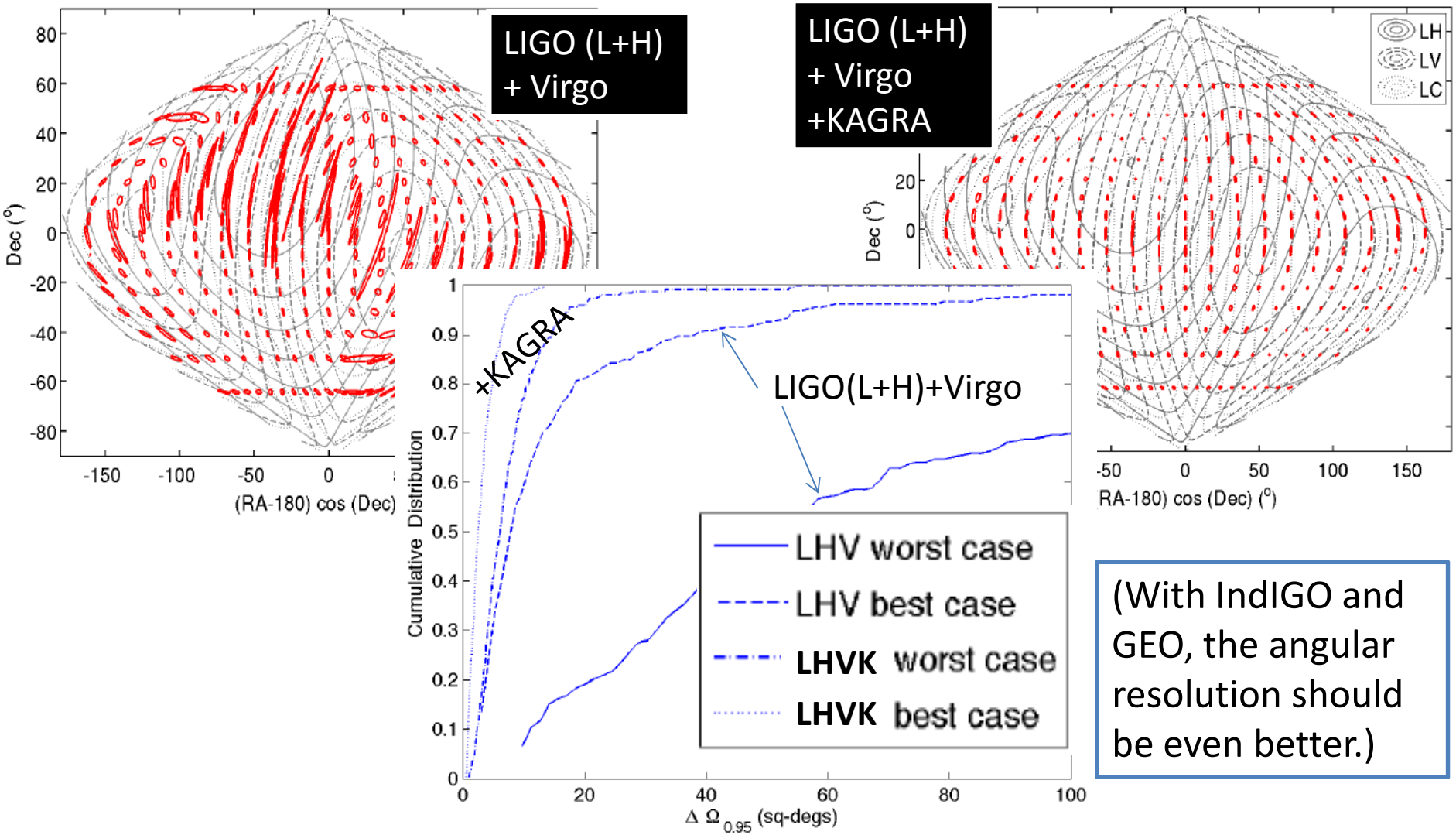
◆KAGRA will start observation in 2017, but the detection range as a function of time not evaluated yet.

◆ With the "design" sensitivity, typical NS-NS rate will be ~10 (Ad. Virgo, KAGRA) to ~40 (Ad. LIGO).

Importance of Global GW Network: Angular res.

Wen and Chen, arXiv: 1003:2504

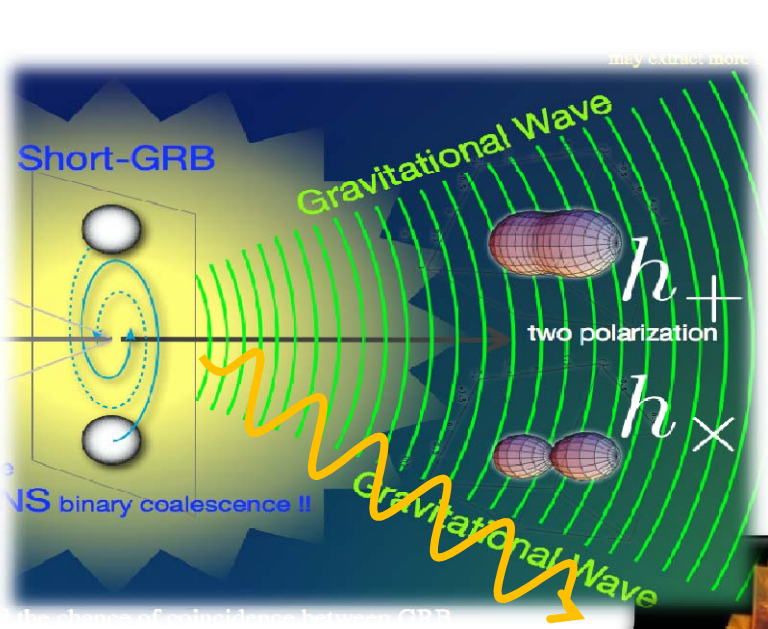
Determination of source sky position: 95%CL, supernova, S/N =10



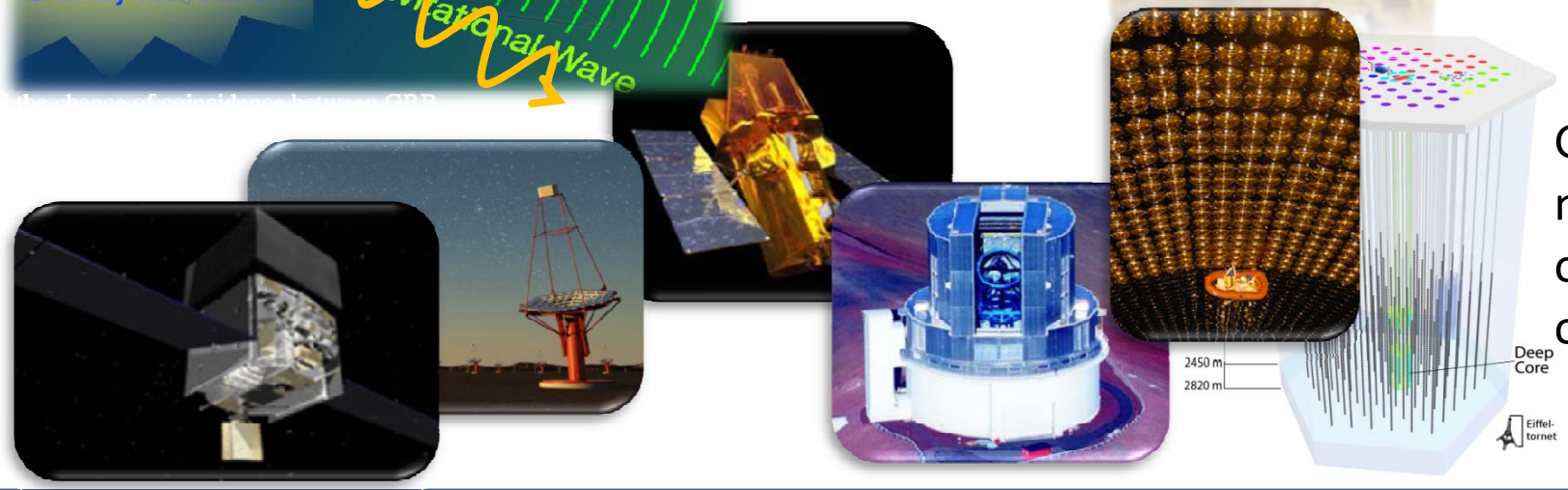
(With IndIGO and GEO, the angular resolution should be even better.)

Multi-messenger astronomy:
Example: Short Gamma Ray Burst

✓ NS-NS binary might be a progenitor of Short-GRB ?

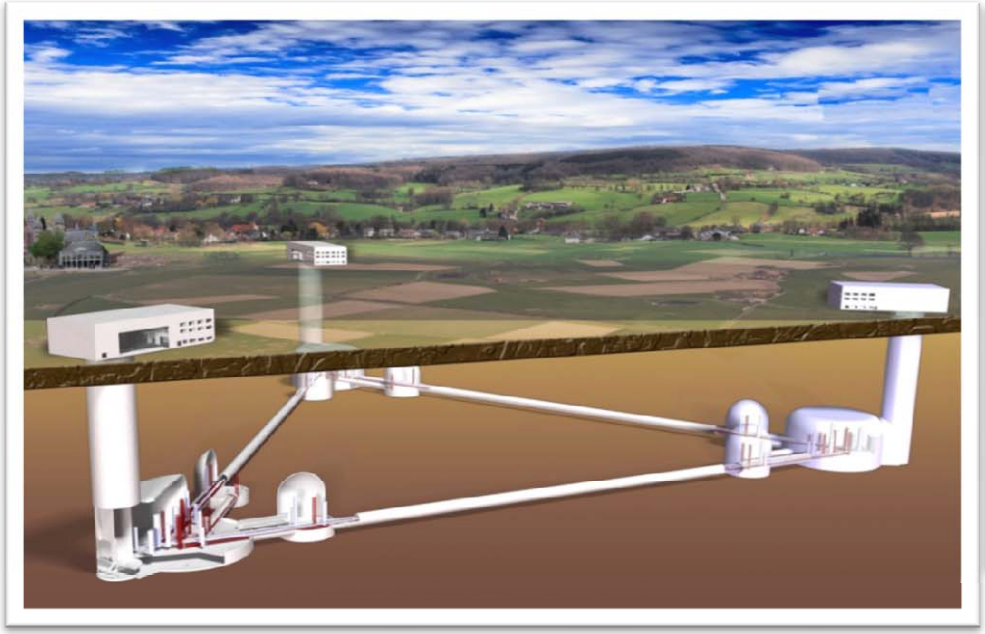


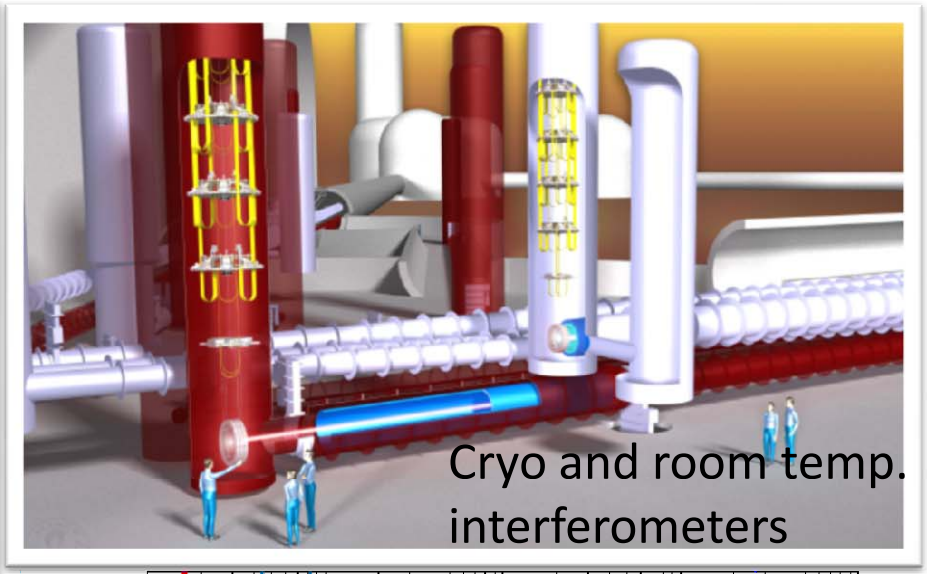
Gravitational wave (Ad.LIGO, Ad.Vergo, KAGRA, IndIGO)



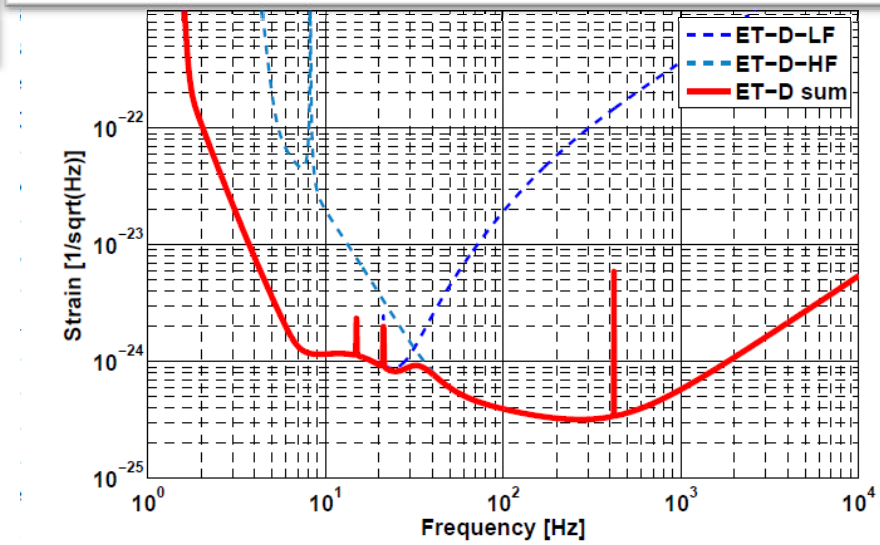
Gamma ray, neutrino and optical observations

Beyond "advanced" generation:
Einstein Telescope (ET)





◆Another 1 order improvement in sensitivity
◆A lot of science!
◆R&D going on with the ASPERA framework
◆Joint R&D effort with KAGRA (ELiTES)
◆Start science run in the late 2020's ?



Summary

- A lot of activities are going on toward the detection of gravitational waves with the advanced detectors in Amorica (Advanced LIGO), Europe (Advanced Virgo, GEO) and Asia (KAGRA, IndIGO).

- TAUP2015: Advanced detector(s) started operation.
- TAUP2017: First GW signal!
- TAUP2019: >3 fold coincidence with detectors in North America, Europe and Asia!
- TAUP2021: 5 deg^2 determination of GW source and "multi-messenger astronomy w/ GW"!
- TAUP202X: Many GW science results!