日本天文学会
@鹿児島大学

Status of LCGT

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On behalf of LCGT Collaboration

Generation of Gravity wave

- Gravity waves are produced dynamic motion of massive terrestial objects. Here consider the radiation by simple rotating equal masses
- Radiation formula of EM

$$\textit{Luminosity} = (2/3c^3)\, e^2 a^2$$

- Radiation from Mass dipole moment = 0
- Radiation of mass quadrupole moment is the lowest term of gravity wave
- Gravity wave luminosity = $(G/5c^5)(\dddot{\mathbb{I}})^2$

  $\mathbb{I} = I_{jk}\, I_{jk}$, $I_{jk} = \Sigma m_A(x_{Aj}x_{Ak} - 1/3\delta_{jk}r_A{}^2)$

  I_{jk}: the reduced quadrupole moment

Test of General Relativity by direct detection of GW

Opening GW Astronomy

- First detection is desired in GW community
- Possible Alarm by GW (international network)
  - Positioning sources by the order less than 1 degree (LVJA)
  - Alarming, the faster, the better
- Short gamma ray burst may be coalescence of CBC
- Long gamma ray burst may be SuperNova explosion
- EM Follow-up : Telescopes are set within 30 minutes (Urbino U)
- Coincidence analysis with neutrino of ANTARES : no traces yet (MPI AEI)

Near future

Ground based detector

+

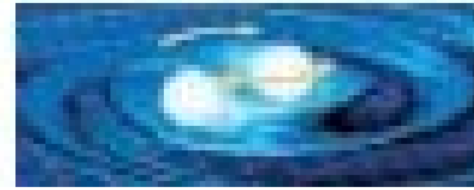
Far future

Space born Interferometer

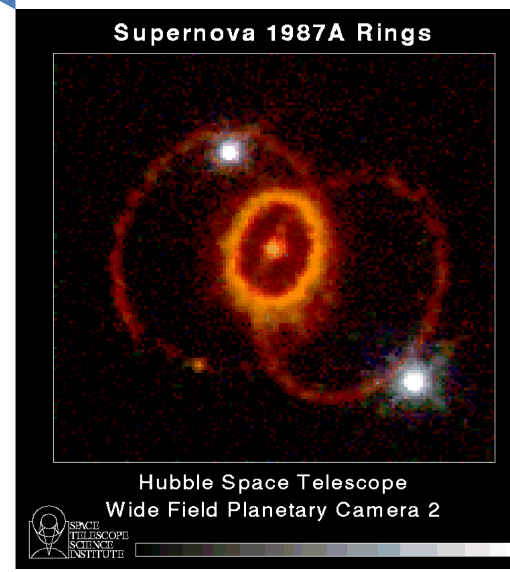
Possible sources of Gravitational wave

- Coalescence of BNS
- Supernova Explosion
- Coalescence of BH
- Falling object to BH
- Spinning NS
- Orbiting BNS
- Cosmic background
- Unknown GW
- etc.....

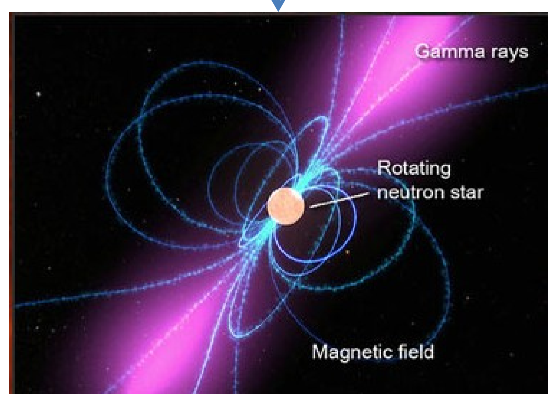
Orbiting BNS lose energy and shrink to coalesce.



Gravitational collapse of star emits GW



Spinning NS emits continuous GW

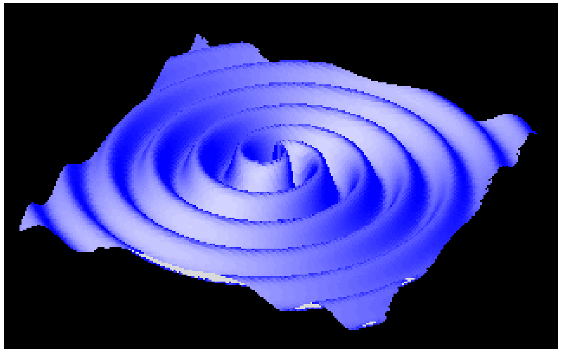


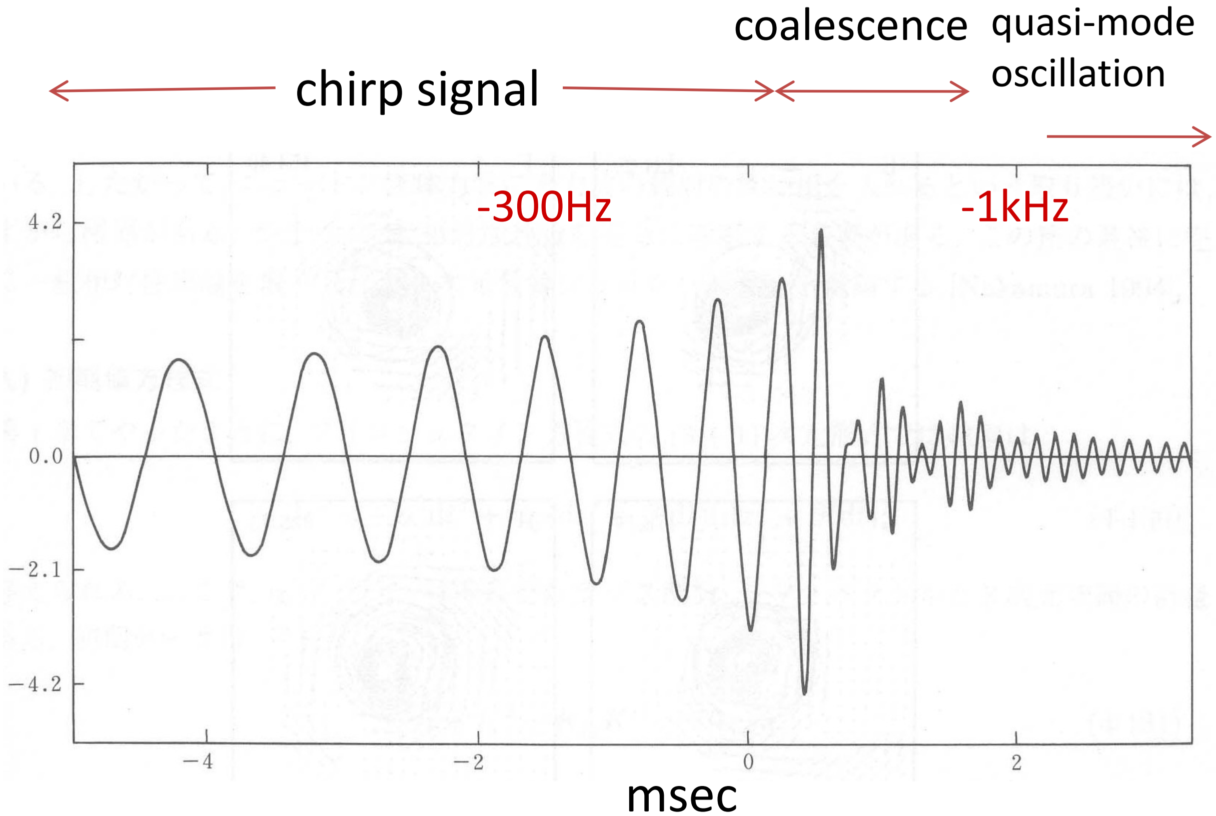
These can be investigated by GW

Binary Neutron Stars

Existing neutron star binaries in our Galaxy

- PSR B1913+16
- PSR B1534+21
- PSR J1141-6545
- PSR J0737-3039
- PSR J1906+0746
- ....





Estimation of Coalescence rate of CBC

	R_{low}	R_{re}	R_{high}	R_{max}
• NS-NS	0.01	1	10	50
• NS-BH	$6X10^{-4}$	0.03	1	
• BH-BH	$1X10^{-4}$	0.005	0.3	

per MWEG per Myr

Density of MWEG

0.012 per cubic Mpc

Detection of gravity wave by Interferometer

Metric perturbation
$g_{ij}=\eta_{ij} + h_{ij}$

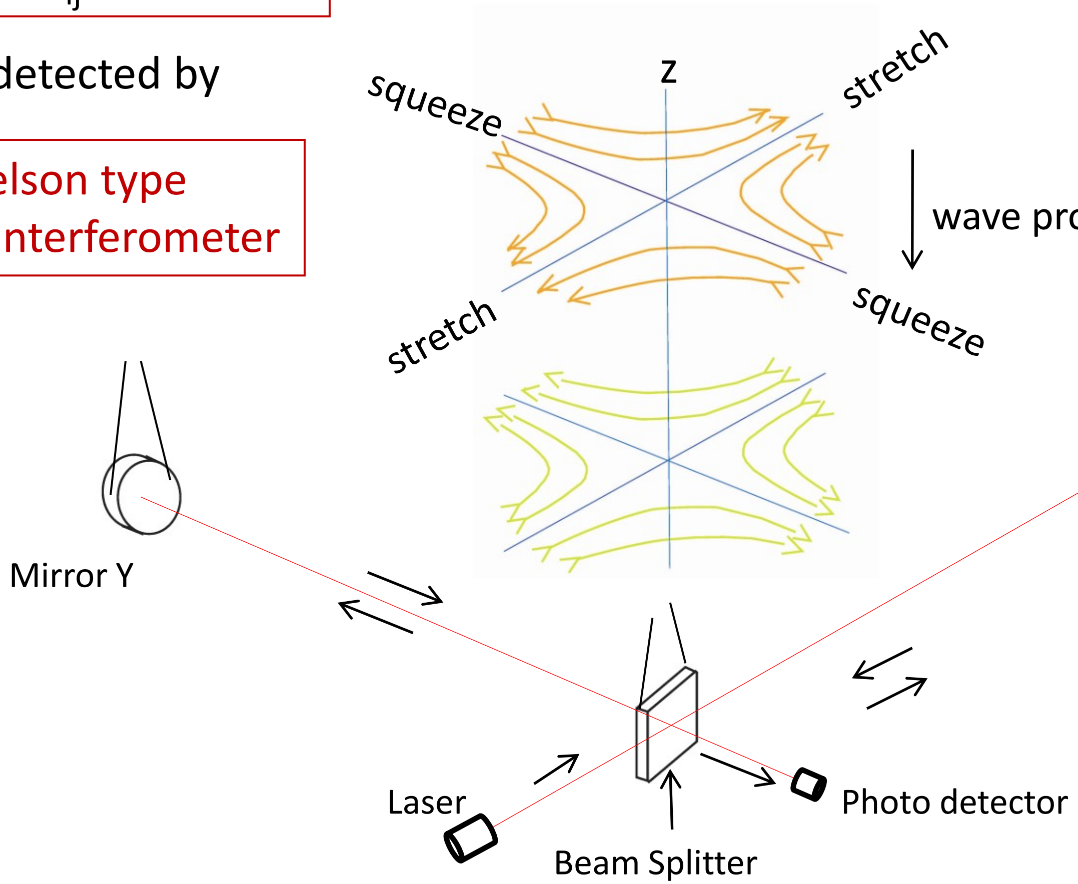
is detected by

Michelson type
laser interferometer

Gravity plane wave

$$h_{ij}=\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_{11} & h_{12} & 0 \\ 0 & h_{21} & h_{22} & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

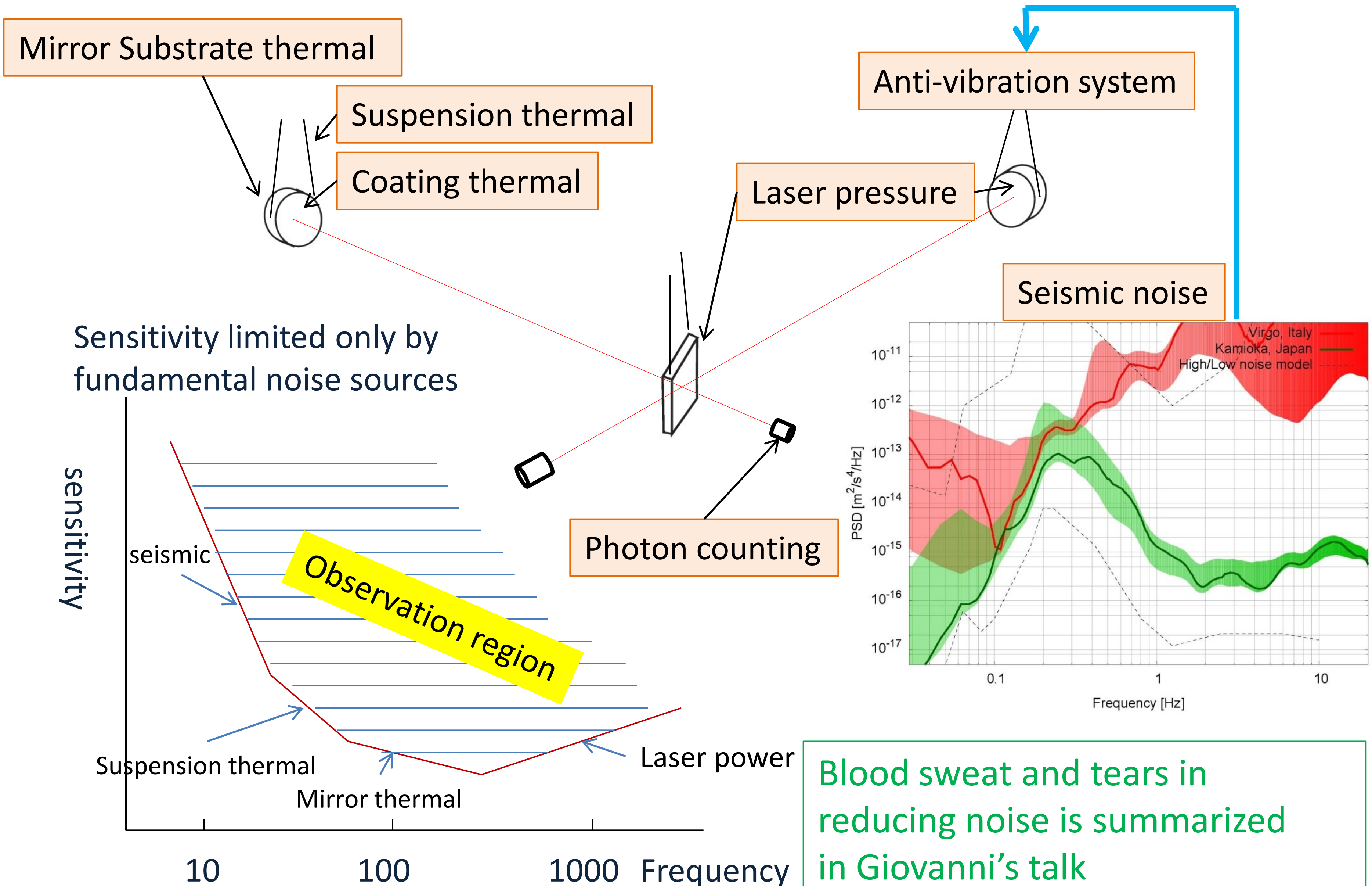
Typical amplitude
$h \sim 10^{-22}$



Light speed of propagation differs for each arms of Interferometer
$\Delta L / L \simeq h/2$

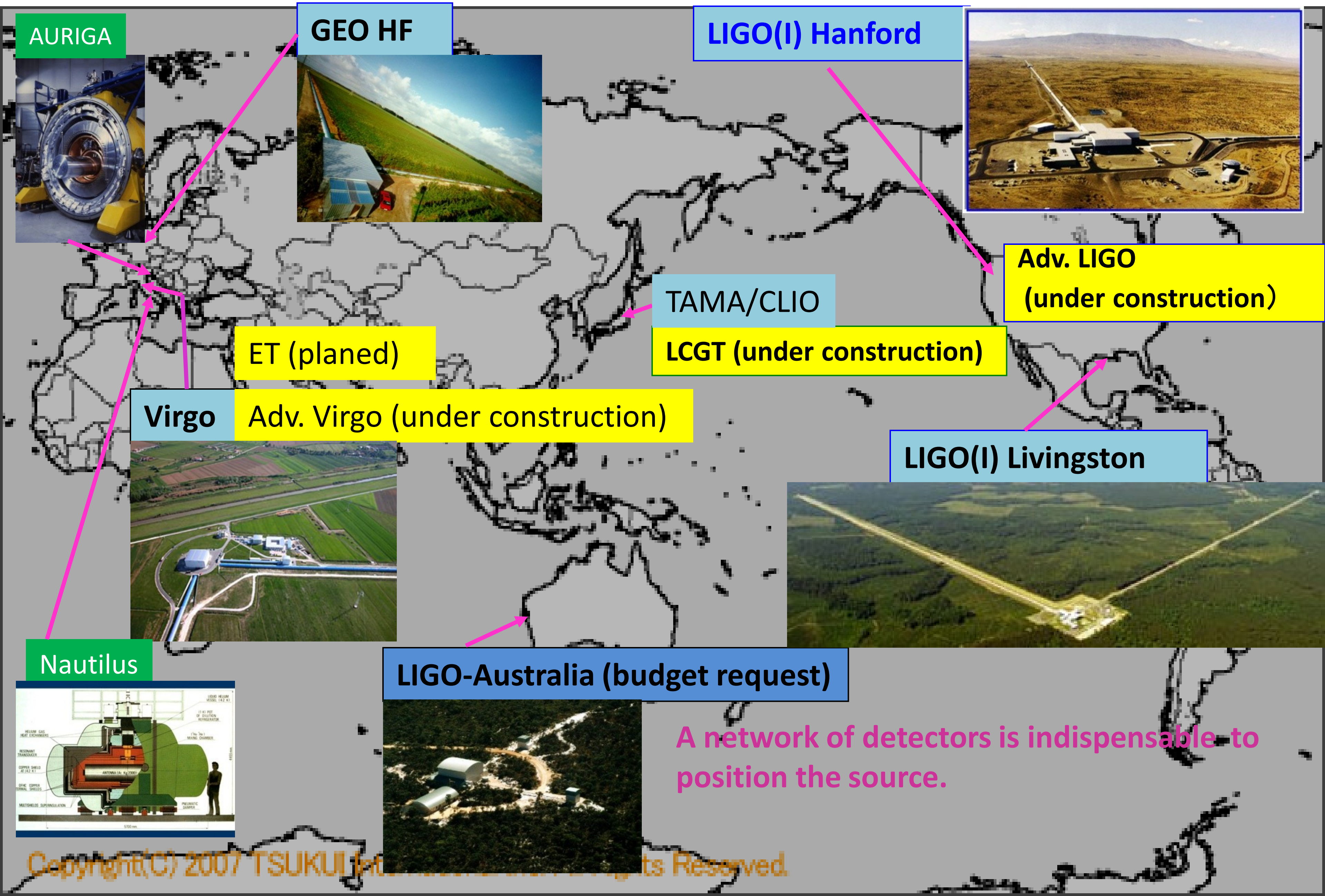
Phase difference at BS is detected by power change of the photodiode

Noise of Current Interferometers



Blood sweat and tears in reducing noise is summarized in Giovanni's talk

Current detectors in the World

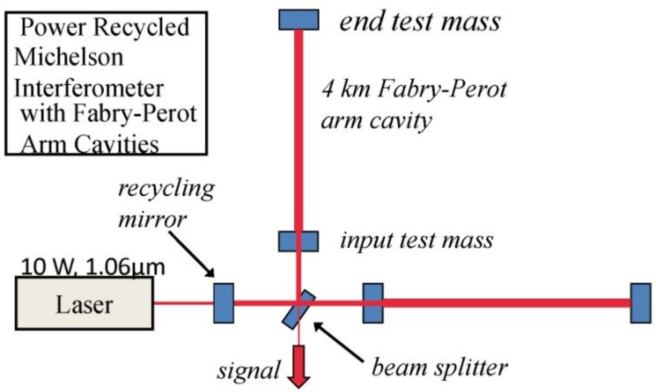


LIGO project and Advanced LIGO

Initial LIGO timeline

- Construction started in 1994
- First data-colletction (S1) 2002
- Design Sensitivity Achieved 2005
- Enhanced LIGO (S6) 2009-2010

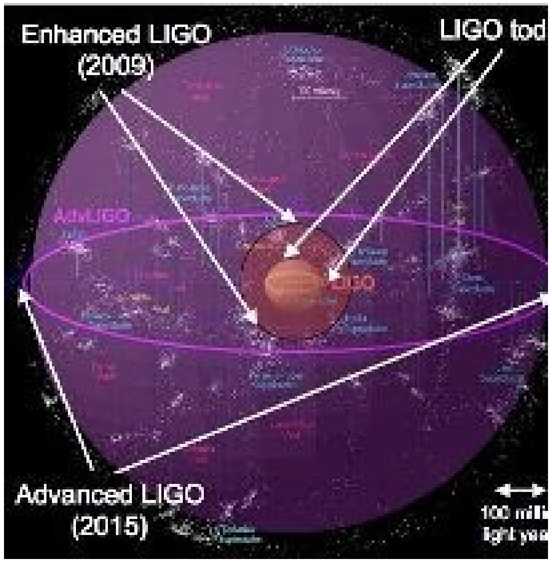
One interferometer with 4 km Arms, One with 2 km Arms

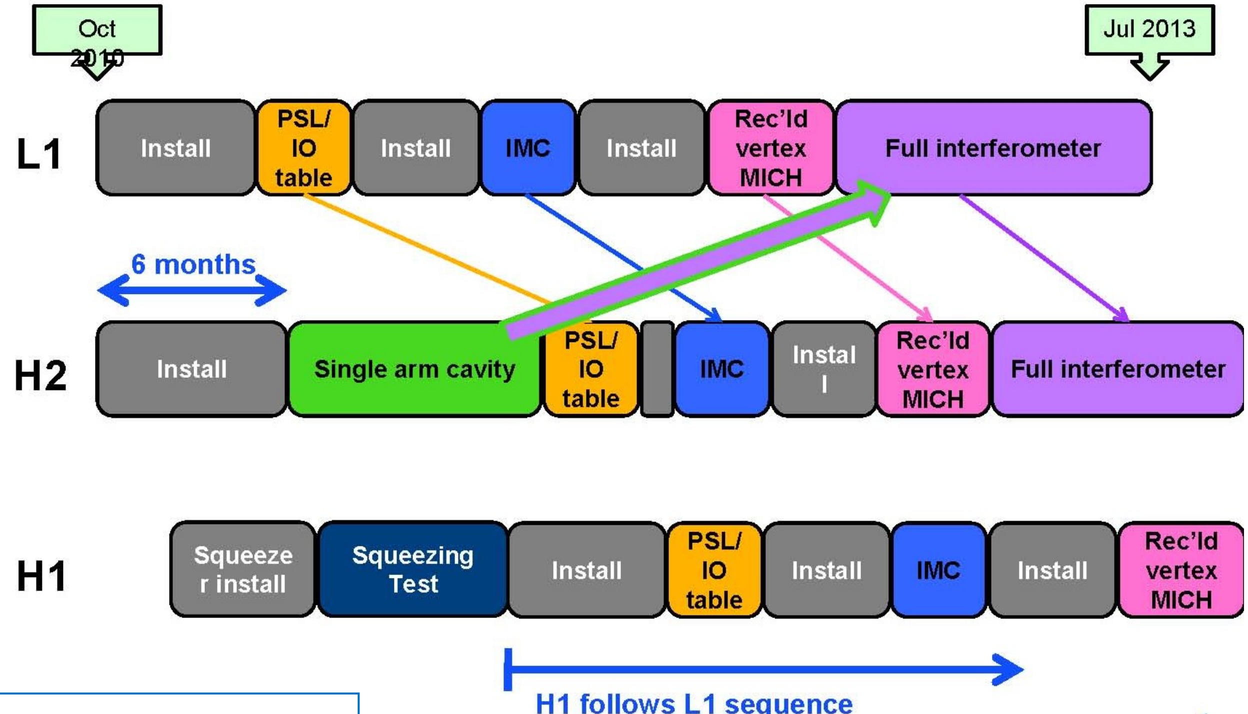


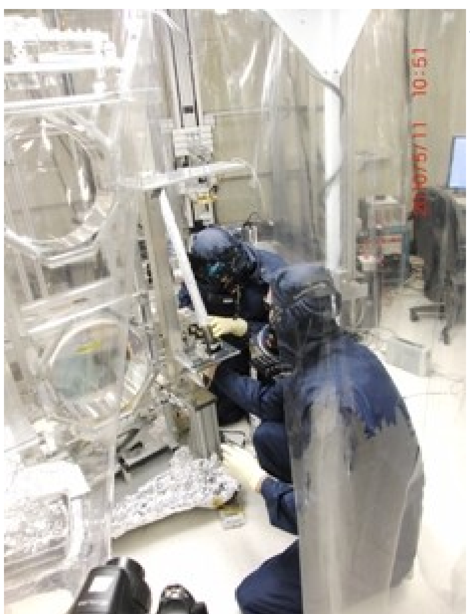
One interferometer with 4 km Arms

Advanced LIGO

Scope of Advanced LIGO

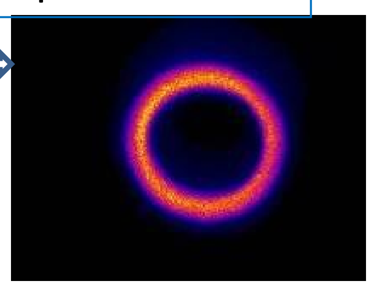






Monolithic suspension

TCS performance



New isolation system

VIRGO

Virgo project

Italian-French Collaboration

Construction completed in 2003

Final configuration in 2005

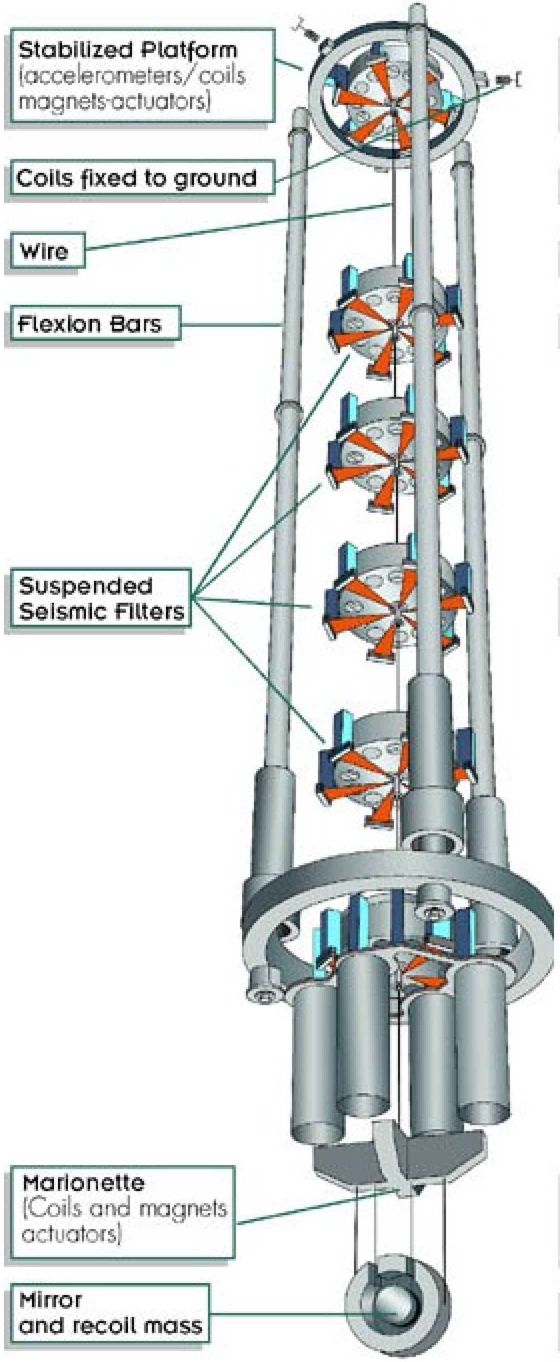
Data-taking started in 2006

(VSR1) ended in 2007 with LSC

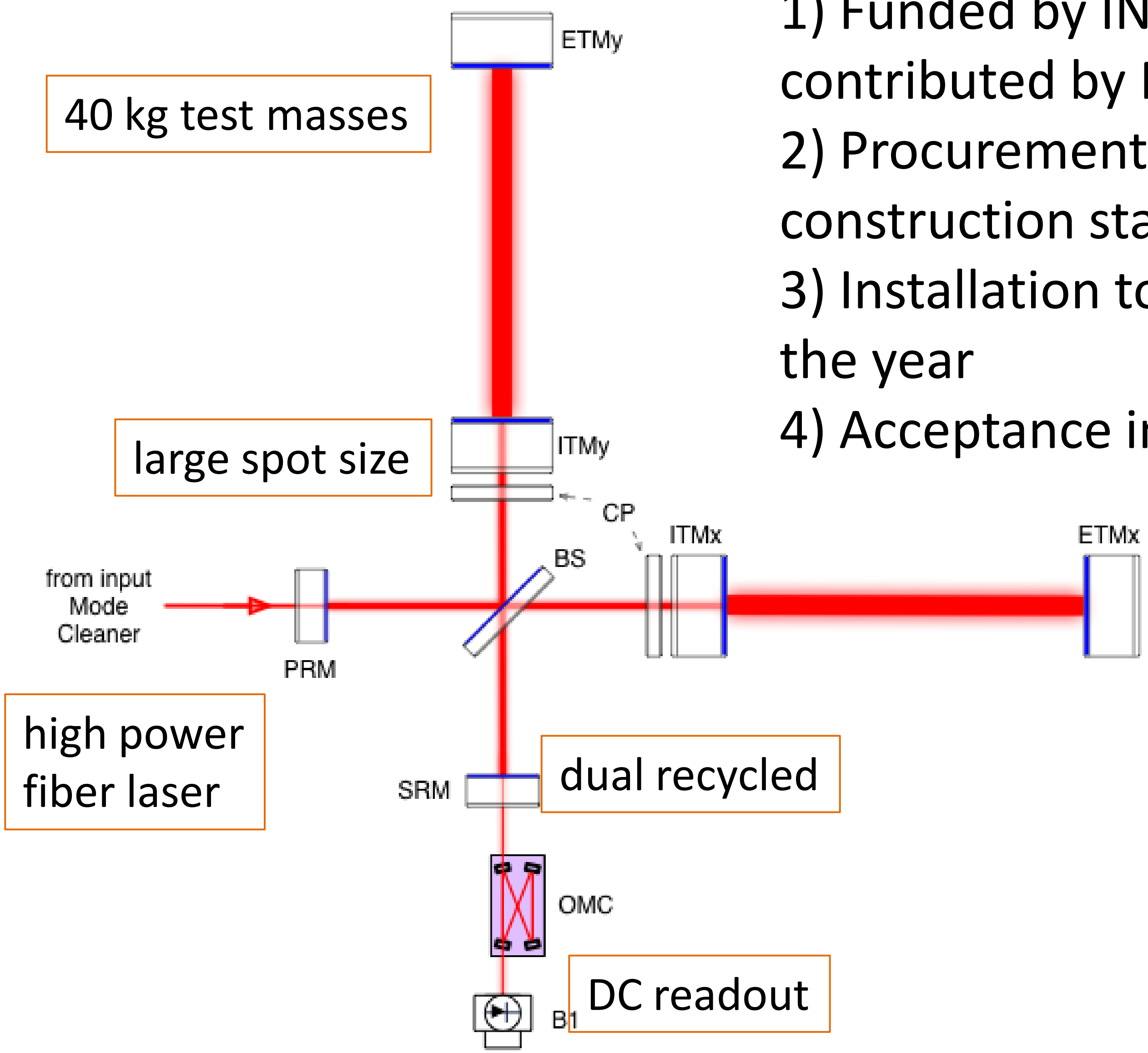
Virgo+ (VSR 2, S6) ended in 2010

Typical features :

- Located at Cascina in Pisa
- 3km baseline length
- Fabry-Perot Michelson Interferometer
- Ultra-low frequency isolation system



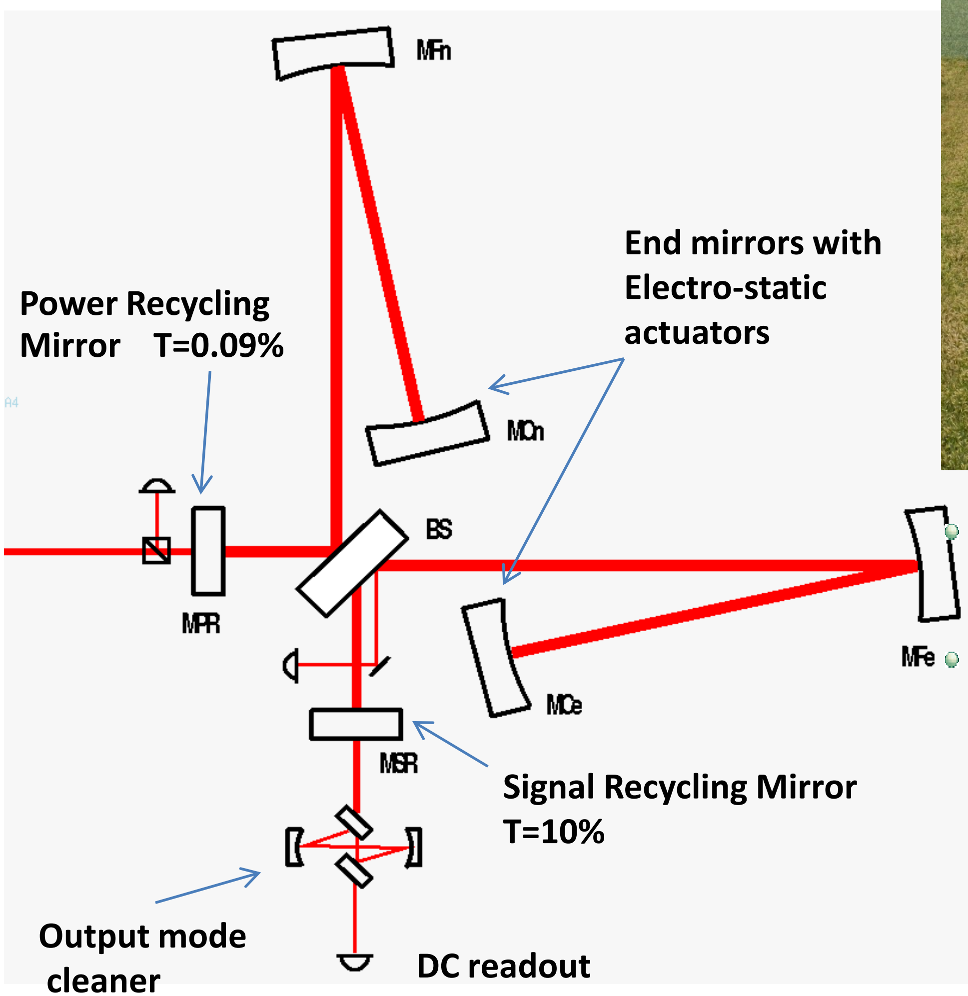
Current design of Advanced Virgo



1) Funded by INFN/CNRS (and contributed by NIKHEF) in Dec 2009
2) Procurements and parts construction started
3) Installation to start at the end of the year
4) Acceptance in 2015

GEO600 project

GEO optical Layout



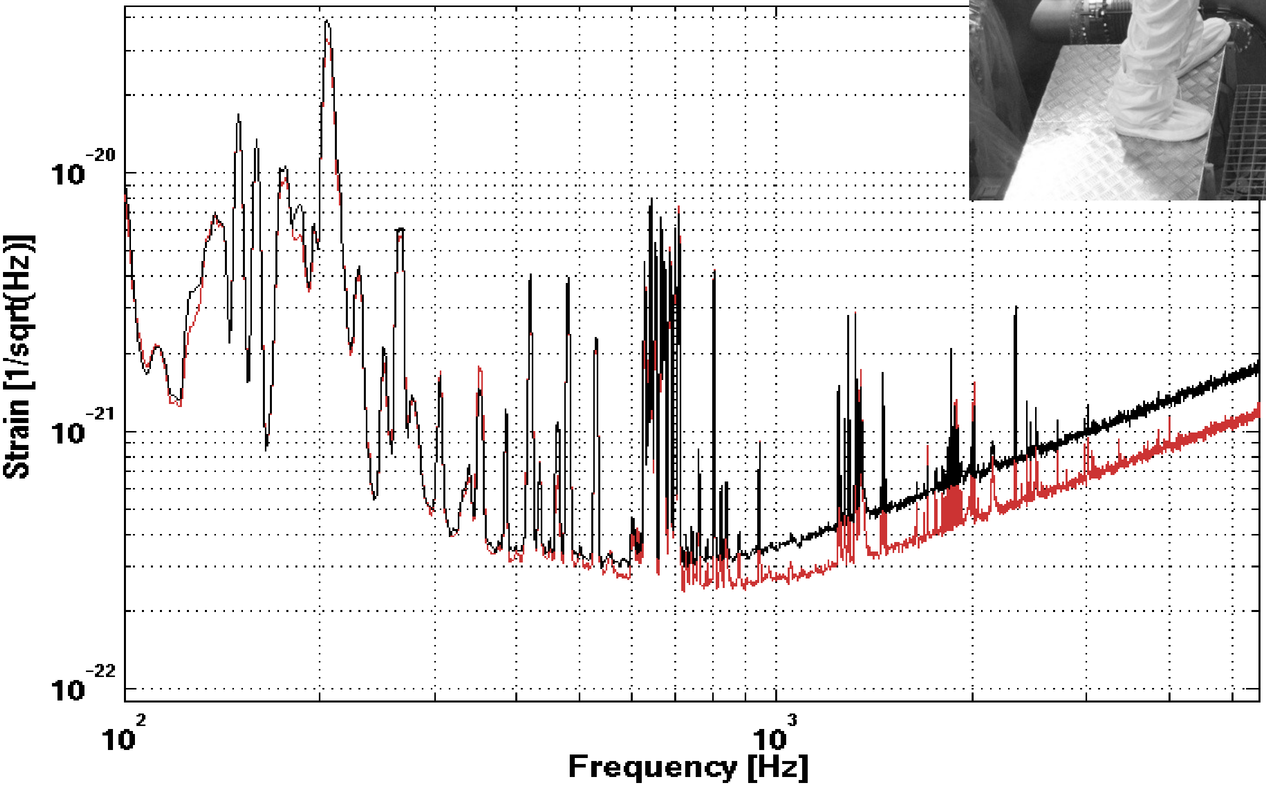
GEO is an observing instrument *and* a prototype for new technologies

'Advanced techniques' of GEO:

- Monolothic suspensions (since ~10 years)
- Electro-static actuators
- Signal recycling
- Squeezing (since 2010)

Squeezer Installation in May 2010

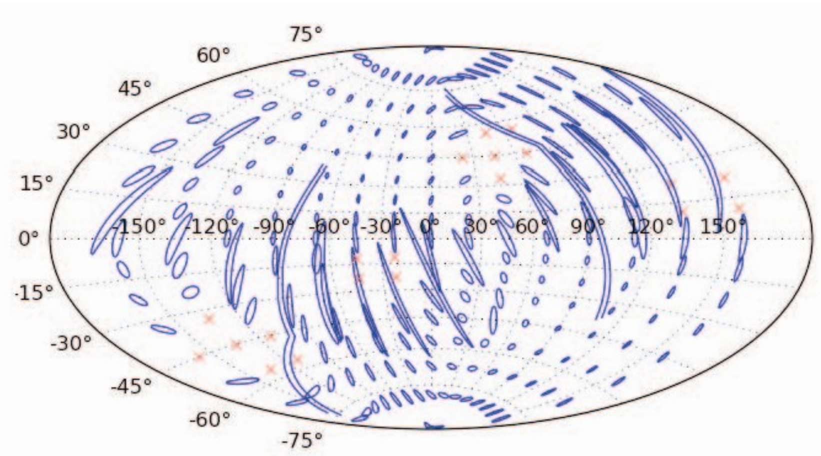
Squeezing light is introduced from signal port to reduce shot noise.
3.5dB Improvement has been achieved and 4dB more is expected in 2011

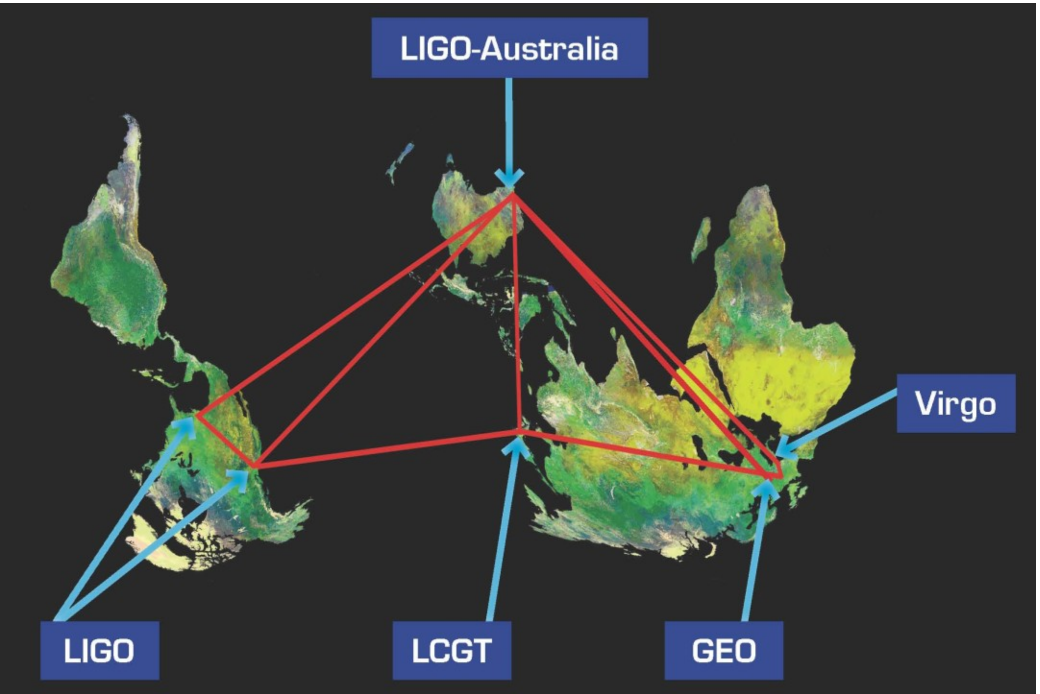


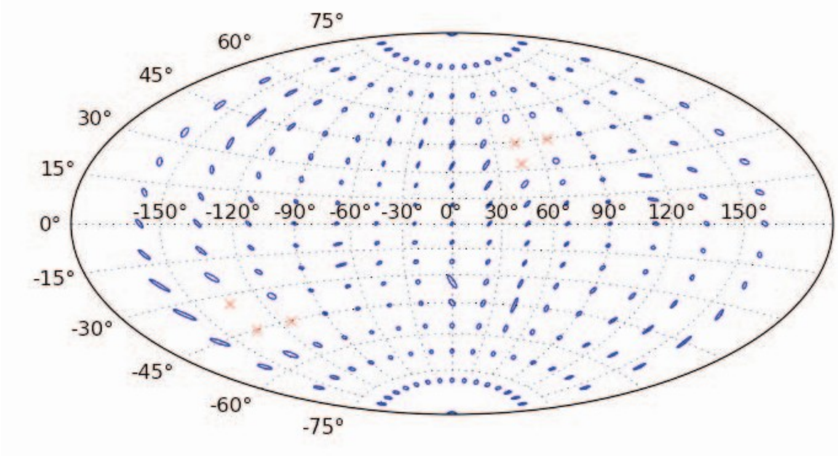
LIGO-Australia

A set of Advanced LIGO is planed to be installed at Gingin north of Perth in Western Australia
(AIGO project of ACIGA consortium, InDIGO, China)

- *) Funding is being requested to Australian government , the result of which will be disclosed, soon.
- *) NSF has approved







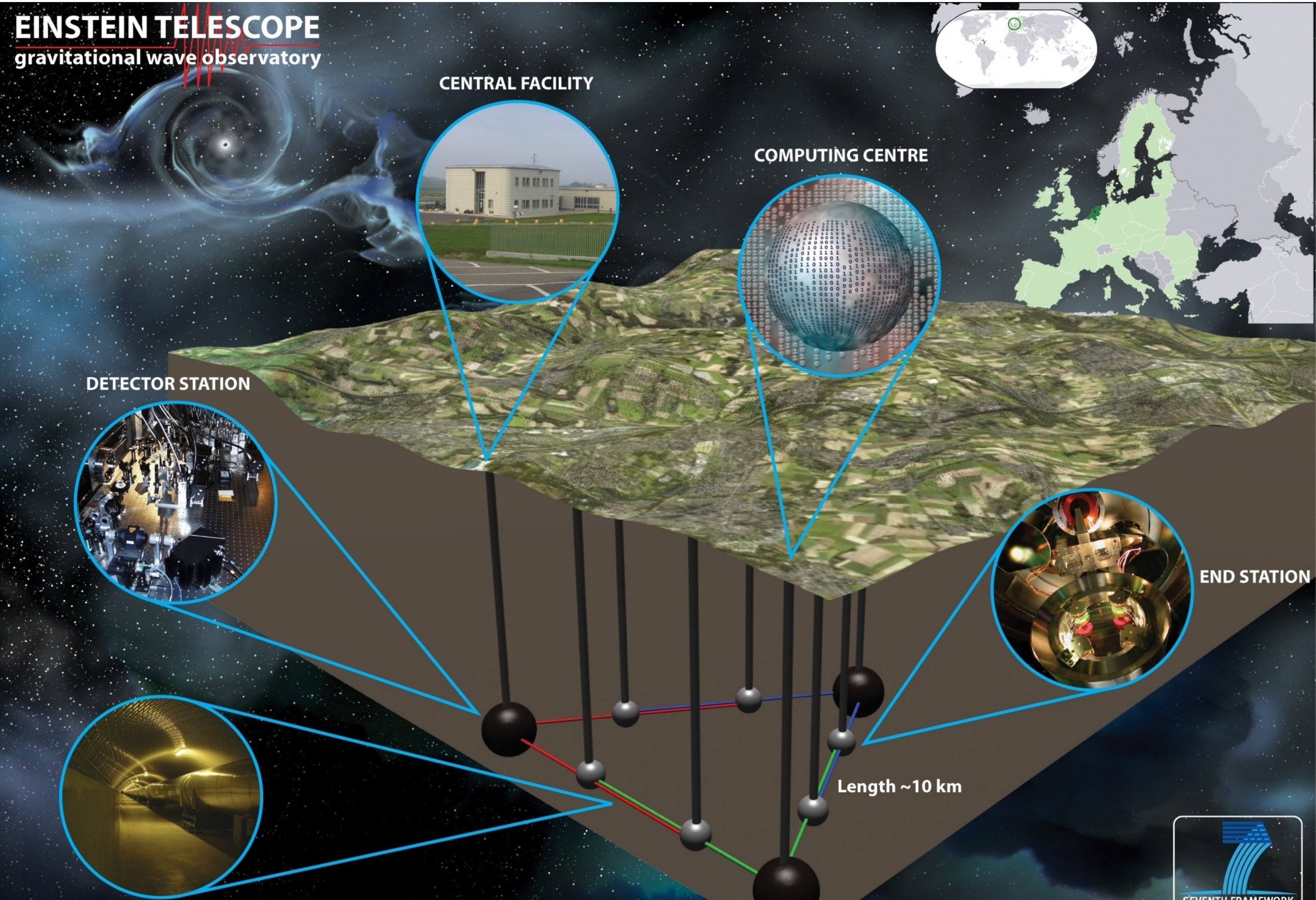
If realized, the positioning accuracy of sources becomes much improved

LIGO-India

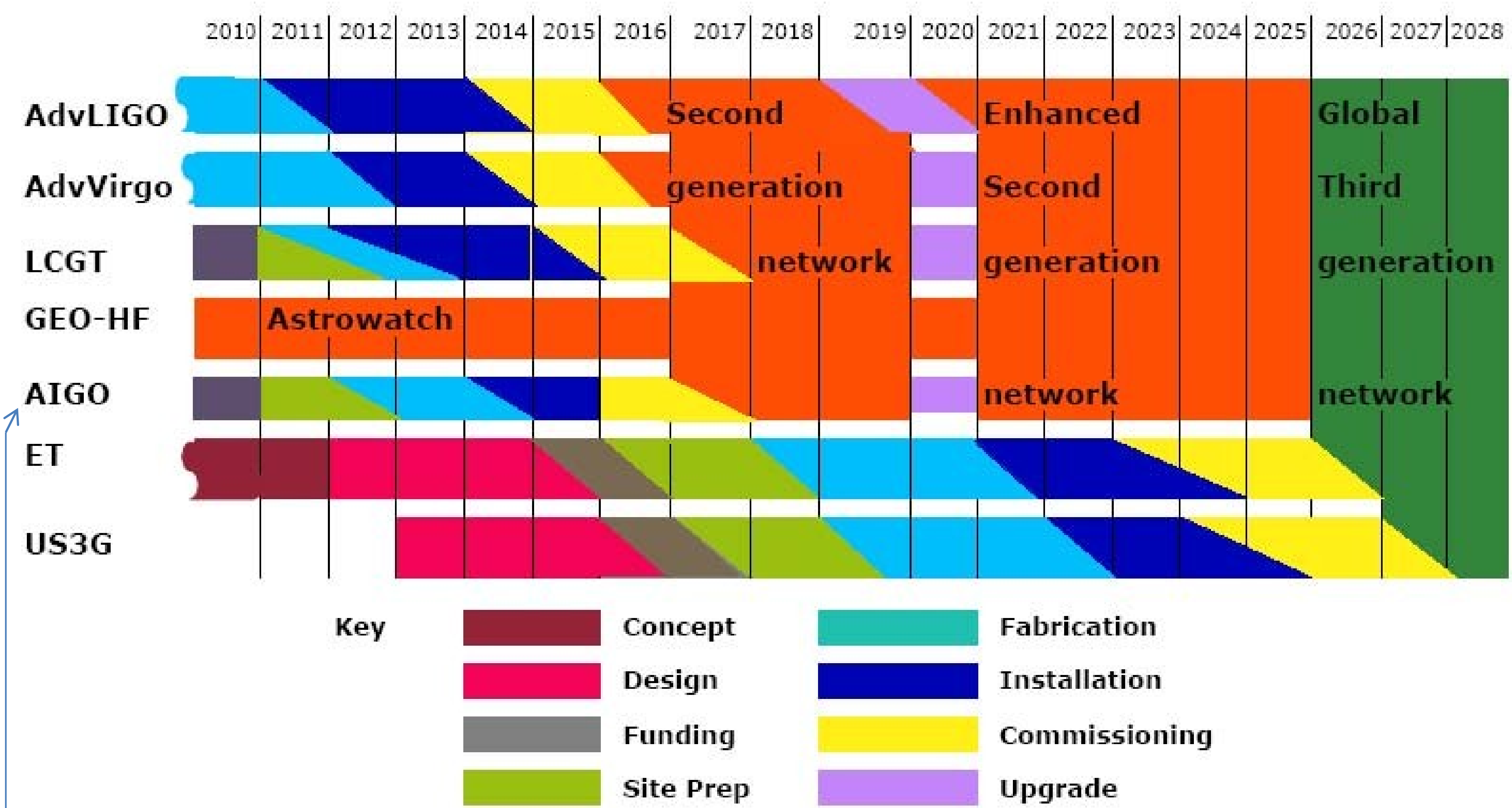
- InDIGO (since 2009)Roadmap workshop in Delhi at University of Delhi, December 2010
- Funding for 3m prototype interferometer at the Tata Institute for Fundamental Research
- Created an Indo-US Center for GWs, funding awarded
- Proposing to participate in LIGO-Australia as a major partner (15%)
- Possible alternative of the case of disapproval of LIGO-Australia

Einstein Telescope

from ET design report



GWIC roadmap of ground based detectors

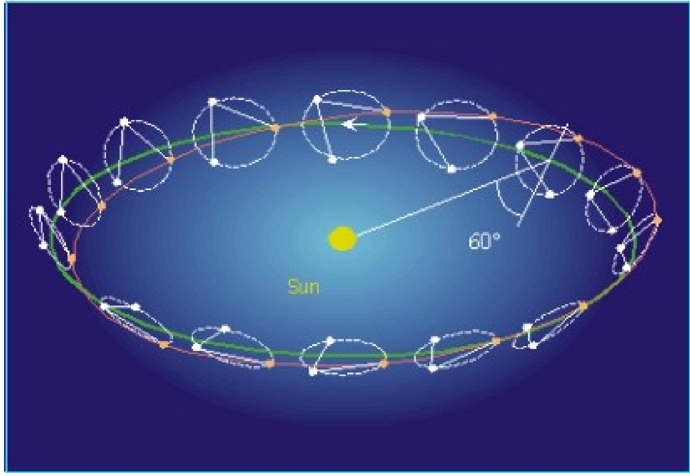


Will be organized as LIGO-Australia or LIGO-India

L I S A

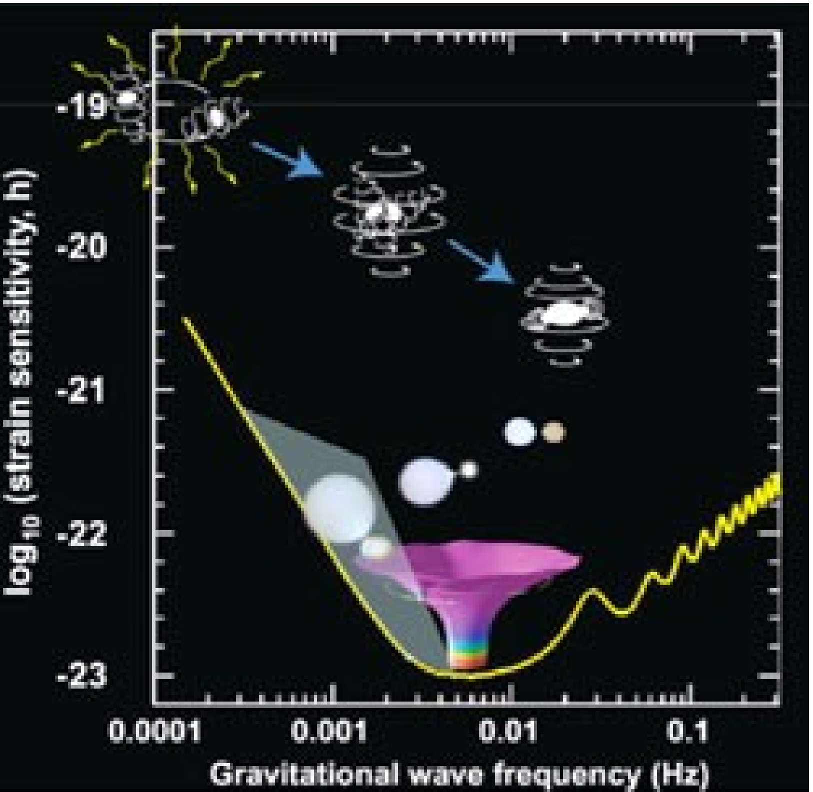
LISA is a joint NASA-ESA space mission of interferometer to see gravity wave events more remotely and more frequently.

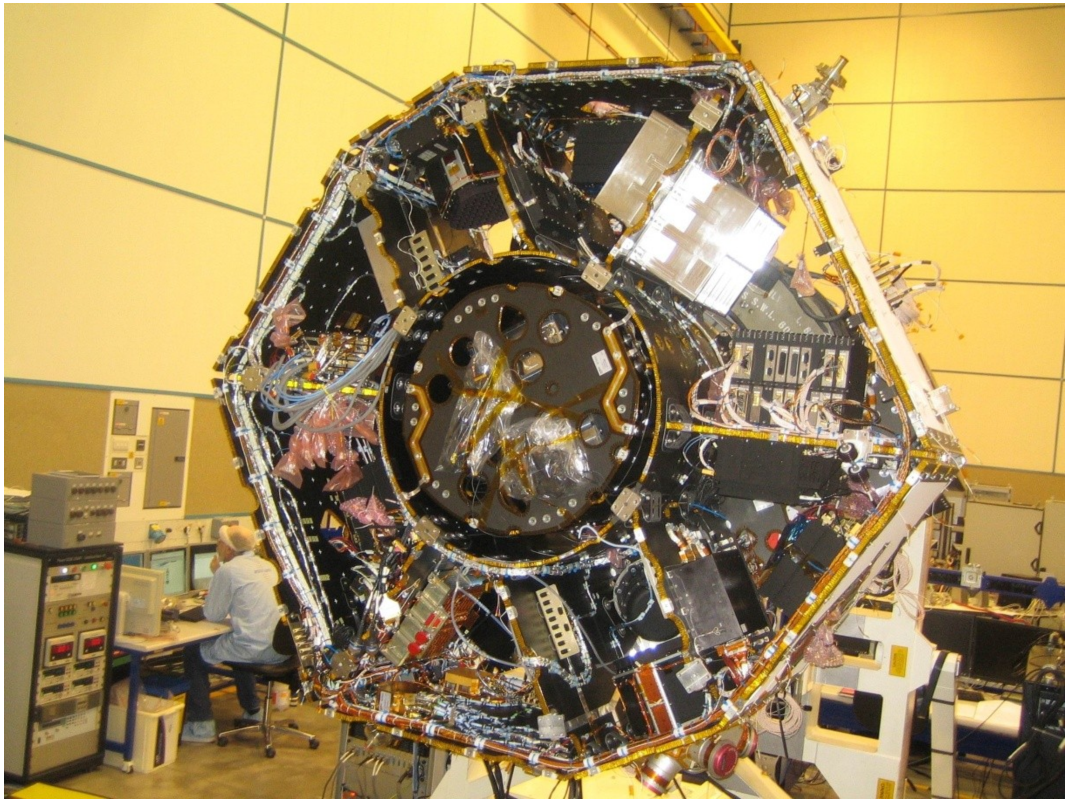
- Frequency band: 0.03mHz-0.1Hz, abundant science objects
- 5 million km baseline length
- LISA Pathfinder will be launched in 2013 for the test of technologies for LISA



Orbital motion of LSIA satellites

Preparation of LISA Pathfinder

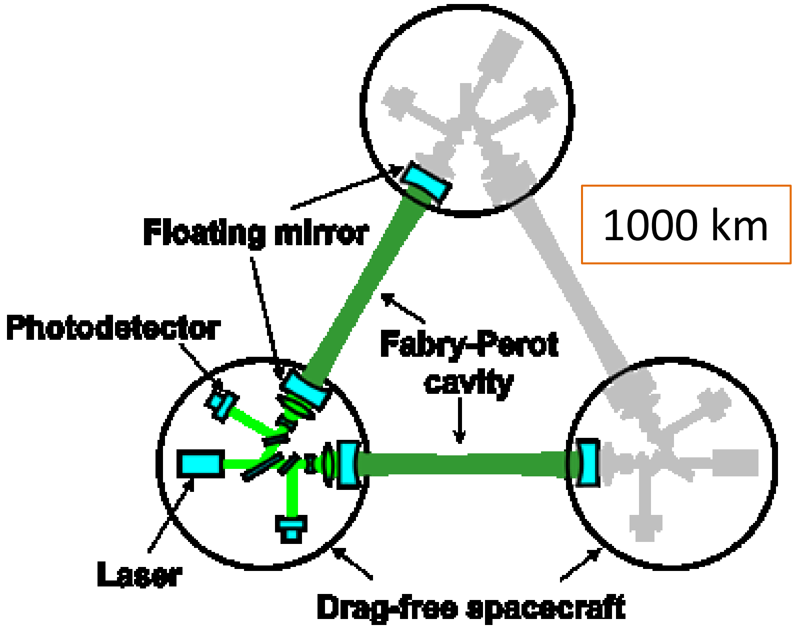


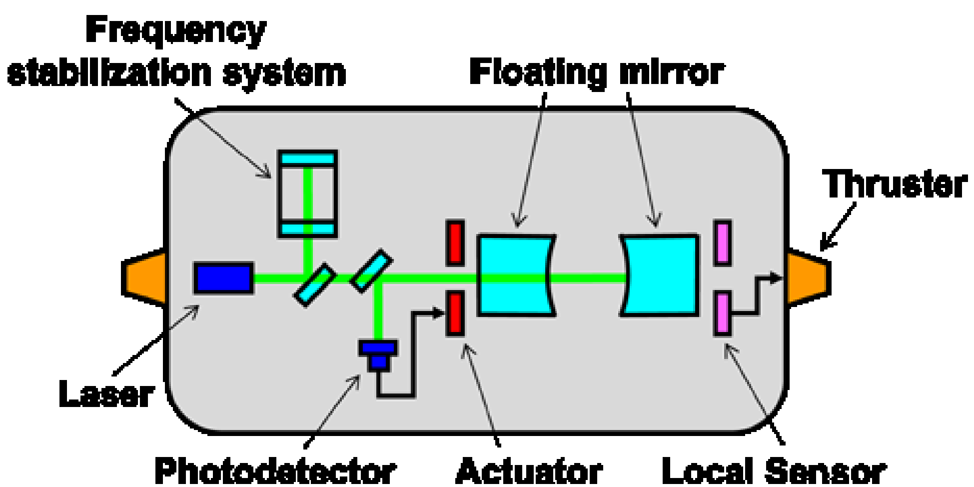


DECIGO

DECIGO: Fabry-Perot space interferometer works in frequencies from 0.1 – 10 Hz

Objective:
1)Direct observation of the beginning of The Universe
2) Measuring the acceleration of the Universe

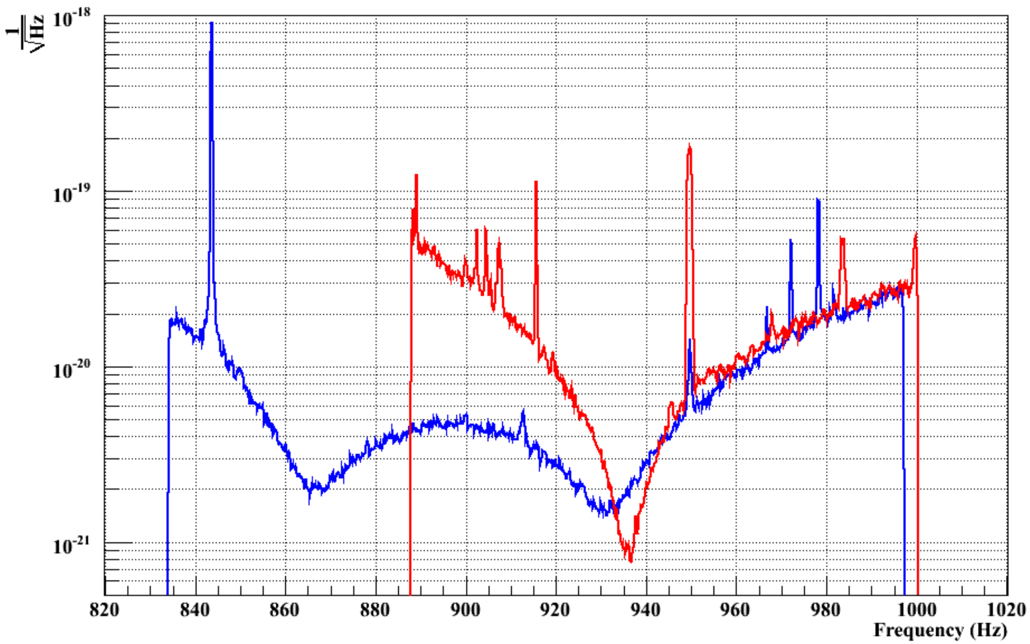




DECIGO Pathfinder tests the technologies required to realize DECIGO
Will be nominated by the small science spacecraft series run by JAXA/ISAS

AstroWatch recommended by GWIC

- AURIGA and NAUTILUS in operation as an "astrowatch" until LIGO/Virgo resume operation after upgrade
- GEO-HF enters this operation as soon as possible



AURIGA & NAUTILUS continously on the air > 95 % with noise close to Gaussian (~ 20 outliers/day at SNR>6) until LIGO/Virgo resume operation

burst sensitivity h_{rss} ~ 10^{-20} $Hz^{-1/2}$ or h_{burst} ~ 2×10^{-19}

AUNA: "astrowatch" of AURIGA & NAUTILUS

TAMA/CLIO

TAMA in Mitaka, Tokyo

TAMA is a 300 m baseline Fabry-Perot Michelson Interferometer with power recycling and achieved the best sensitivity and long observation run earlier than any other long baseline interferometers by 2000.

R&D are being conducted for advanced interferometer techniques for LCGT.

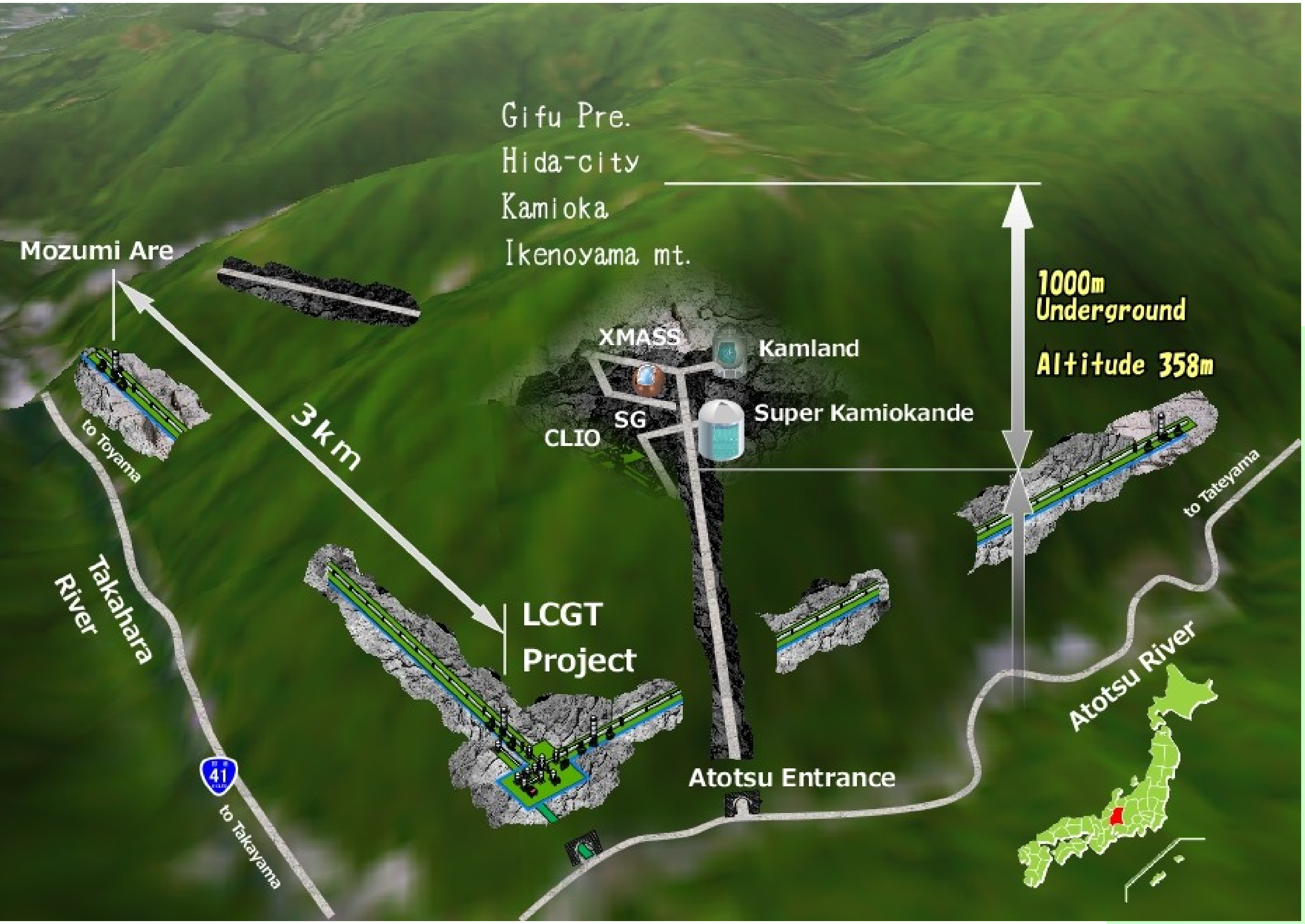
CLIO is a 100 m cryogenic locked Fabry-Perot interferometer placed underground at Kamioka mine.

Thermally limited sensitivity was achieved in 2009 by cooling mirrors down to 10 K. It is a test bench for cryogenic part of LCGT.

CLIO underground at Kamioka

LCGT

(Large-scale Cryogenic Gravitational-wave Telescope)



Large-scale Detector

Baseline length: 3km

High-power Interferometer

Cryogenic interferometer

Mirror temperature: 20K

Underground site

Kamioka mine,

200m underground

Objective: First detection of Gravitational wave & Opening GW astronomy

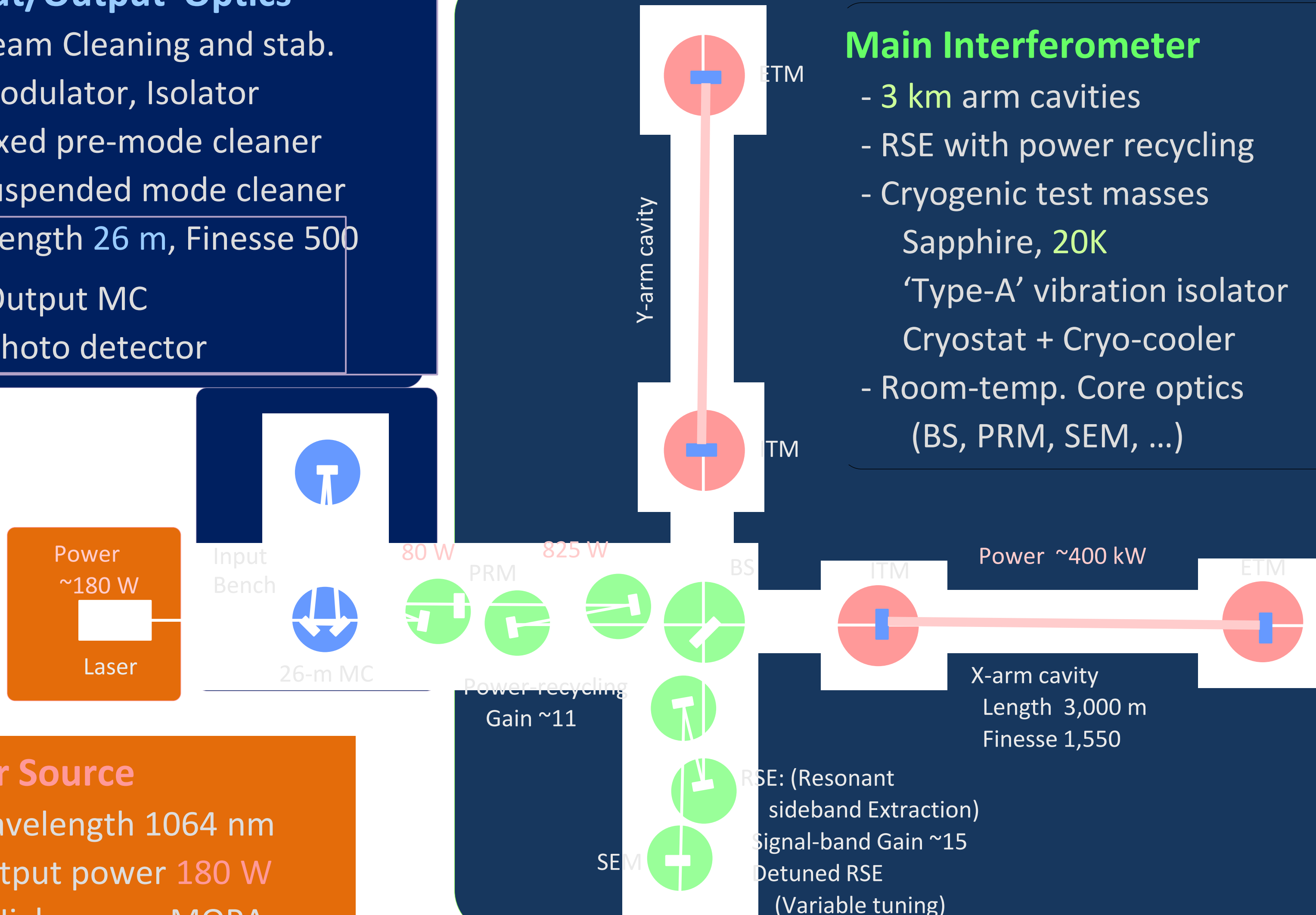
LCGT configuration

Input/Output Optics

- Beam Cleaning and stab.
- Modulator, Isolator
- Fixed pre-mode cleaner
- Suspended mode cleaner
  Length 26 m, Finesse 500
- Output MC
- Photo detector

Main Interferometer

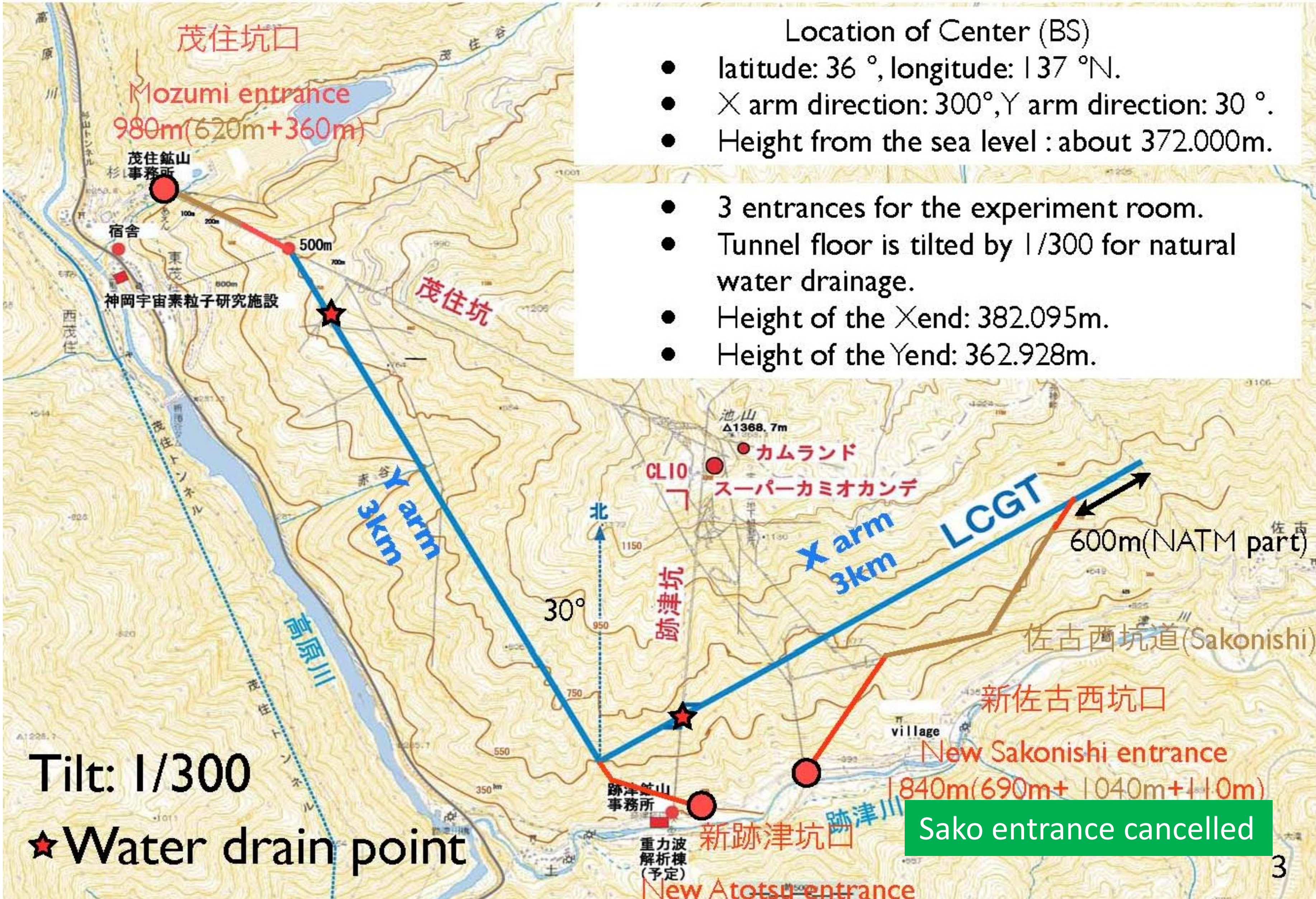
- 3 km arm cavities
- RSE with power recycling
- Cryogenic test masses
  Sapphire, 20K
  'Type-A' vibration isolator
  Cryostat + Cryo-cooler
- Room-temp. Core optics
  (BS, PRM, SEM, ...)



Laser Source

- Wavelength 1064 nm
- Output power 180 W
  High-power MOPA

Location of LCGT at Kamioka

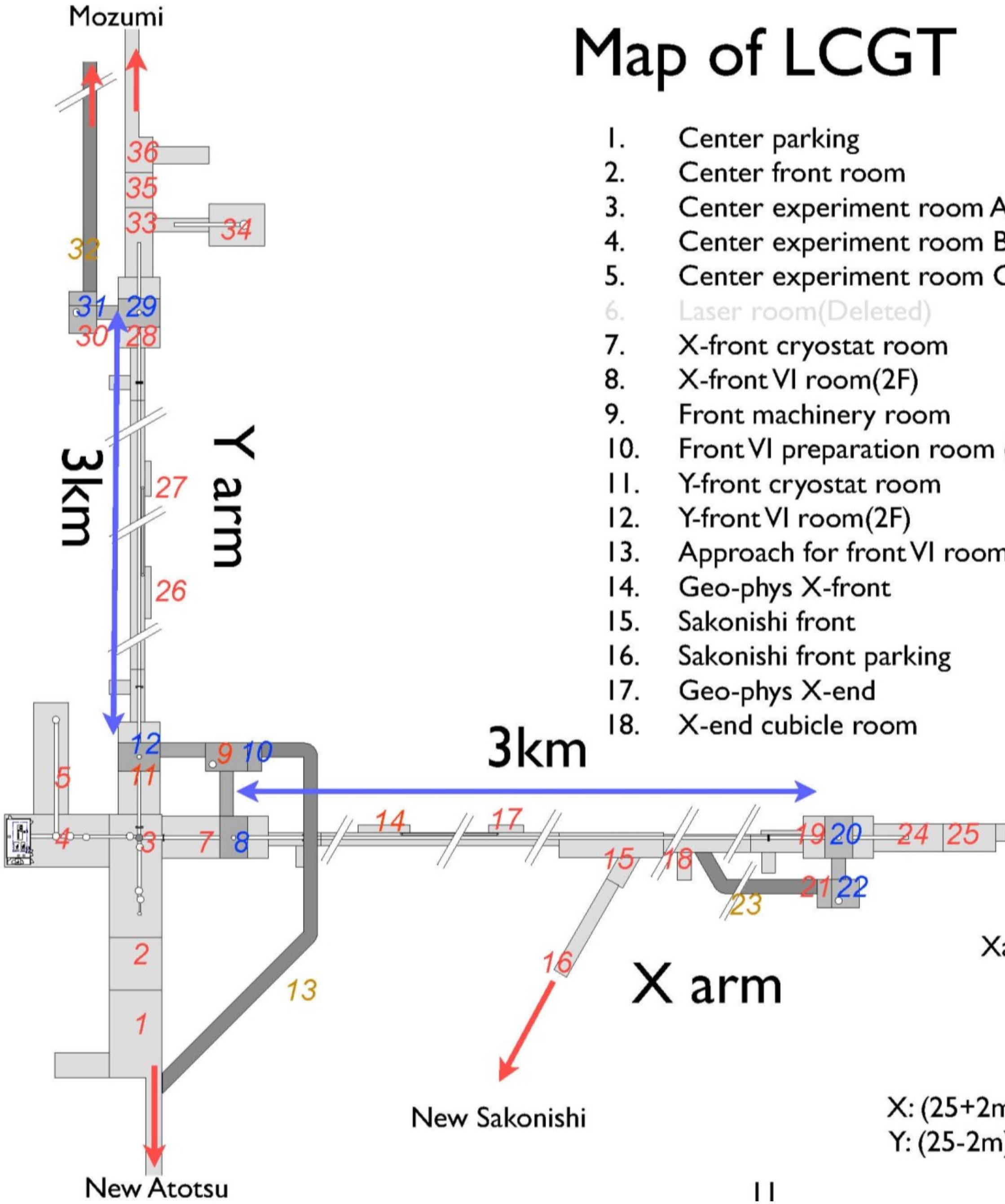


Location of Center (BS)

- latitude: 36 °, longitude: 137 °N.
- X arm direction: 300°, Y arm direction: 30 °.
- Height from the sea level : about 372.000m.

- 3 entrances for the experiment room.
- Tunnel floor is tilted by 1/300 for natural water drainage.
- Height of the Xend: 382.095m.
- Height of the Yend: 362.928m.

Map of LCGT



1. Center parking
2. Center front room
3. Center experiment room A
4. Center experiment room B
5. Center experiment room C
6. Laser room(Deleted)
7. X-front cryostat room
8. X-front VI room(2F)
9. Front machinery room
10. Front VI preparation room (2F)
11. Y-front cryostat room
12. Y-front VI room(2F)
13. Approach for front VI room
14. Geo-phys X-front
15. Sakonishi front
16. Sakonishi front parking
17. Geo-phys X-end
18. X-end cubicle room
19. X-end cryostat room
20. X-end VI room(2F)
21. X-end machinery room
22. X-end VI preparation room (2F)
23. Approach for X-end VI room
24. X-end experiment room
25. X-end staff room
26. Geo-phys Y-front
27. Geo-phys Y-end
28. Y-end cryostat room
29. Y-endVI room(2F)
30. Y-end machinery room
31. Y-end VI preparation room (2F)
32. Approach for Y-end VI room
33. Y-end experiment room
34. Cryogenic experiment room
35. Y-end staff room
36. Y-end parking

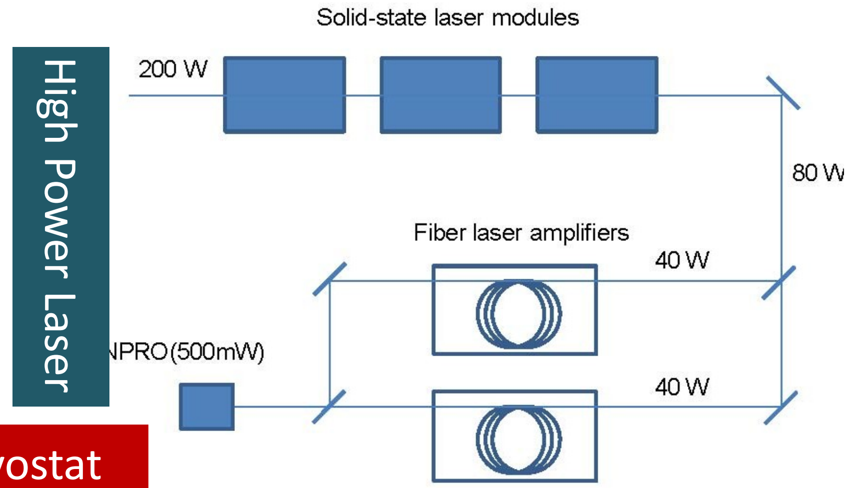
Xarm and Yarm cross perpendicularly at the center of BS chamber.

3km:

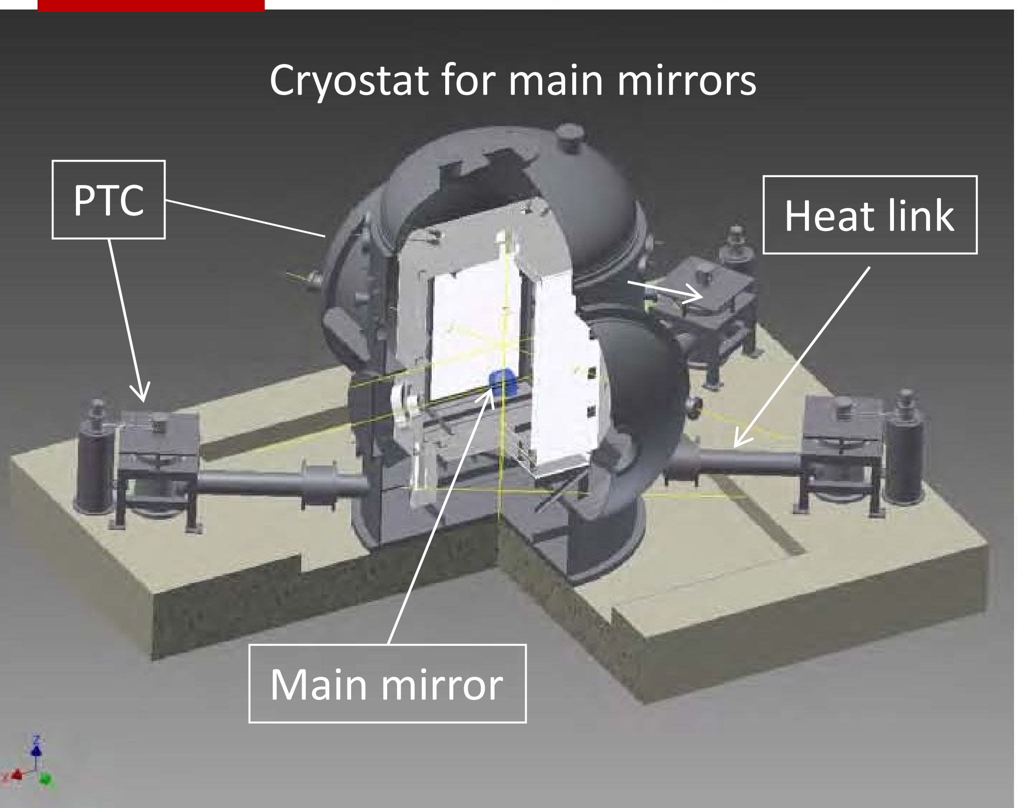
X: (25+2m)from BS - Center of X end cryostat room

Y: (25-2m) from BS - Center of Y end cryostat room

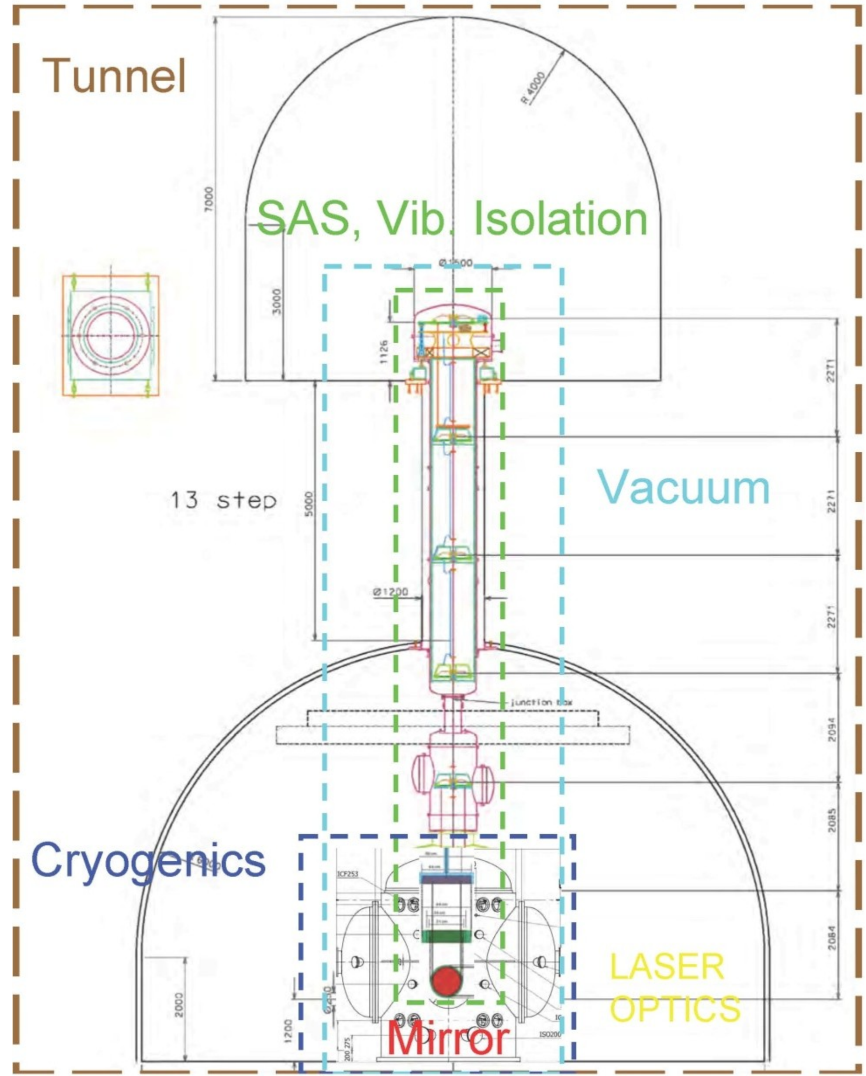
LCGT design Items



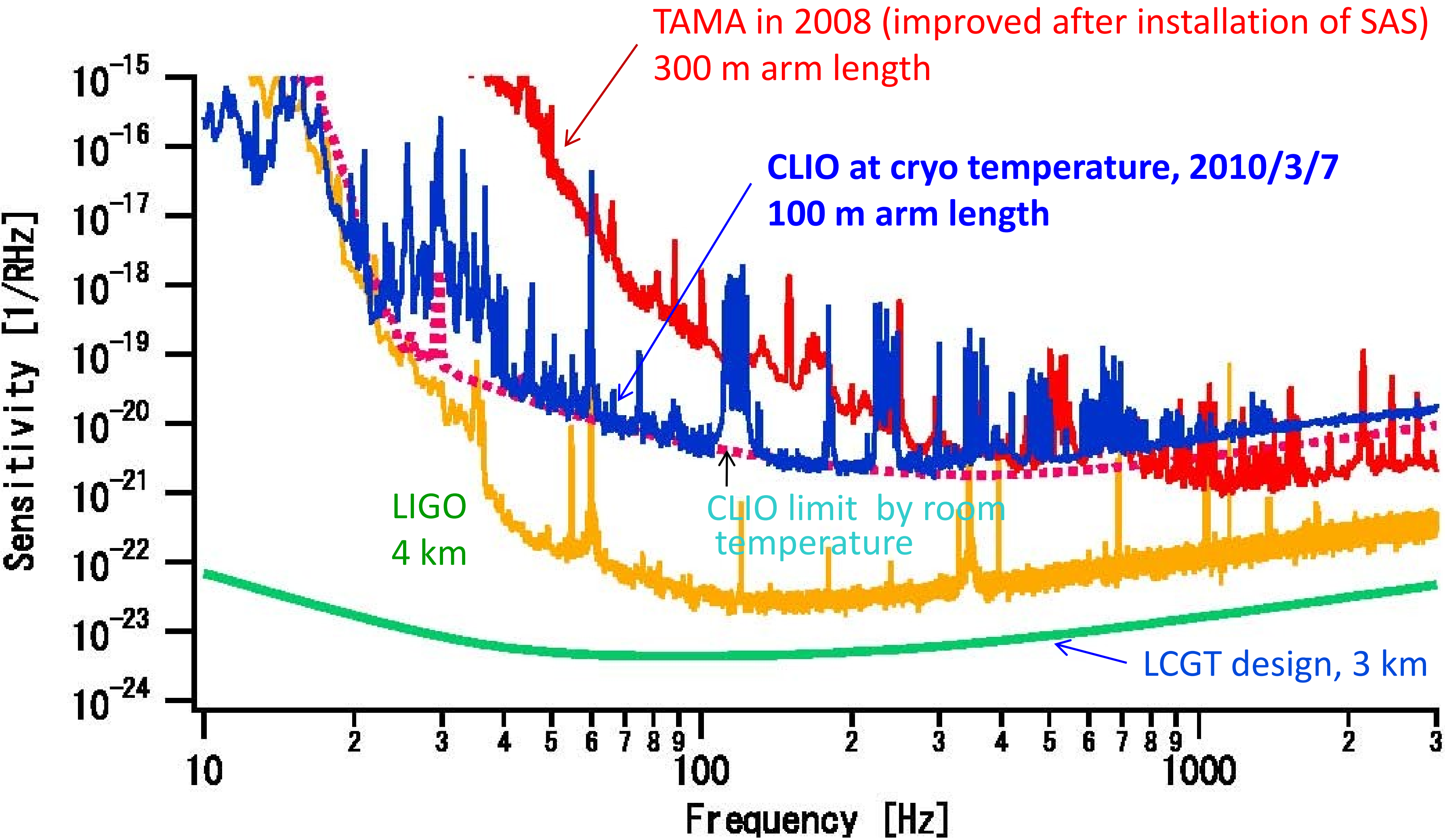
Cryostat



Double floor isolation system
Mounted above cryostat

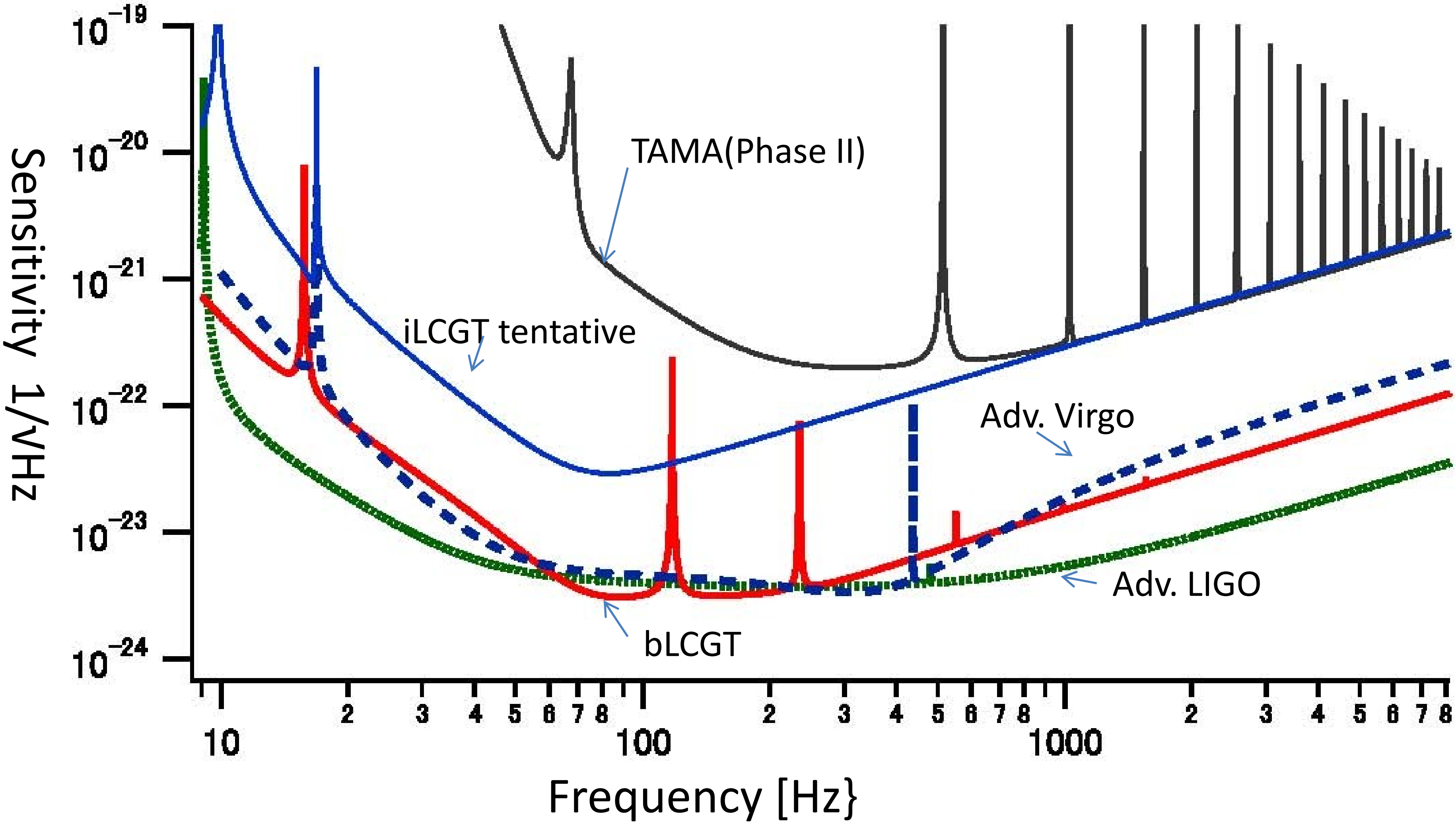


R&D results by TAMA and CLIO for LCGT

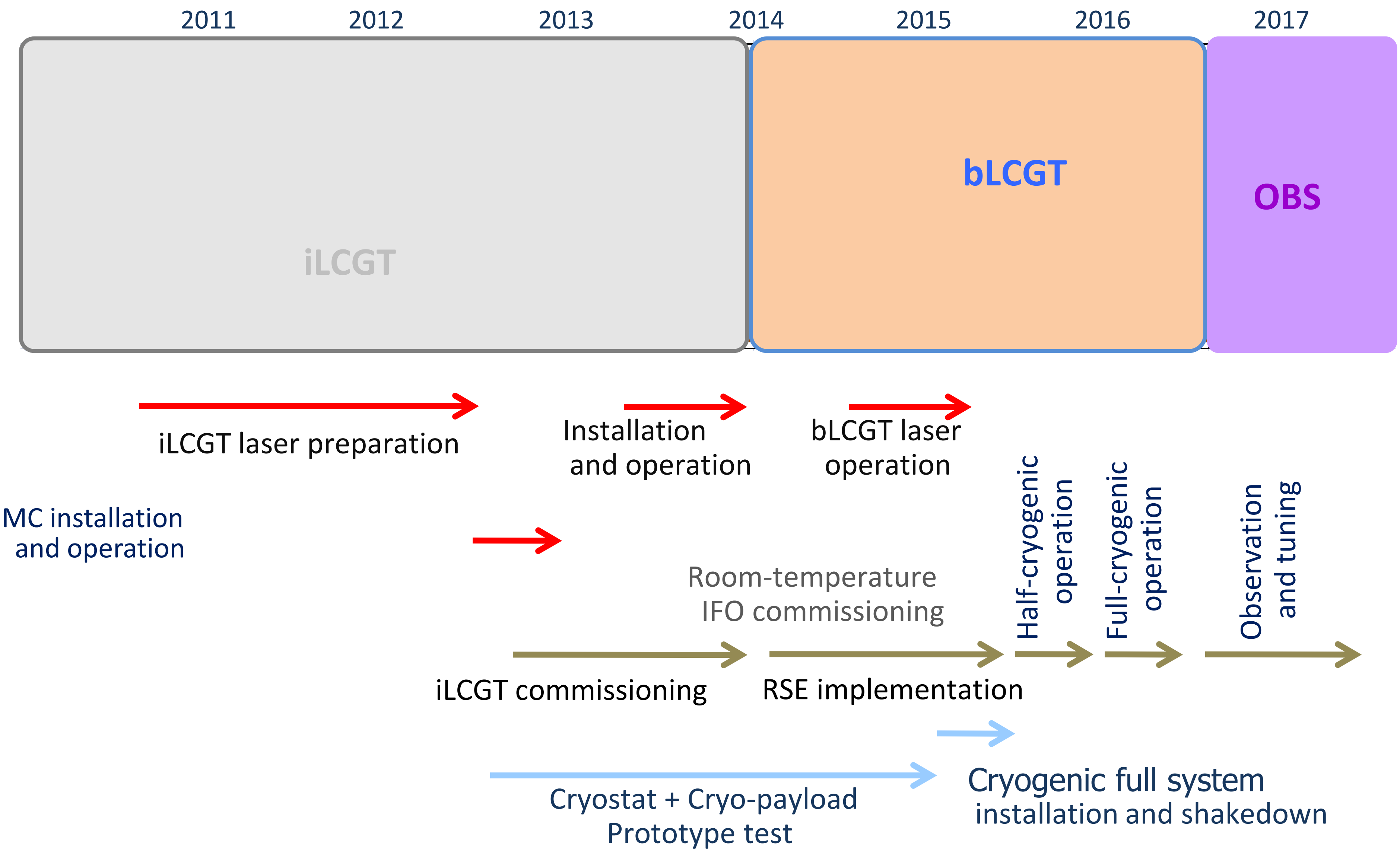


The sensitivities of Advanced LIGO & Advanced Virgo are shown next

Comparison with other detectors



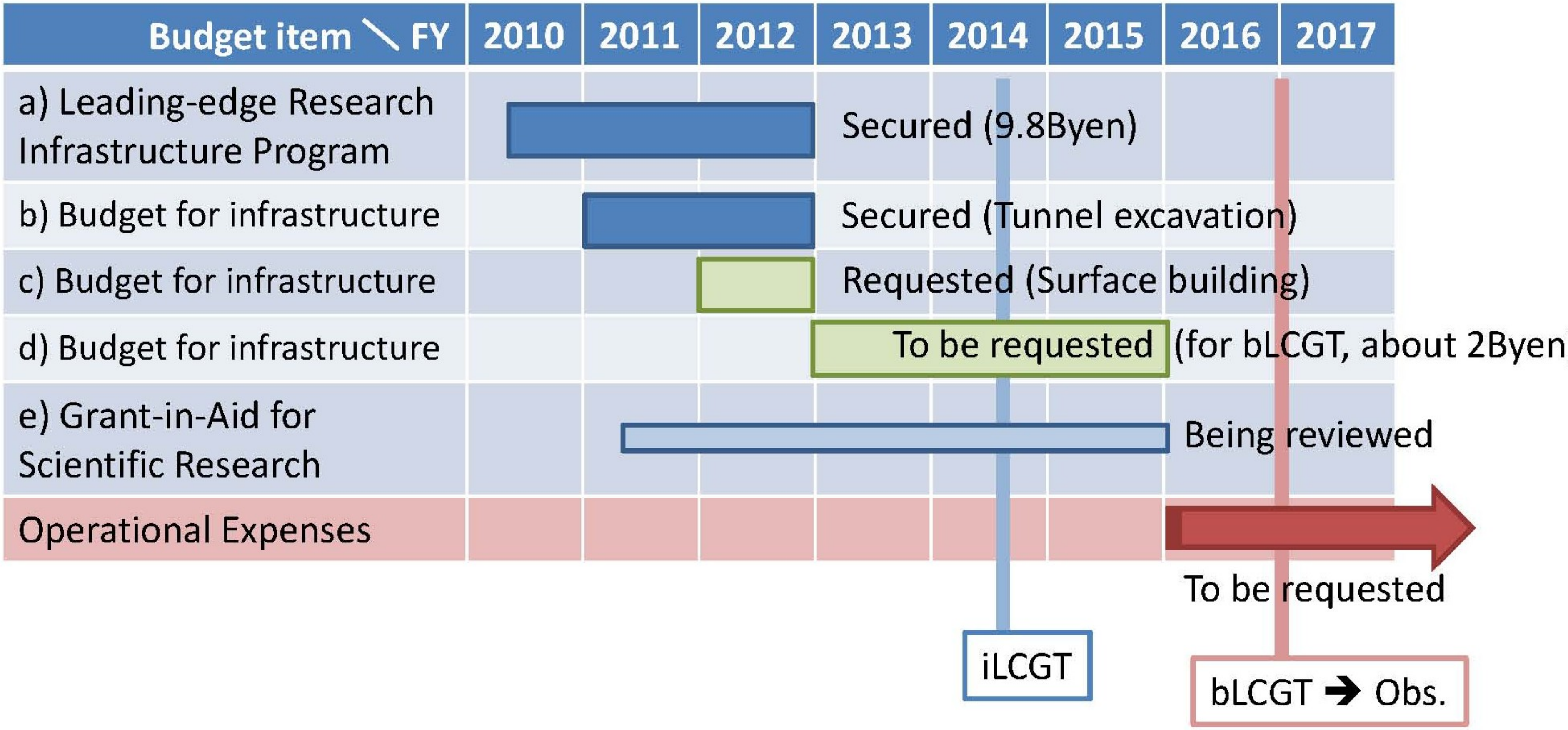
Schedule



LCGT is one year behind in the world but steady construction guarantees success

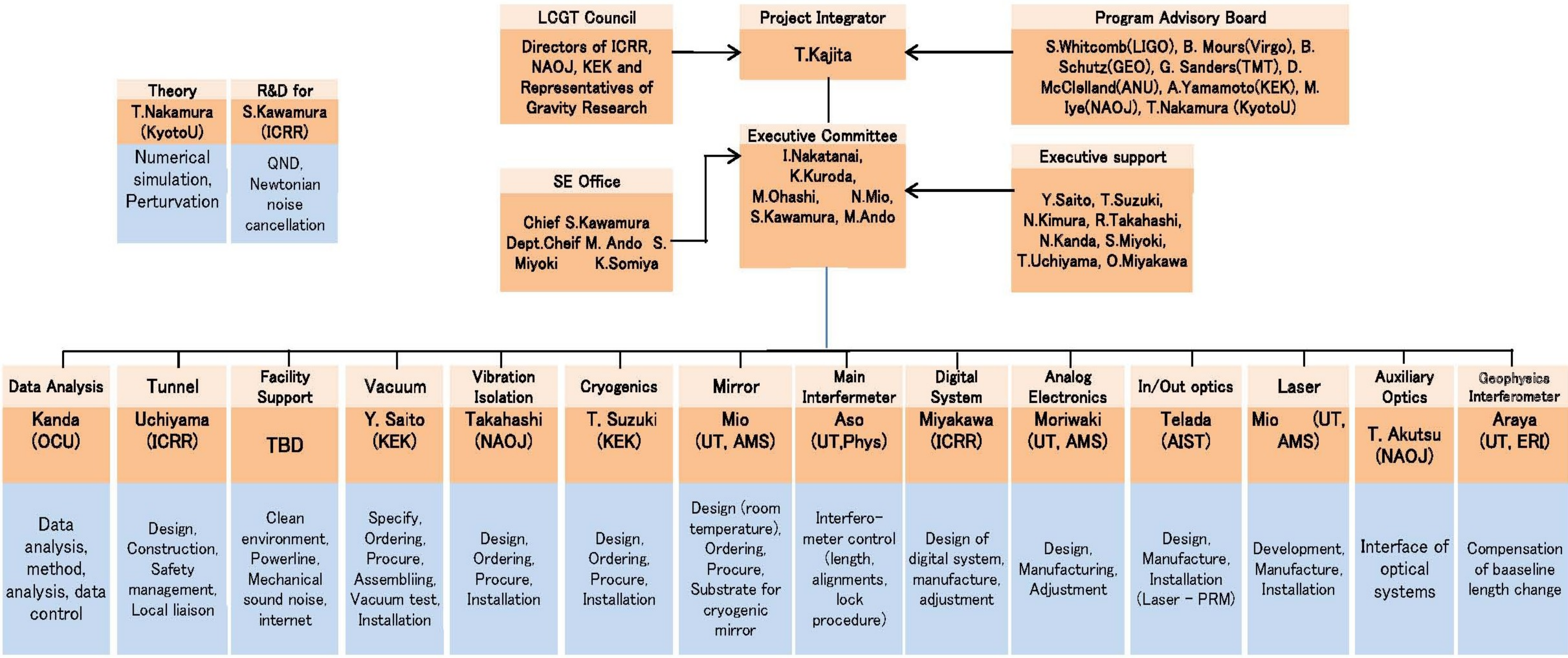
Budget

There are several budget categories in the LCGT project:



A total of 15.7 billion yen (a+b+c+d+e) is estimated for the construction of LCGT.

LCGT Organization Chart



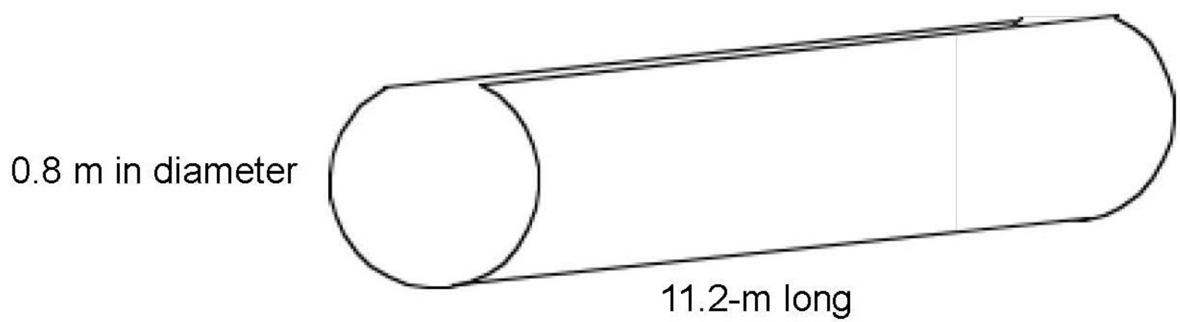
Vacuum tube production (for example of construction)

** manufacturing process of 12-m long tube

* hot roll → austenitic process (Annealing & Pickling) → surface grinding

finish condition
grinding: Grit # 150, wet

* press forming → one-seam weld (plasma welding without filler)

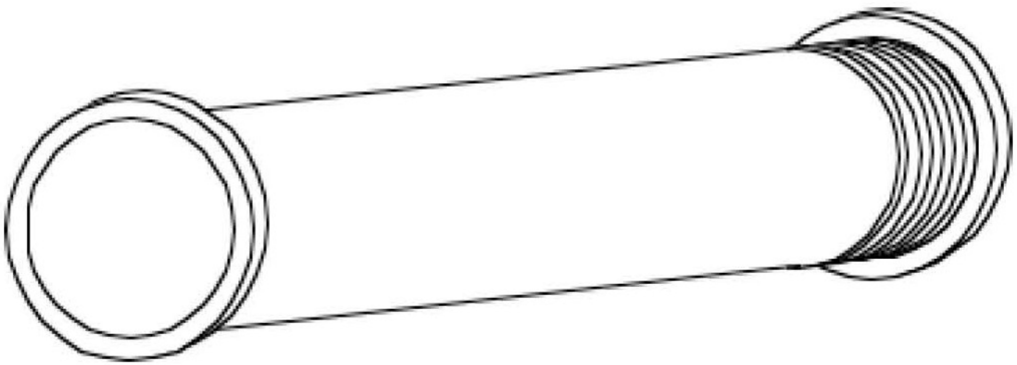


geometrical tolerance
straightness: 0.1%/L
circularity: 1%/D
perpendicularity: 0.2%/D

Vacuum tube production 2

** manufacturing process of 12-m long tube

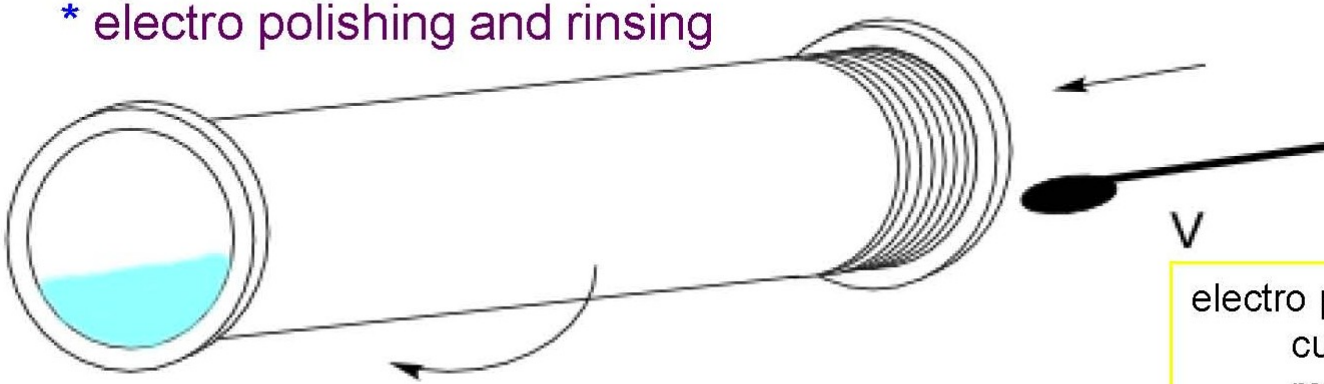
* weld flanges and bellows



flange
- SS F 304; rotary forging
- thickness; 30 mm
- welding neck; 120 mm long
- flatness: 0.1 mm

bellows
- SS316L; hydroformed
- stiffness; 100 N/mm or less
- finish: chemical polishing

* electro polishing and rinsing



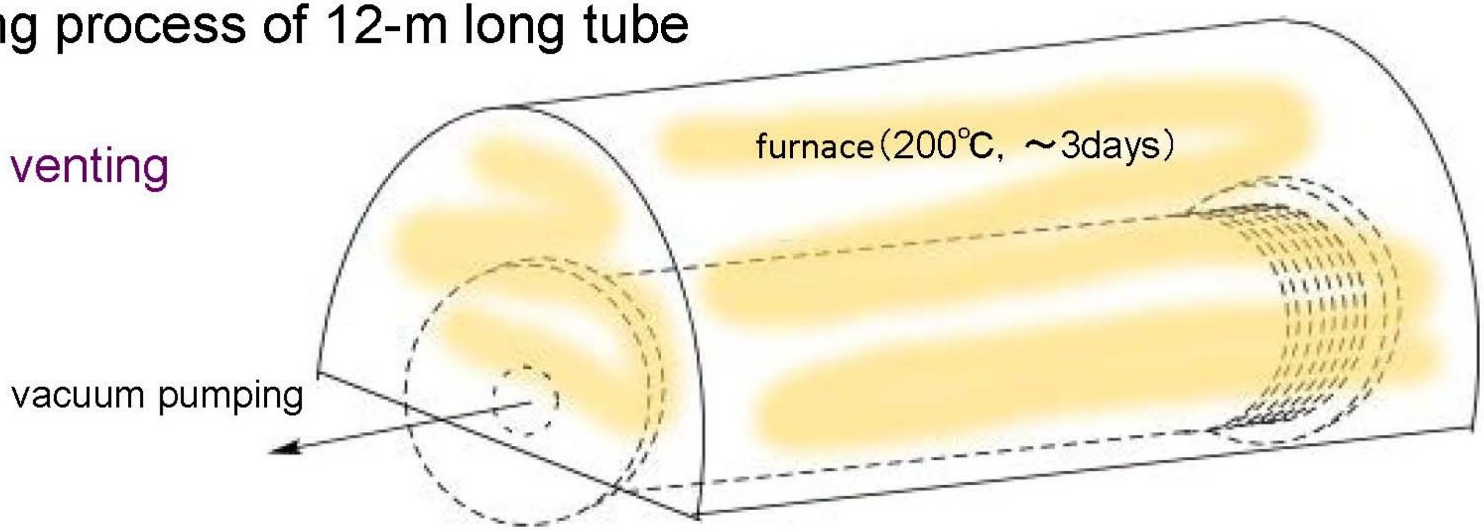
electro polishing
- current density; 50 A/dm2
- removal; 30 μm

rinsing
- pure water; 15 MΩ

Vacuum tube production 3

** manufacturing process of 12-m long tube

* pre-baking
  → dry air venting
  → seal



* storage (one year, or more, before installation) → in the railway tunnel

Mozumi tunnel of Kamioka Mining Railway (not in service)

Reviews

Category	Type A Review	Type B Review	Type C Review
Name	Internal Review	External Review	Program Advisory Board Review
Objectives	·Understanding detailed design/development status of other subsystems ·Identifying potential problems with other subsystems ·Clarifying the interfaces among subsystems	·Confirming detailed design/development status of the subsystems ·Identifying potential problems with each subsystem ·Recommendation on go/no-go for proceeding to the next development phase	·Confirming the LCGT development status
Reviewees	subsystem leaders	subsystem leaders	LCGT management and members
Reviewers	internal peers (External peers if necessary)	mostly external peers and a few internal reviewers	Program Advisory Board members
Frequency	at each milestone	at major milestones	once a year
Language	Japanese	Japanese (English if necessary)	English
Presentation materials	Japanese/English	English	English
Participants	any LCGT members	any LCGT members	any LCGT members
Presentation materials	Japanese/English	English	English

Review B Reviewers

Name	Affiliation	Remarks
Masaki Ando	LCGT/ Kyoto University	Deputy chief of secretariat
Stefan Ballmer	LSC/ Syracuse University	
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Warren Johnson	LSC/ Louisiana State University	
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Bernard Schutz (GEO, AEI, Potsdam)
Gary Sanders (Thirty Meter Telescope Project)
Akira Yamamoto (Cryogenics Science Center, KEK)
Stan Whitcomb (LIGO, Caltech)　Chair

Academic Exchanges with other projects

- LIGO Laboratory
  - Quarter request submission
  - Support to collaboration with researchers of LSC
- EGO/Virgo
  - Exchange technical information and R&D for ET
- GEO (Glasgow)
  - Exchange technical information and R&D for ET
- Shanghai United Center for Astrophysics
  - Advanced study for next generation techniques
- GEO(AEI) in preparation
- University of Sannio in preparation
- Tsing-Hua University (Taiwan) in preparation

Summary

- LCGT is under construction for the first detection of GW and opening GW astronomy as 2^{nd} generation detector
- Advanced LIGO and Advanced Virgo have the similar sensitivity of LCGT
- AIGO-Australia / Indo-Australia is considered to be built
- Among 2^{nd} generation detectors, LCGT solely adopts straight forward way to improve sensitivity by cryogenics and underground (techniques of 3^{rd} generation detector)
- Although the schedule of LCGT completion is one year later, still there is a chance to firstly detect GW
- Studies of arranging EM follow-up and joint analysis using neutrino detector (ANTARES) show the step of multi-messenger astronomy by GW