共同利用運営委員会
19 December 2009

大型低温重力波望遠鏡(LCGT)の開発・設計(XI)

LCGT Collaboration
宇宙線研究所
黒田和明

NASA PHOTO

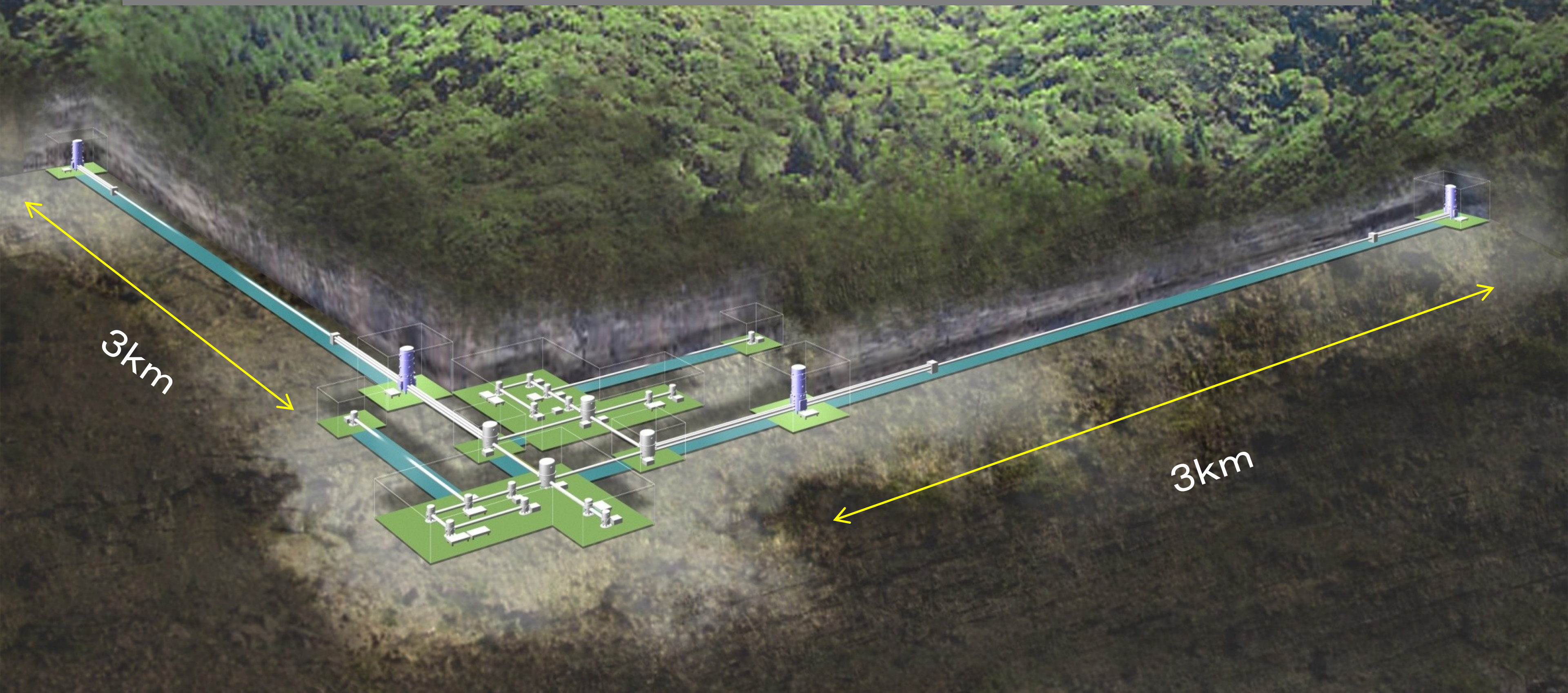
LCGT共同研究者
（2009年10月時点）

K Kuroda[1], I Nakatani[1], M Ohashi[1], S Miyoki[1], T Uchiyama[1], O Miyakawa[1], H Ishiduka[1], K Agatsuma[1], T Saito[1], M-K Fujimoto[2], S Kawamura[2], R Takahashi[2], D Tatsumi[2], A Ueda[2], M Fukushima[2], H Ishizaki[2], Y Torii[2], S Sakata[2], A Nishizawa[2], K Kotake[2], Y Sekiguchi[2], A Yamamoto[3], Y Saito[3], T Haruyama[3], T Suzuki[3], N Kimura[3], T Tomaru[3], K Ioka[3], K Tsubono[4,5], Y Aso[4], K Ishidoshiro[4], K Takahashi[4], W Kokuyama[4], K Okada[4], S Kawara[4], N Matsumoto[4], F Takahashi[4], A Taruie[4], J Yokoyama[5], K Ueda[6], H Yoneda[6], K Nakagawa[6], M Musha[6], N Mio[7], S Moriwaki[7], N Ohmae[7], T Mori[7], A Ogikubo[7], Y Tokuda[7], A Araya[8], A Takamori[8], K Izumi[9], N Kanda[10], K Nakao[10], S Sato[11], S Telada[12], T Takatsuji[12], Y Bito[12], S Nagano[13], H Tagoshi[14], T Nakamura[15], N Seto[15], M Ando[15], M Sasaki[16], M Shibata[16], T Tanaka[16], N Sago[16], E Nishida[17], Y Wakabayashi[17], T Shintomi[18], H Asada[19], Y Itho[20], T Futamase[20], K Oohara[21], M Saijo[22], T Harada[22], S Yamada[23], N Himemoto[24], H Takahashi[25], Y Kojima[26], K Uryu[27], K Yamamoto[28], F Kawazoe[28], A Pai[28], K Hayama[28], Y Chen[29], K Kawabe[29], K Arai[29], K Somiya[29], M E Tobar[30], D Blair[30], J Li[30], C Zhao[30], L Wen[30], J Warren[31], H Nakano[32], R Stuart[33], S Márka[34], K Kokeyama[35], Z-H Zhu[36], S Dhurandhar[37], S Mitra[37], H Mukhopadhyay[37], V Milyukov[38], L Baggio[39], Y Zhang[40], J Cao[41], C-G Huang[42], W-T Ni[43], S-S Pan[44], S-J Chen[44], K Numata[45]

[1]Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, JAPAN
[2]National Astronomical Observatory (NAOJ), Osawa, Mitaka, JAPAN
[3]High Energy Accelerator Research Organization (KEK), Tsukuba, JAPAN
[4]Department of Physics, University of Tokyo, Tokyo, JAPAN
[5]Research Center for the Early Universe, University of Tokyo, Tokyo,Japan
[6]Institute for Laser Science, University of Electro-Communications, Chofu, JAPAN
[7]Department of Advanced Materials Science, University of Tokyo, Kashiwa, JAPAN
[8]Earthquake Research Institute, University of Tokyo, Tokyo, JAPAN
[9]Department of Astronomy, University of Tokyo, Tokyo, JAPAN
[10]Department of Physics, Osaka City University, Osaka, JAPAN
[11]Faculty of Engineering, Hosei University, Koganei, JAPAN
[12]National Institute of AIST, Tsukuba, JAPAN
[13]National Institute of Information and Communication Technology, JAPAN
[14]Department of Earth and Space Science, Osaka University, Osaka, JAPAN
[15]Department of Physics, Kyoto University, Kyoto, JAPAN
[16]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, JAPAN
[17]Graduate School of Humanities and Sciences, Ocahnomizu University, JAPAN
[18]Advanced Research Institute for the Sciences and Humanities, Nihon University, Tokyo, JAPAN
[19]Department of Advanced Physics, Hirosaki University, Hirosaki, JAPAN
[20]Astronomical Institute, Tohoku University, Sendai, JAPAN
[21]Department of Physics, Niigata University, Niigata, JAPAN
[22]Department of Physics, Rikkyo University, Tokyo, JAPAN
[23]Department of Physics, Waseda University, Tokyo, JAPAN
[24]College of Industrial Technology, Nihon University, Chiba, JAPAN
[25]School of Engineering, Nagaoka University of Technology, Nagaoka, JAPAN
[26]Department of Physical Science, Hiroshima University, Hiroshima, JAPAN
[27]University of the Ryukyu, Okinawa, JAPAN
[28]Max Planck Institute for Gravitational physics (AEI), Hanover, GERMANY
[29]California Institute of Technology, Pasadena, CA, USA
[30]Department of Physics, University of Western Australia, WA, AUSTRALIA
[31]Department of Physics, Louisiana State University, Louisiana, USA
[32]Center for Computational Relativity and Gravitation, Rochester Institute of Technology, Rochester, New York, USA
[33]Department of Physics, Glasgow University, Glasgow, UK
[34]Columbia Astrophysics Laboratory, Columbia University in the city of New York, USA
[35]Department of Physics, Birmingham University, Birmingham, UK
[36]Department of Astronomy, Beijing Normal University, Beijing, CHINA
[37]Inter University Center for Astronomy & Astrophysics, Pune University, INDIA
[38]Sternberg State Astronomical Institute of Moscow University, Moscow, RUSSIA
[39]LATMOS, CNRS, 10-12 Avenue de l'Europe 78140, Velizy, FRANCE
[40]Center for Astrophysics, University of Science and Technology of China, CHINA
[41]Tsinghua University, Beijing, CHINA
[42]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, CHINA
[43]Center for Gravitation and Cosmology, Purple Mountain Observatory, Chinese Academy of Sciences, Nanging, CHINA
[44]Center for Measurement Standards, Industrial Technology Research Institute, Hsinchu, Taiwan, ROC
[45]Goddard Space Flight Center, NASA, Greenbelt, MD, USA

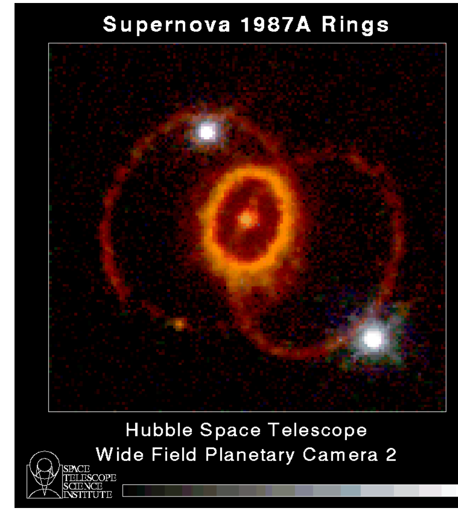
LCGTの目的

1) 世界に先駆け重力波の発見
2) 重力波天文学の創生と展開



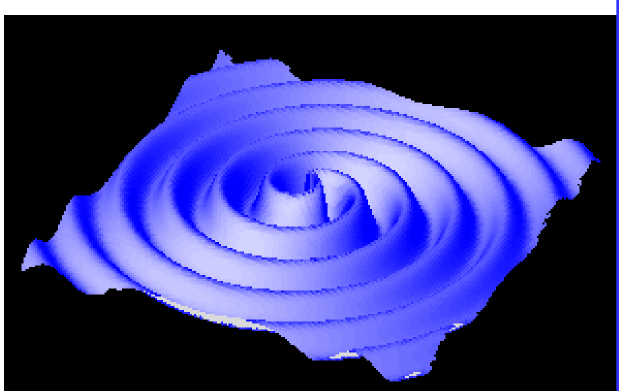
LCGTの重力波源

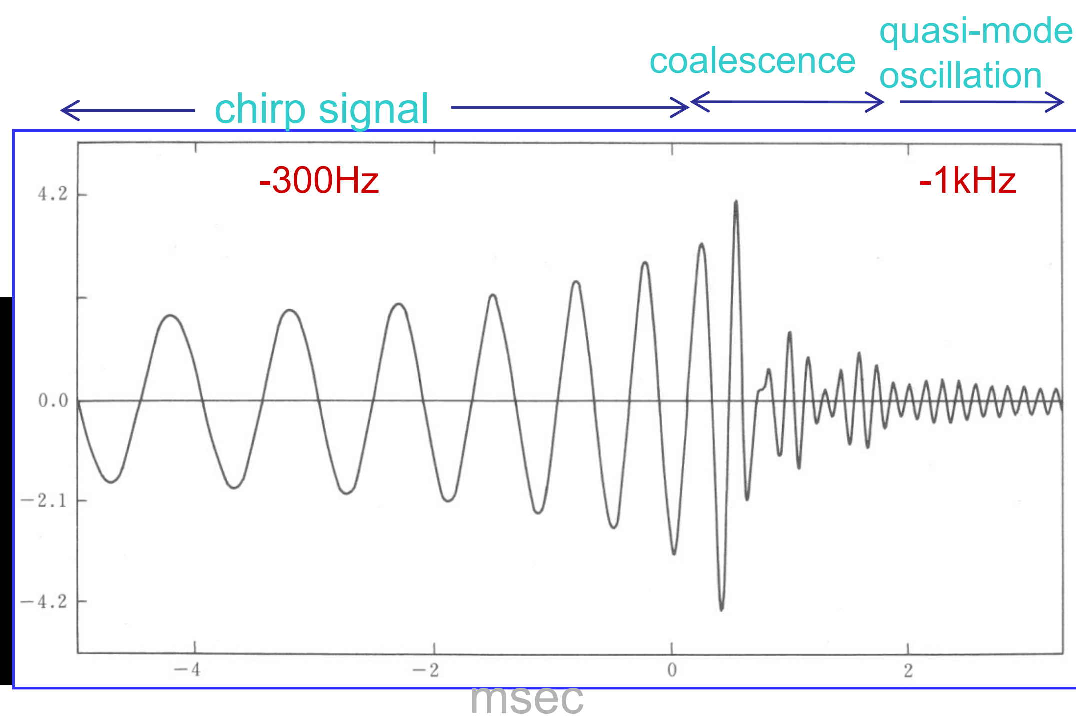
1. Coalescence of neutron star binaries
2. Coalescence of black hole binaries
3. Core collapse of massive stars
4. Rotation of pulsar



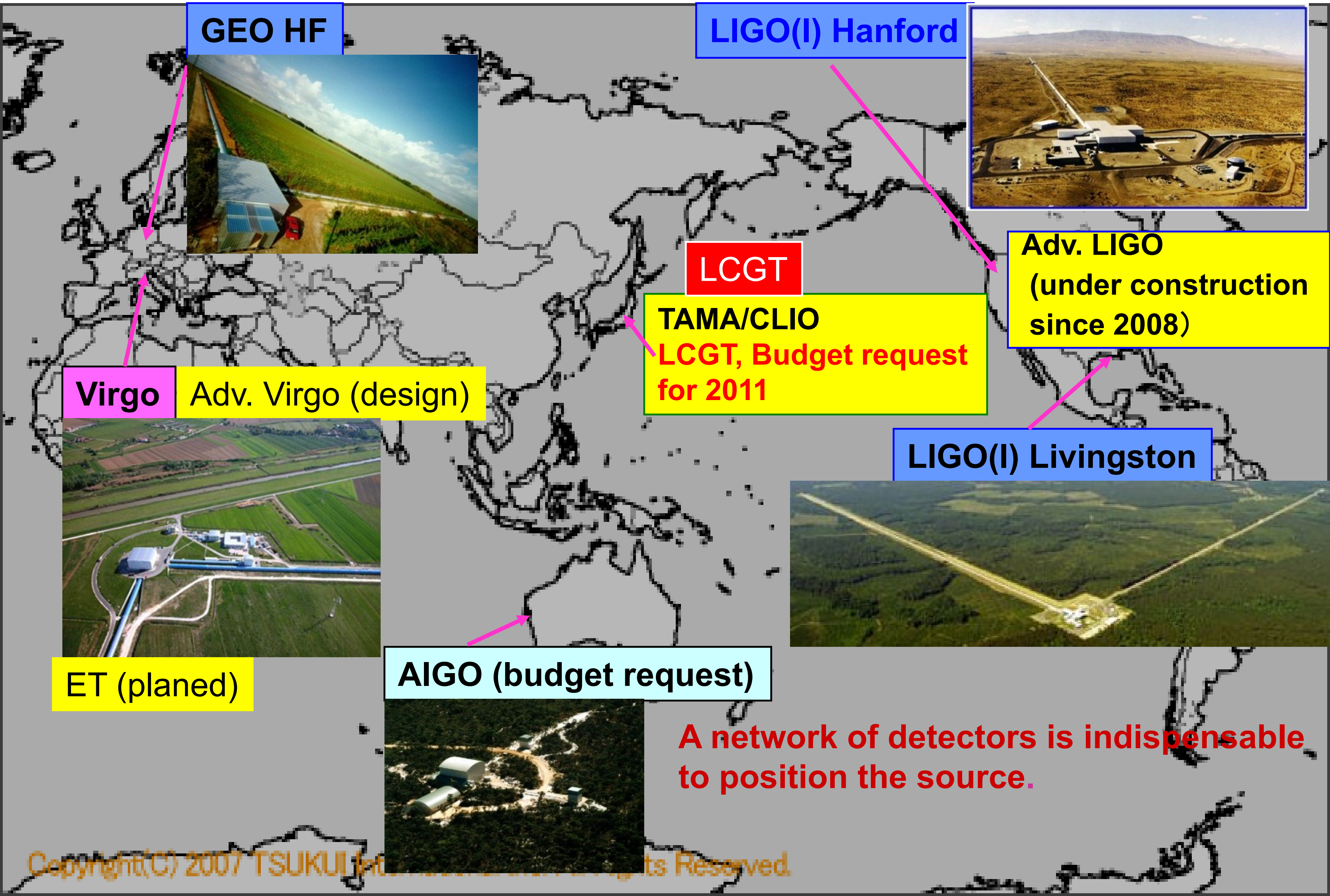
Existing neutron star binaries in our Galaxy

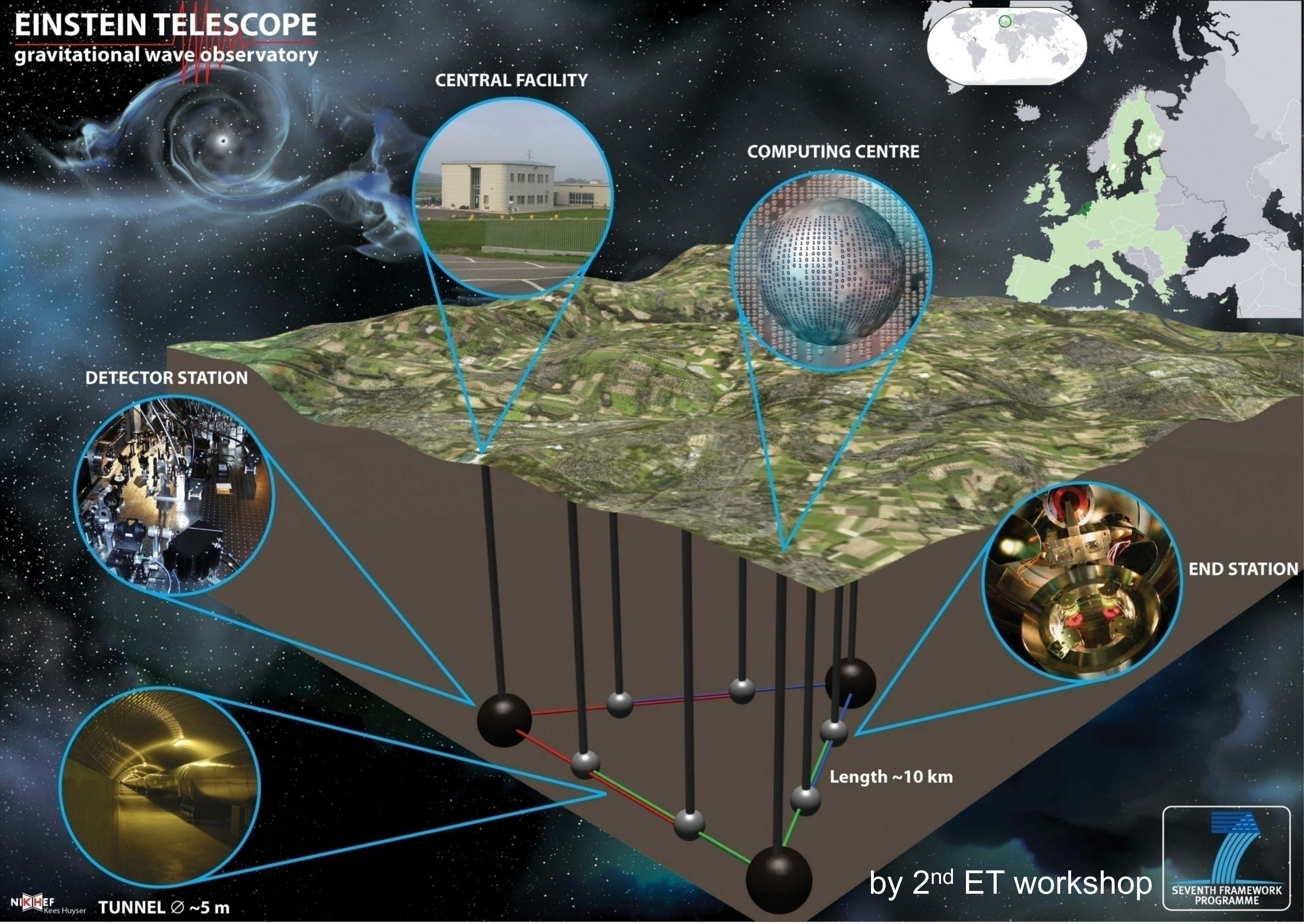
- PSR B1913+16
- PSR B1534+12
- PSR J1141-6545
- PSR J0737-3039
- PSR J1906+0746



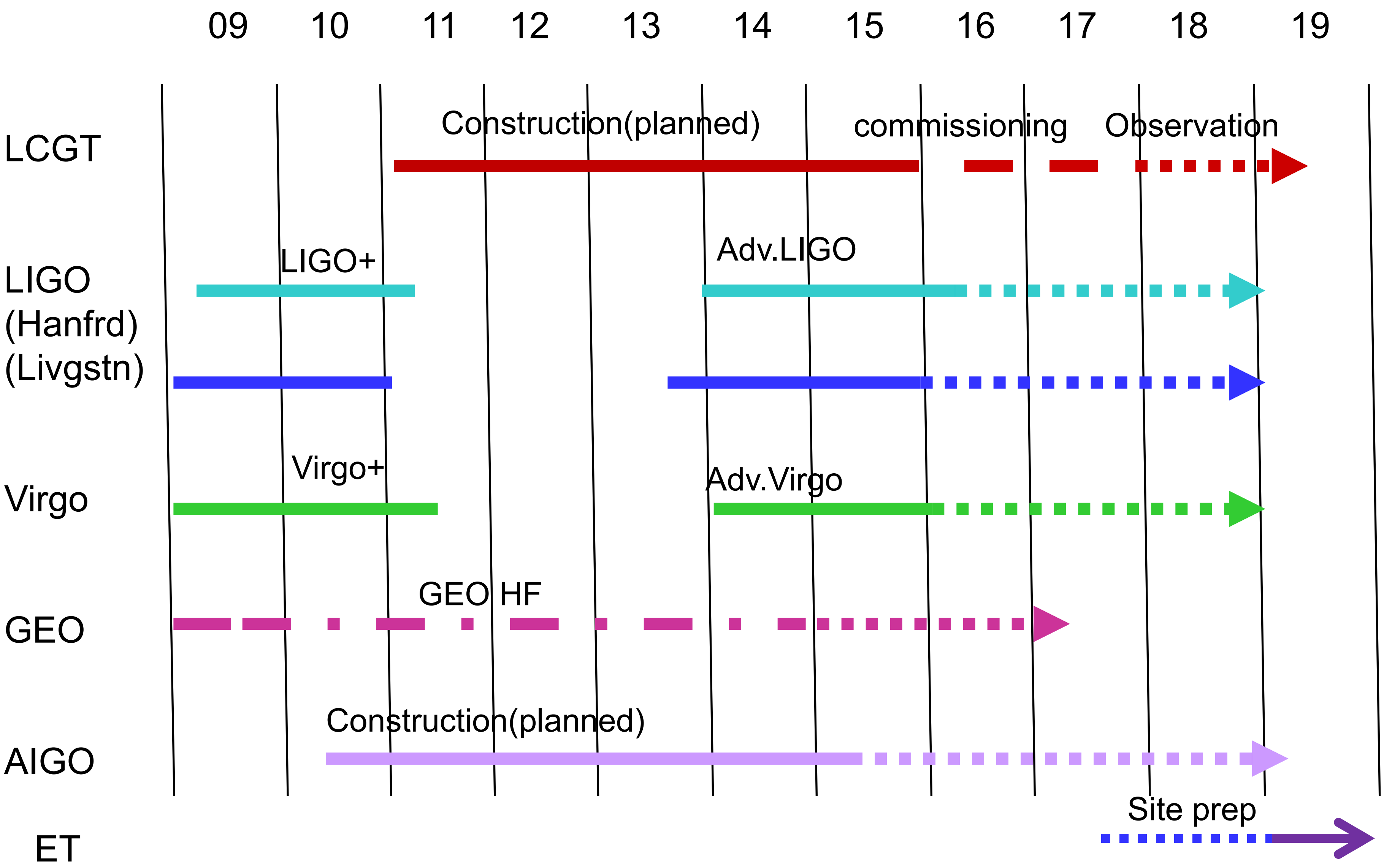


世界の重力波観測網

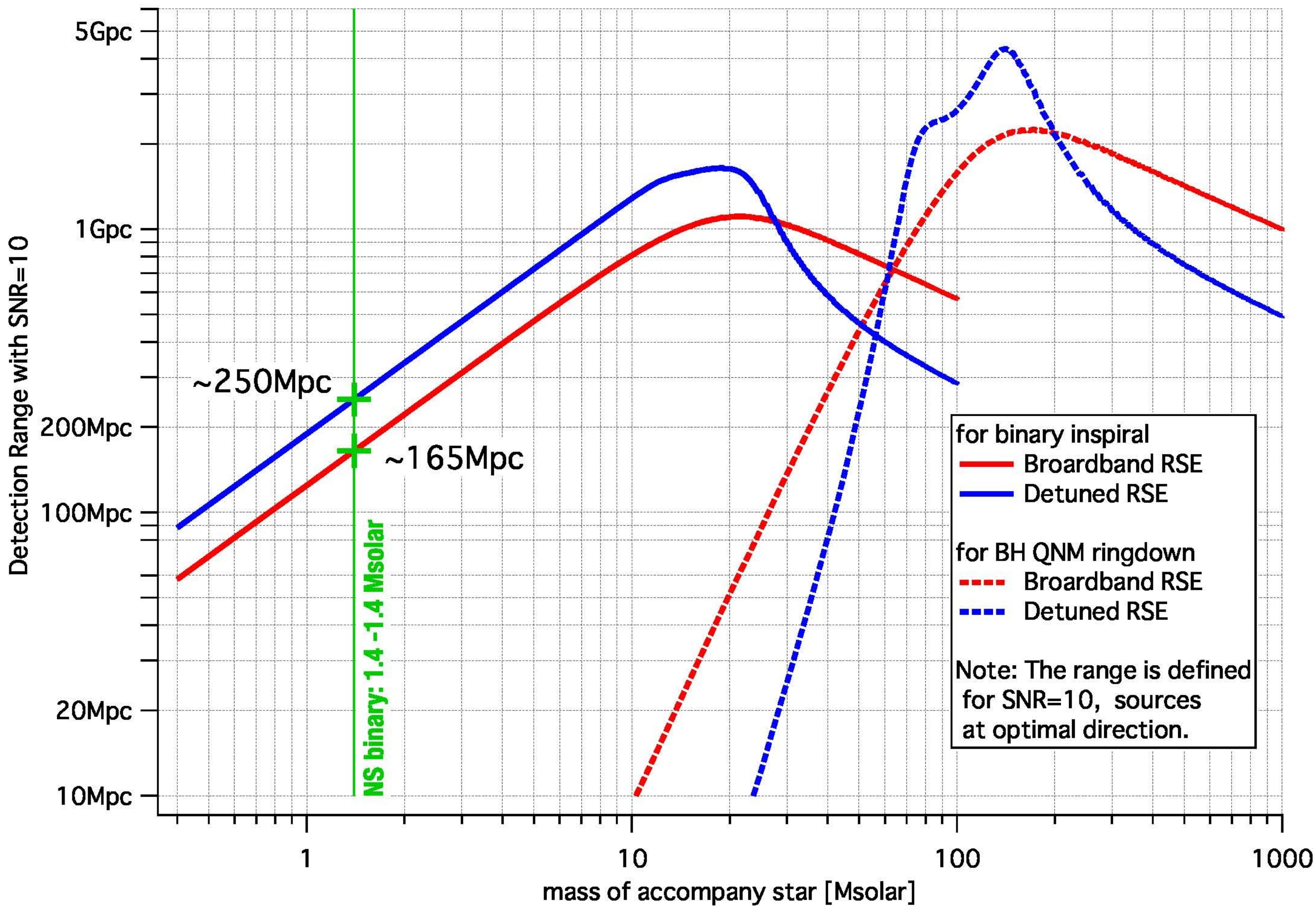

GEO HF
LIGO(I) Hanford
Adv. LIGO
(under construction
since 2008)
LCGT
TAMA/CLIO
LCGT, Budget request
for 2011
Virgo
Adv. Virgo (design)
LIGO(I) Livingston
ET (planed)
AIGO (budget request)
A network of detectors is indispensable
to position the source.


EINSTEIN TELESCOPE
gravitational wave observatory
CENTRAL FACILITY
COMPUTING CENTRE
DETECTOR STATION
END STATION
Length ~10 km
TUNNEL ∅ ~5 m
NIKHEF
Kees Huyser
by 2nd ET workshop
SEVENTH FRAMEWORK PROGRAMME

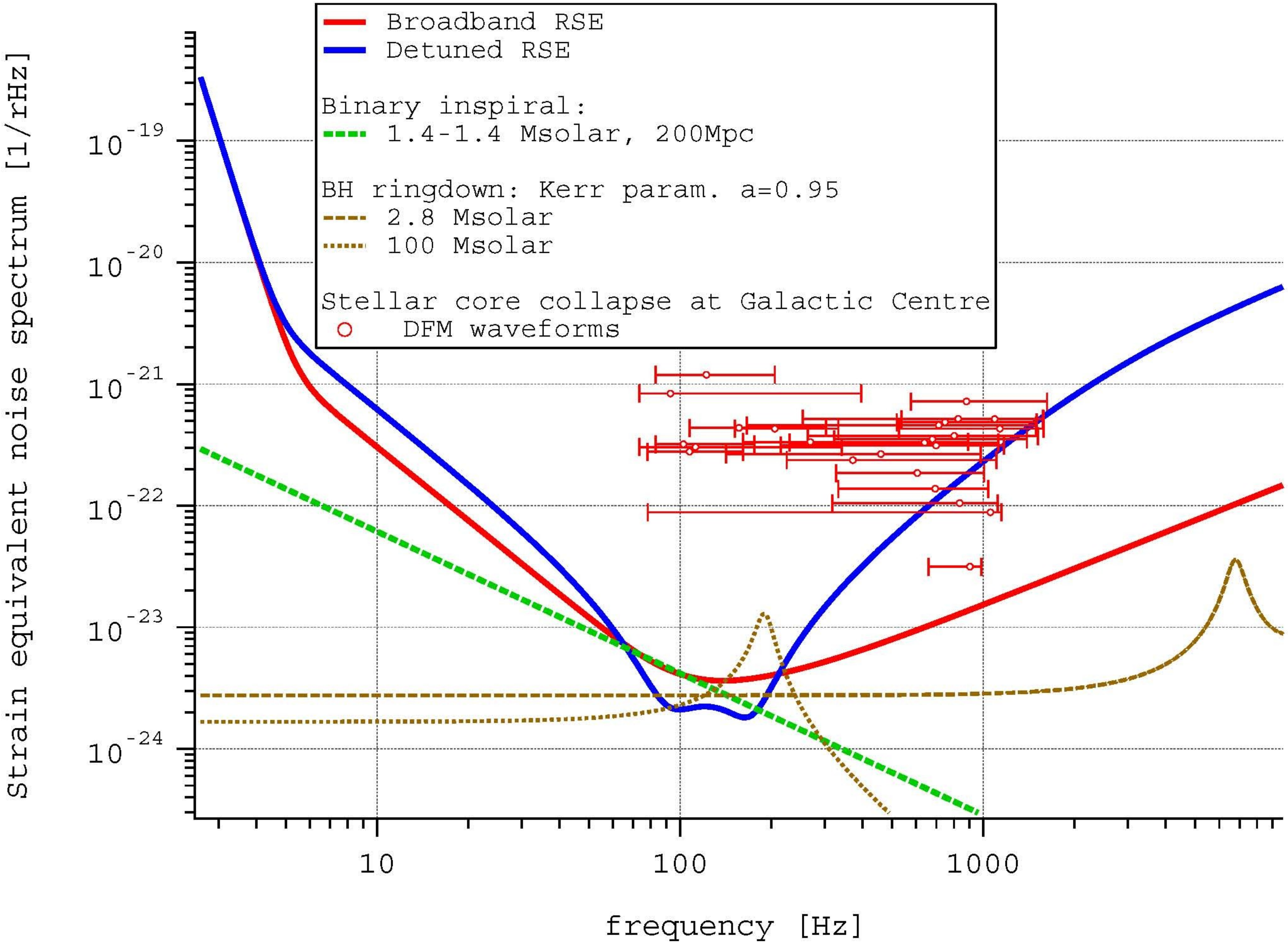
LCGTと他の地上計画のスケジュール



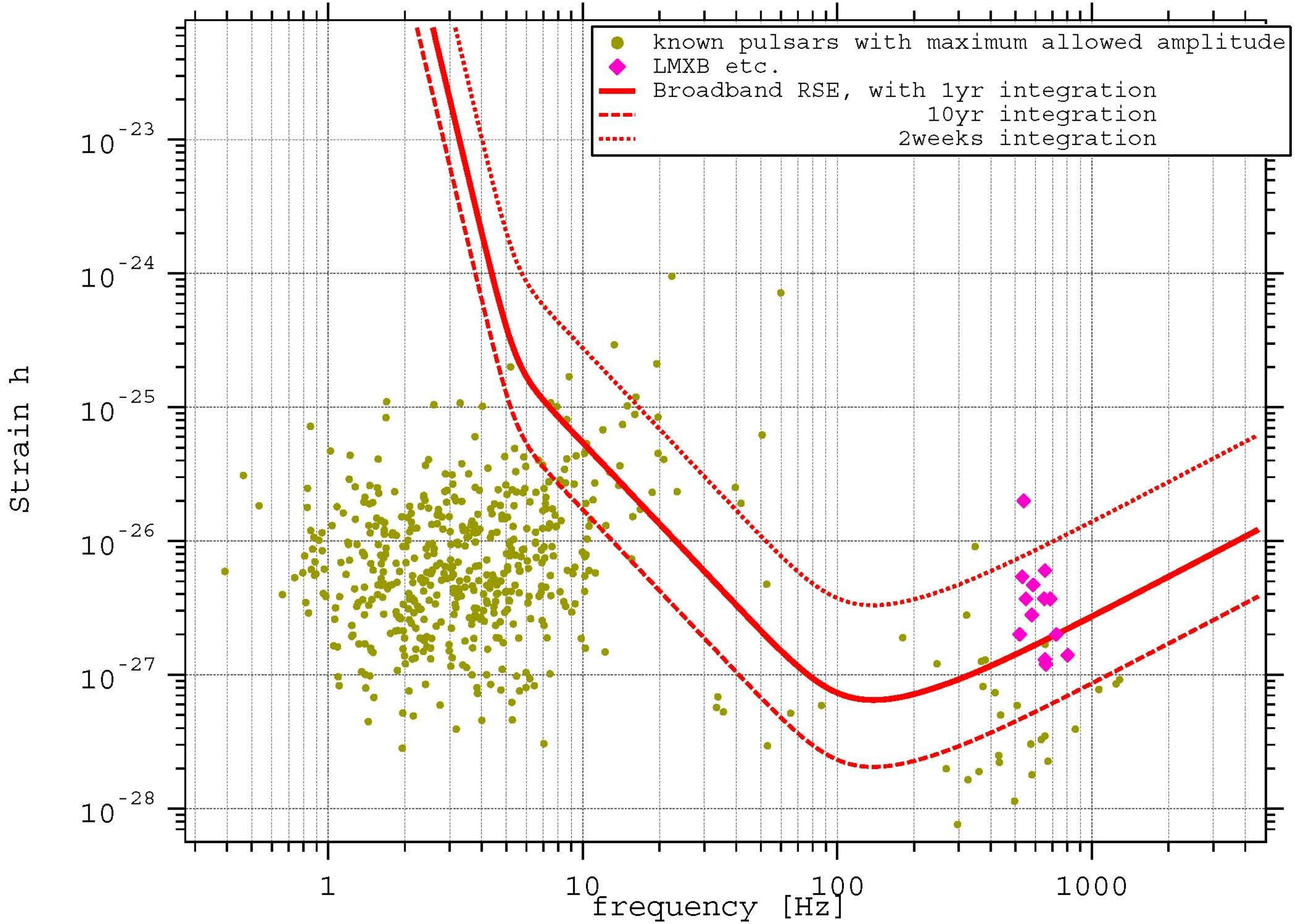
LCGTの目標感度と 将来の向上感度



LCGT の感度と重力波源 (1)



LCGT の感度と重力波源 (2)

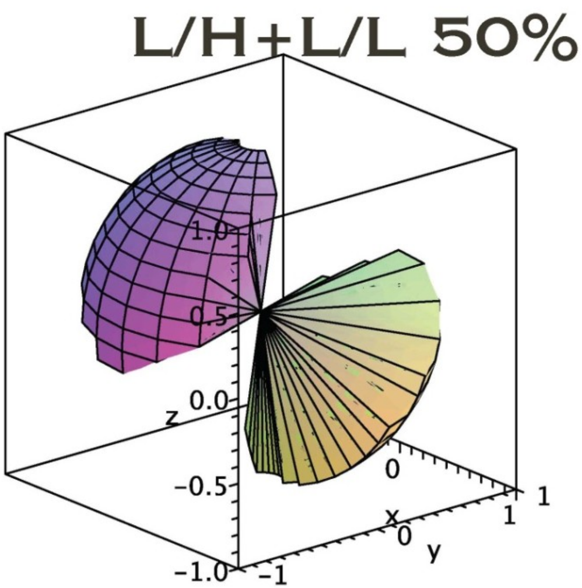


世界の観測網におけるLCGTの役割

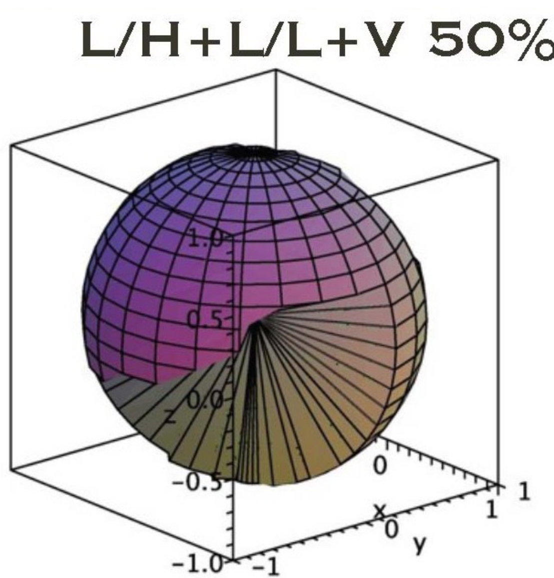
1）Long baseline length required to determine positioning of sources（20 ms time flight among North America, Europe and Asia）
2）Laser interferometer has angular dependent sensitivity pattern

LCGT increases sky coverage by 60% compared with L/H-L/L-Virgo (50% sensitivity of its peak)

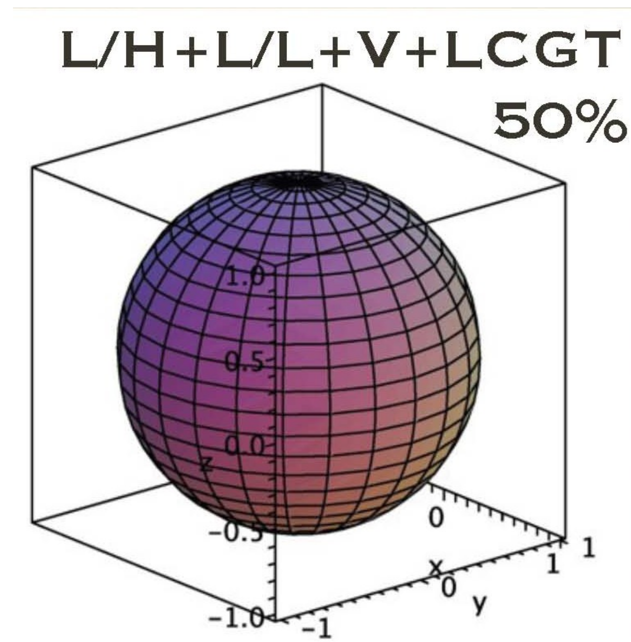
33% coverage



By global network



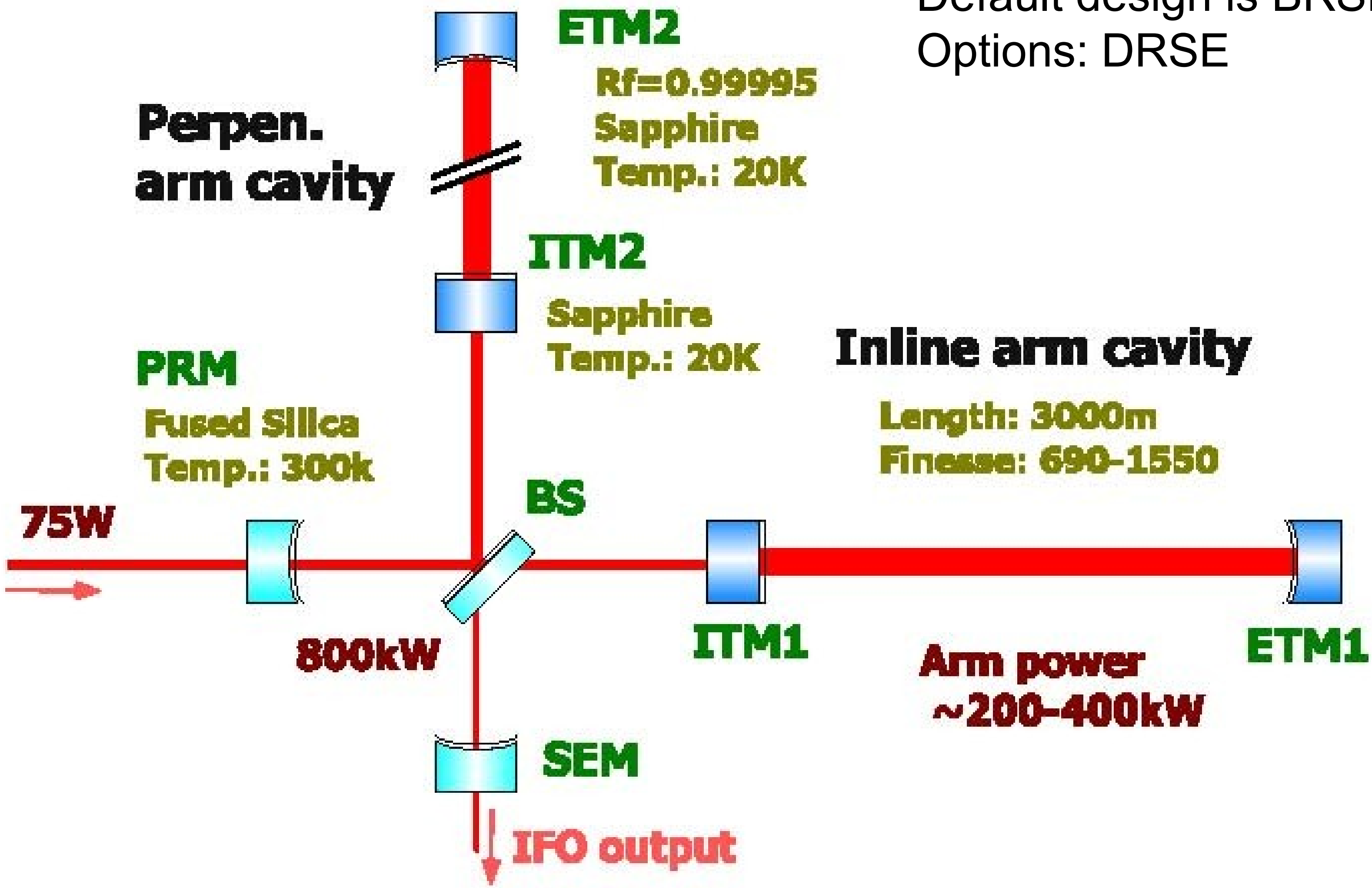
100% coverage



@B. Schutz(Fujihara seminar, May 2009)

LCGTの基本設計

Default design is BRSE
Options: DRSE

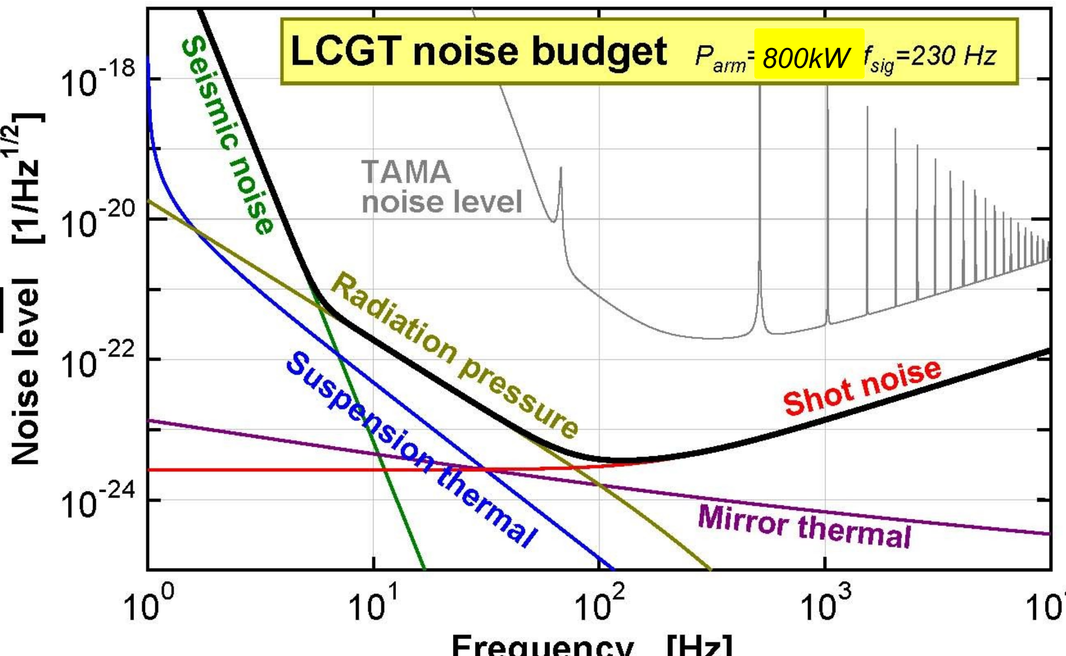


LCGTの設計パラメーター

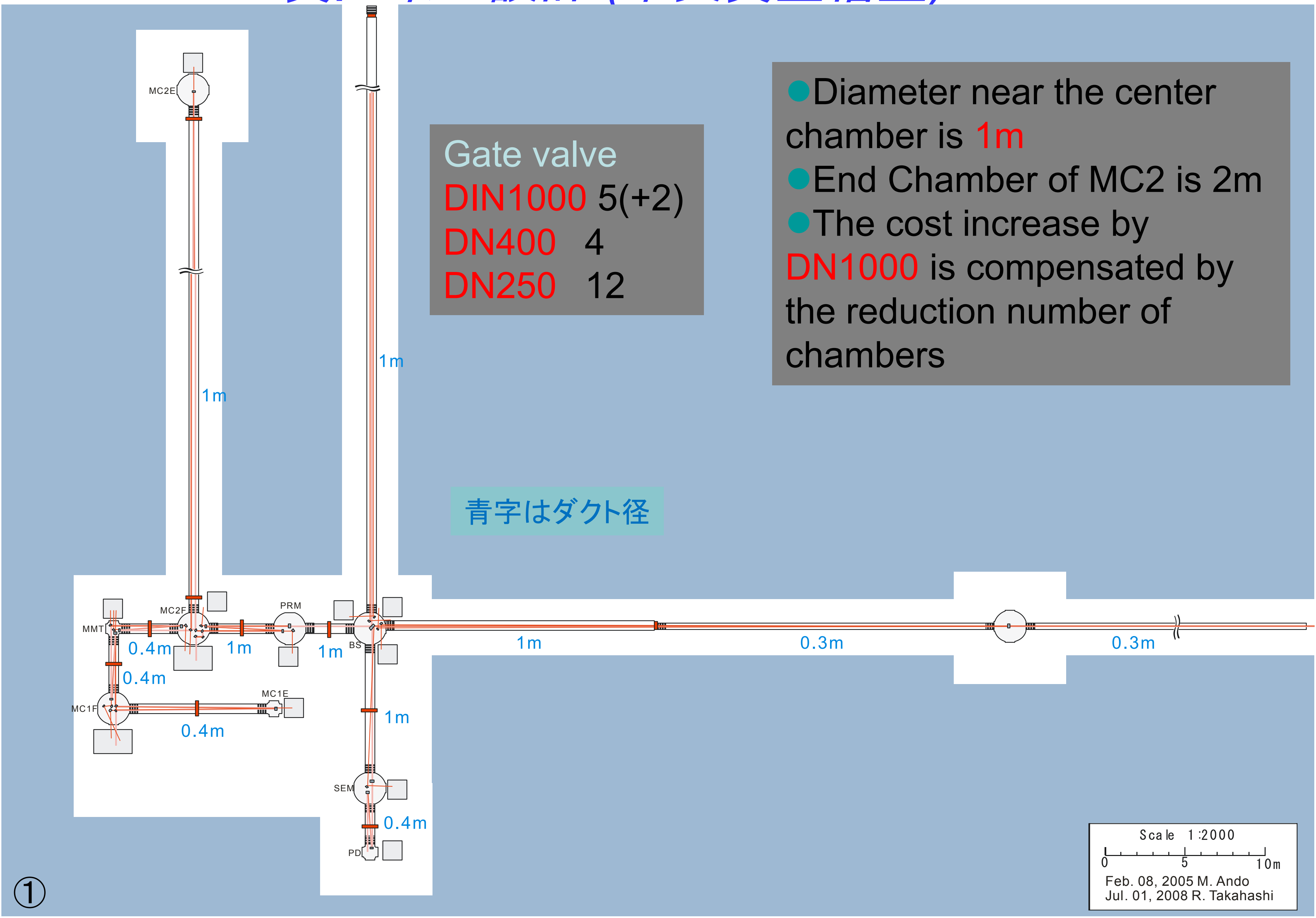
In order to attain the sensitivity to catch the event at ~185Mpc, we need to reduce shot noise determined by 800kW optical power (400 kW each cavity).

Thermal noise of the mirror, coating of the mirror, and suspension need to be suppressed by cryogenic temperature, 20K. Mechanical losses of these parts are required to satisfy this thermal noise limit; they are 10^{-8}, 4×10^{-4}, 10^{-8}

Final sensitivity is limited by quantum noises in the observation frequency band, 230Hz. Radiation pressure noise is determined both by the optical power and by mass, 30kg.



真空系の設計 (中央真空槽室)



Gate valve
DIN1000 5(+2)
DN400 4
DN250 12

- Diameter near the center chamber is 1m
- End Chamber of MC2 is 2m
- The cost increase by DN1000 is compensated by the reduction number of chambers

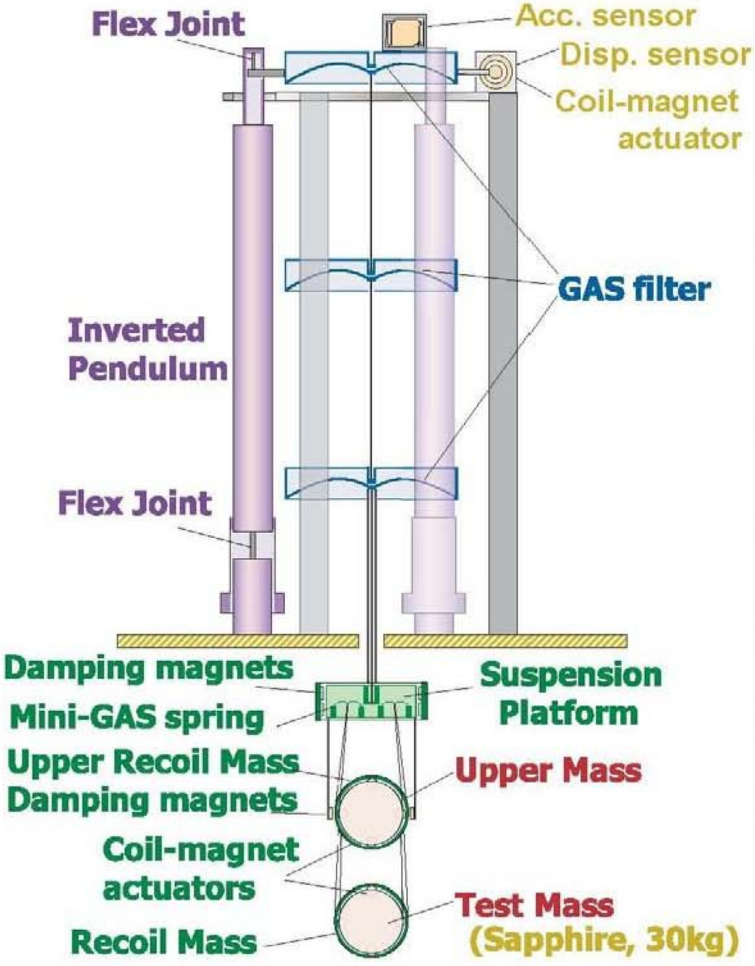
青字はダクト径

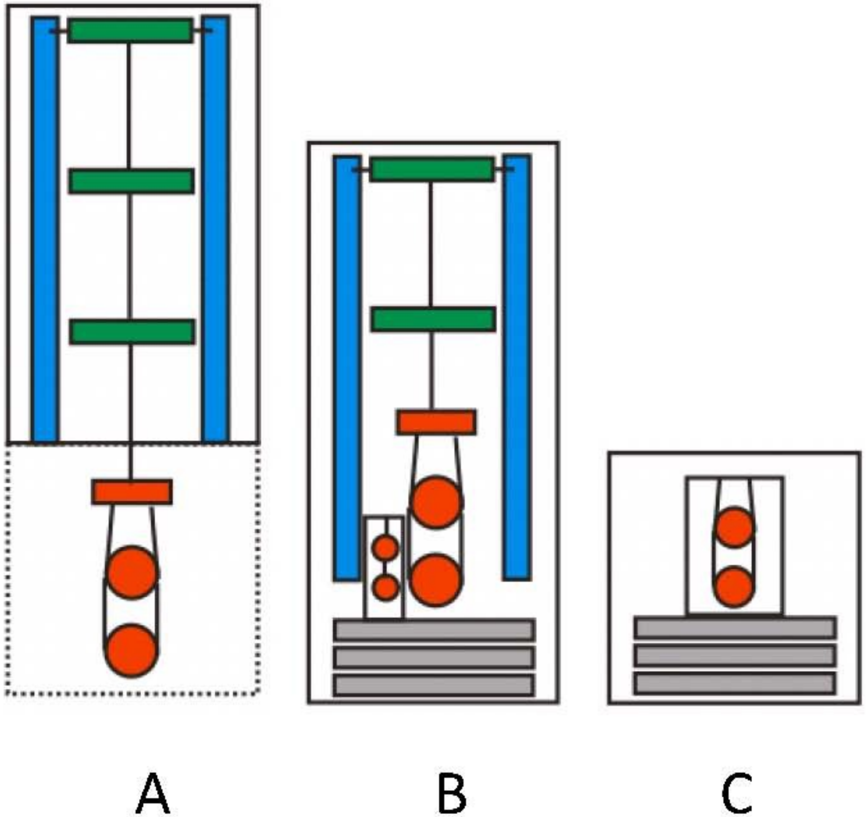
Scale 1:2000
0 5 10m
Feb. 08, 2005 M. Ando
Jul. 01, 2008 R. Takahashi

①

防振装置の設計

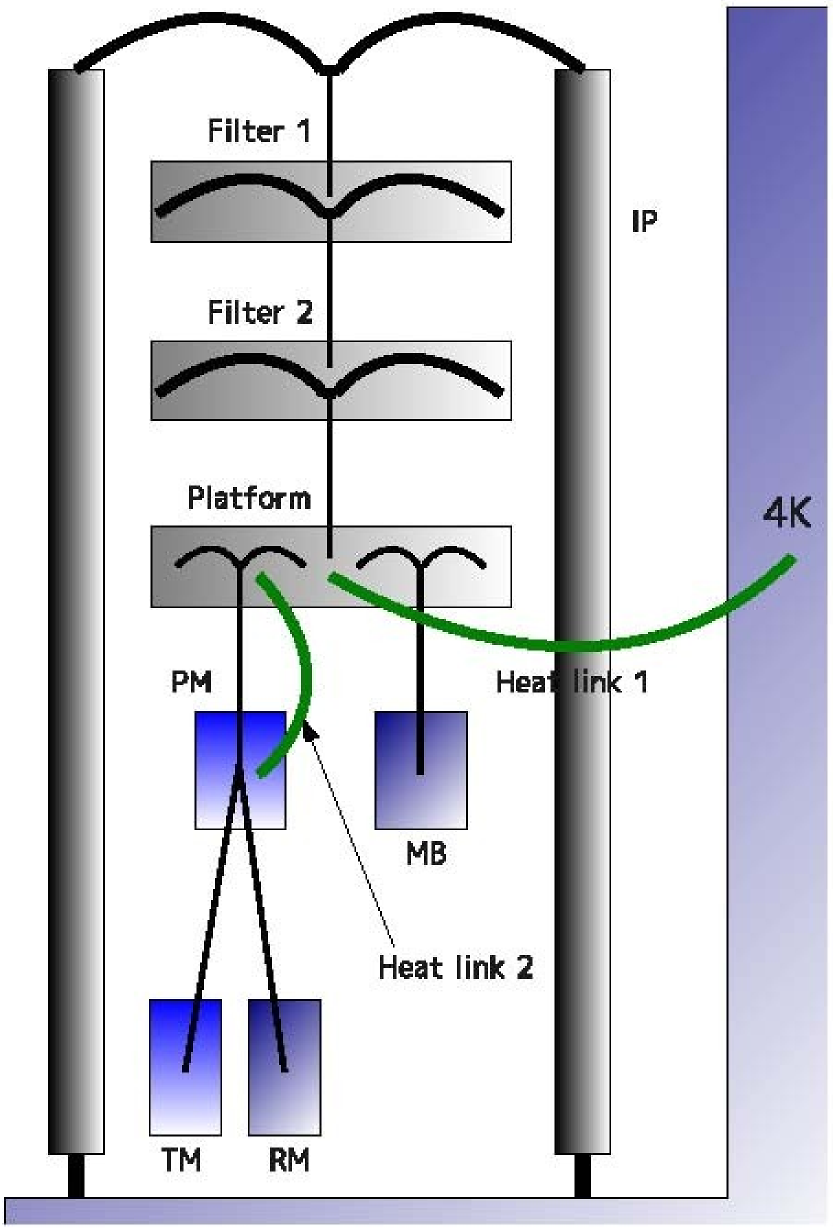
A)SAS(GASF 3stage)+cryo-sus:
FM1、FM2、EM1、EM2
B)SAS(GASF 2stage)+non-cryo:
BS、PRM、SEM、MC2F、MC2E
C)STACK+2stages: MC1F、MC1E、MMT、PD





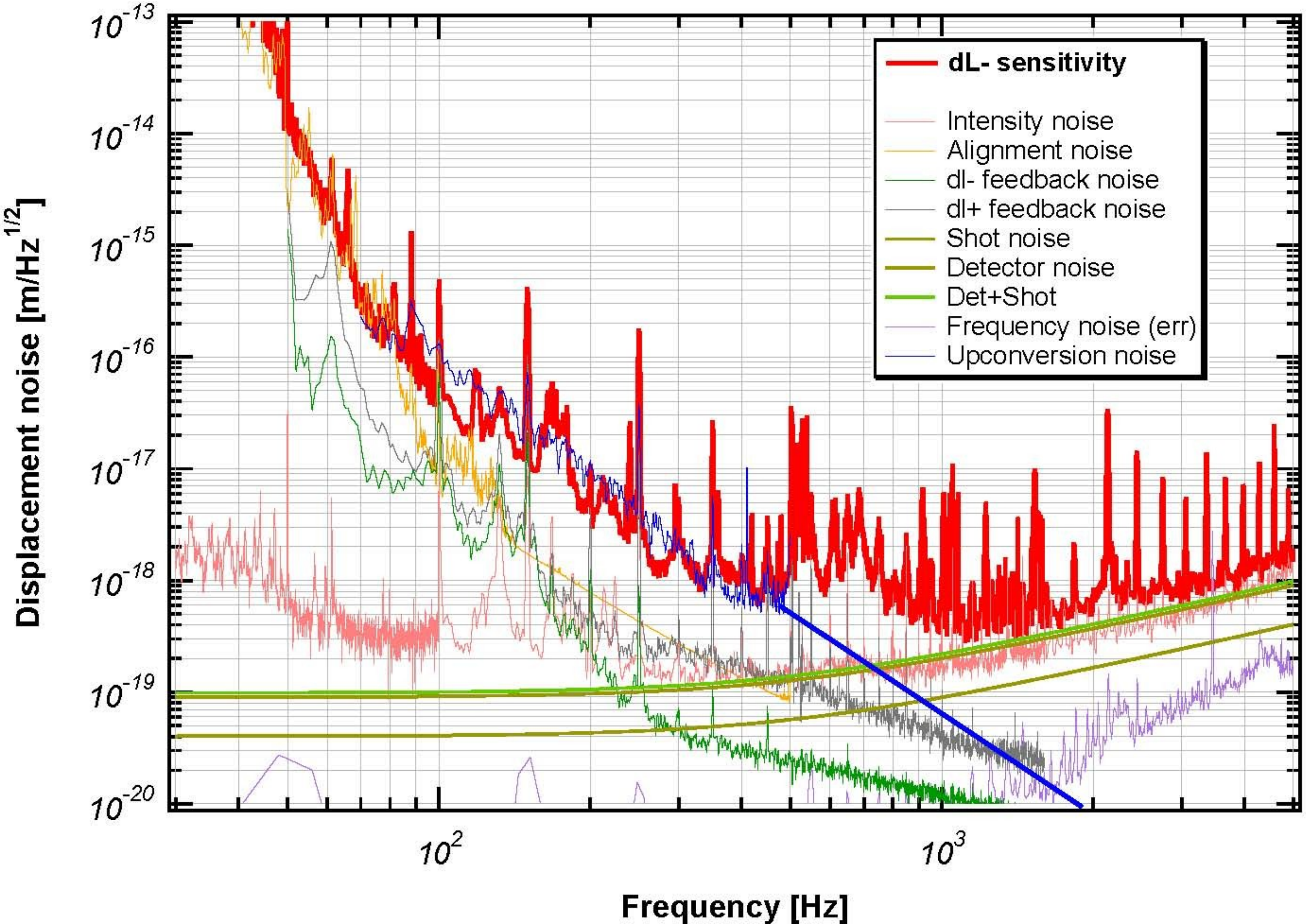
熱リンクつきLCGT-SASの物理モデル

IP: inverted pendulum
PM: penultimate mass
MB: magnet box
TM: test mass
RM: recoil mass

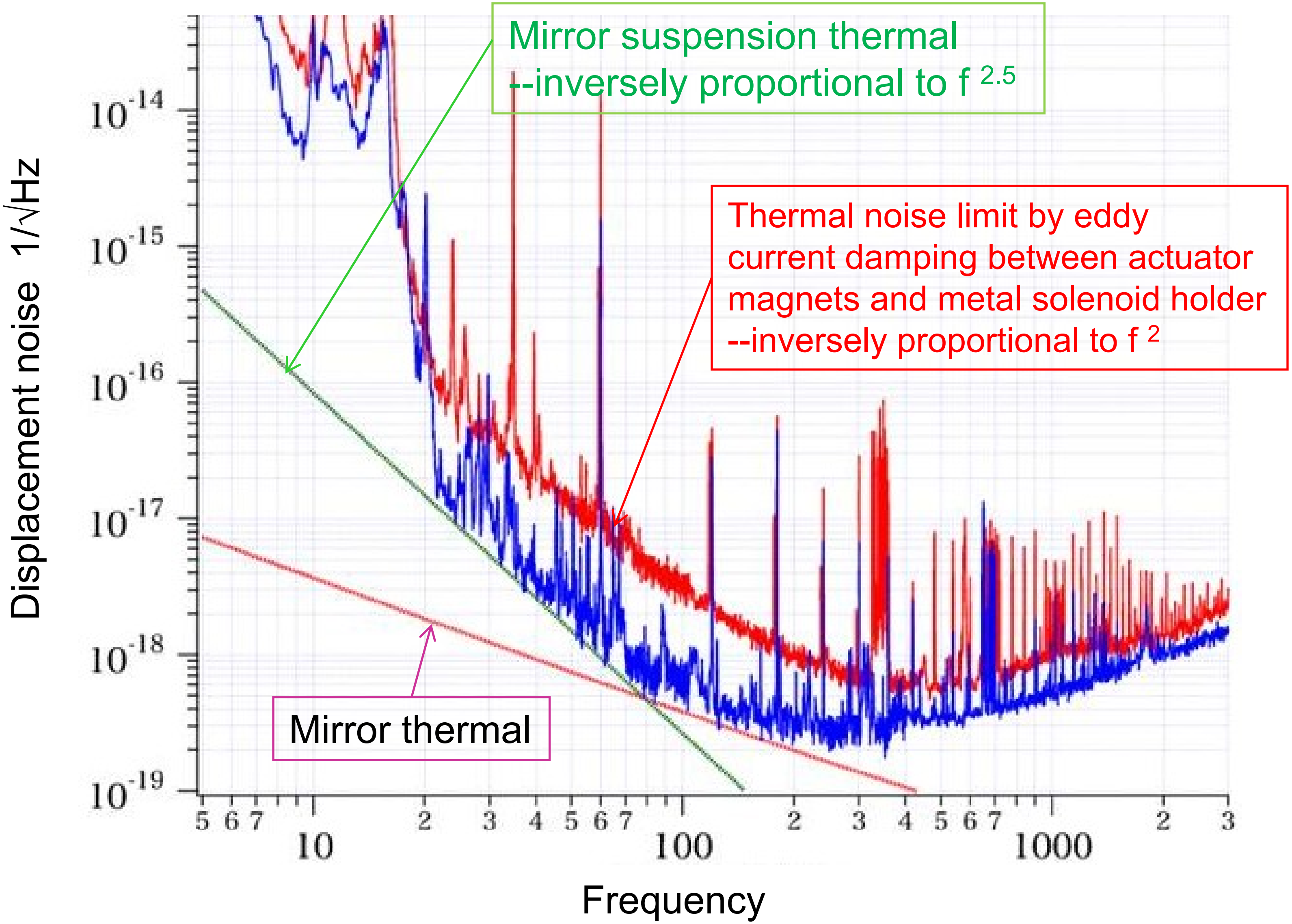


TAMAの状況

- Almost all noise sources that limit TAMA sensitivity have been recognized.
- Low frequency region of TAMA sensitivity is limited by up-conversion noise

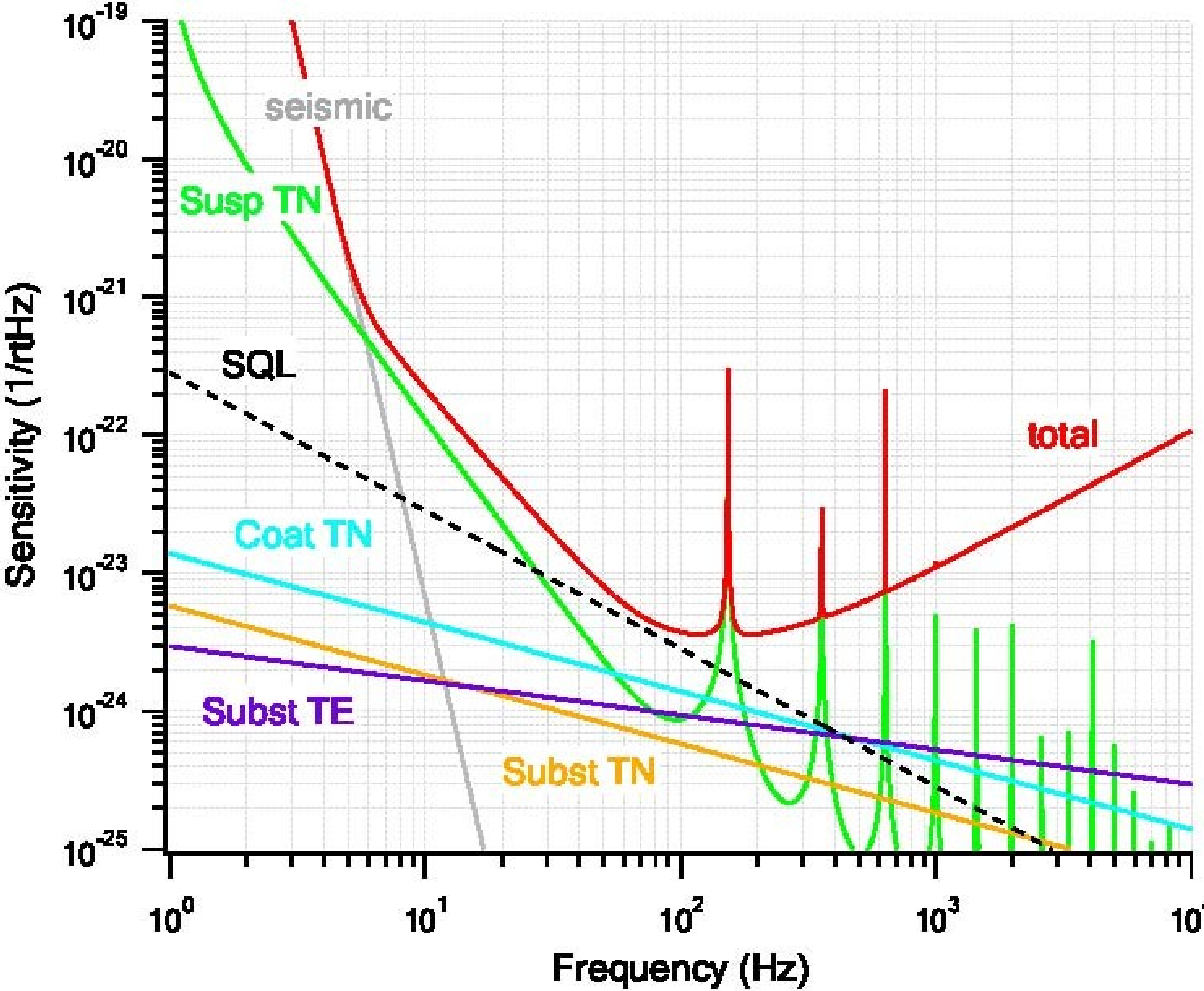


CLIOの状況

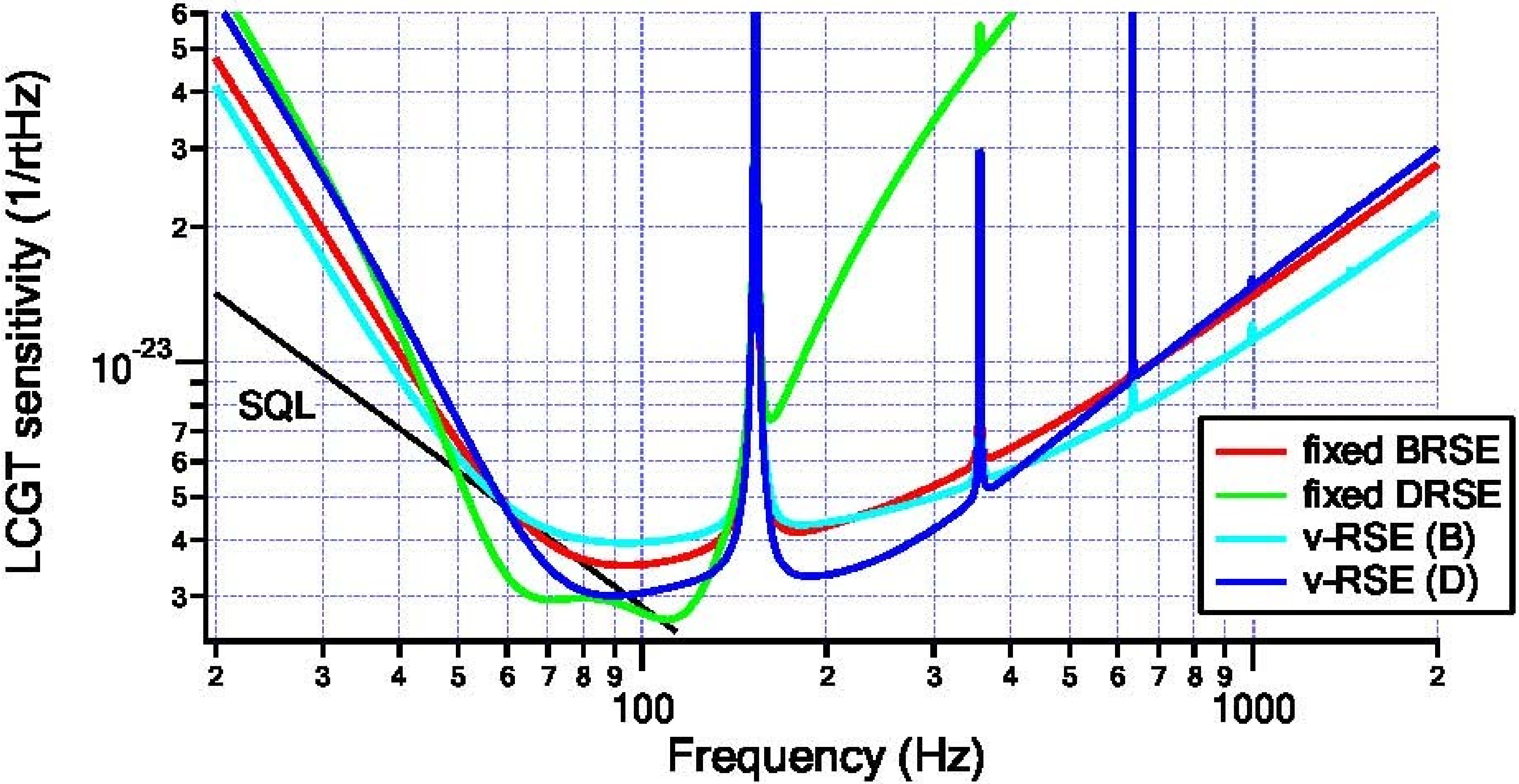


Mirror suspension thermal
--inversely proportional to f 2.5
Thermal noise limit by eddy current damping between actuator magnets and metal solenoid holder
--inversely proportional to f 2
Mirror thermal
Displacement noise 1/√Hz
10-14
10-15
10-16
10-17
10-18
10-19
5 6 7
10
2
3
4
5 6 7
100
2
3
4
5 6 7
1000
2
3
Frequency

LCGT のdefault 設計はDC readout を用いた広帯域RSE方式



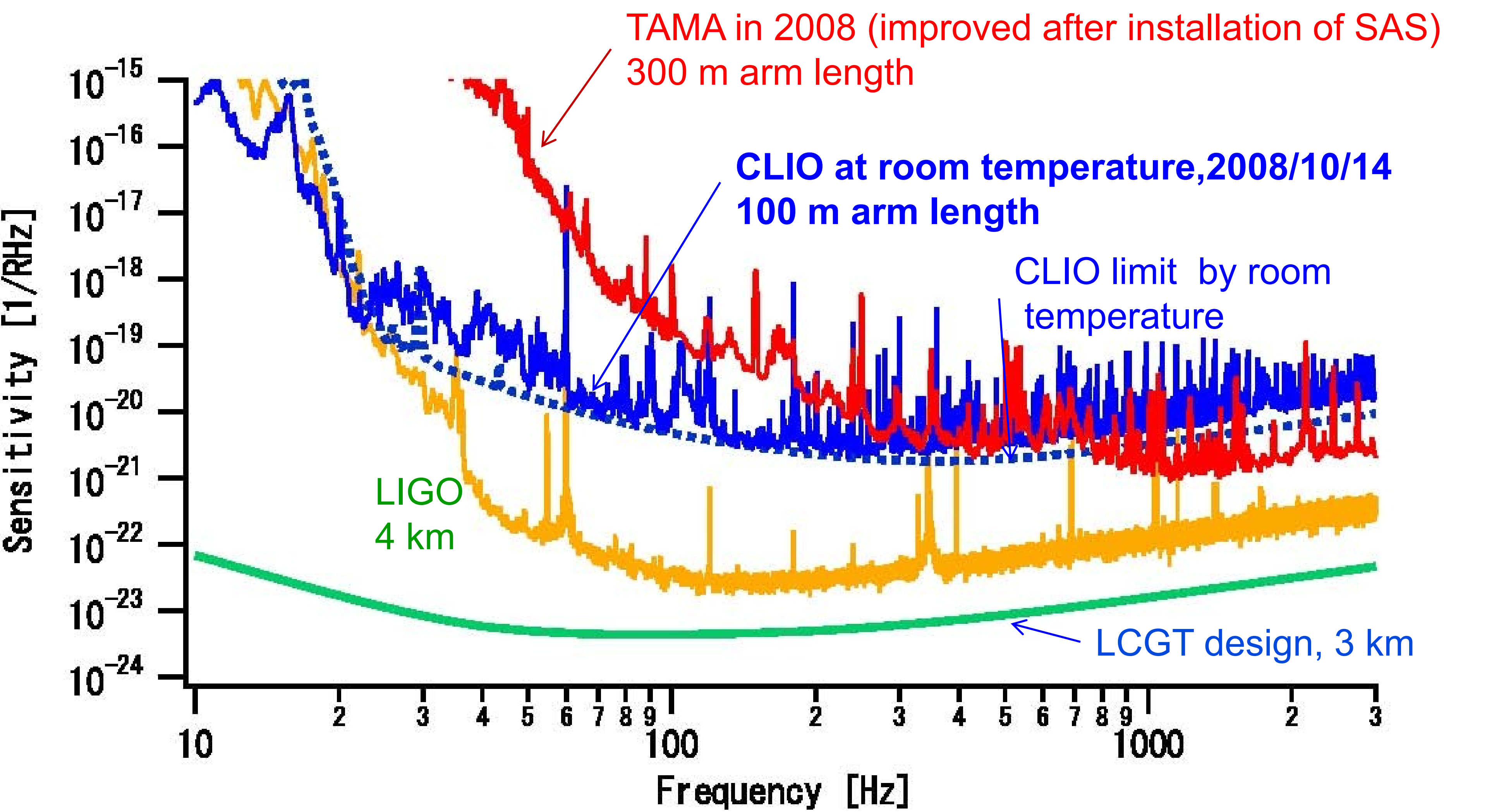
LCGT光学設計の各種様式による感度向上



他のR&D 項目 (TAMAとCLIO以外)

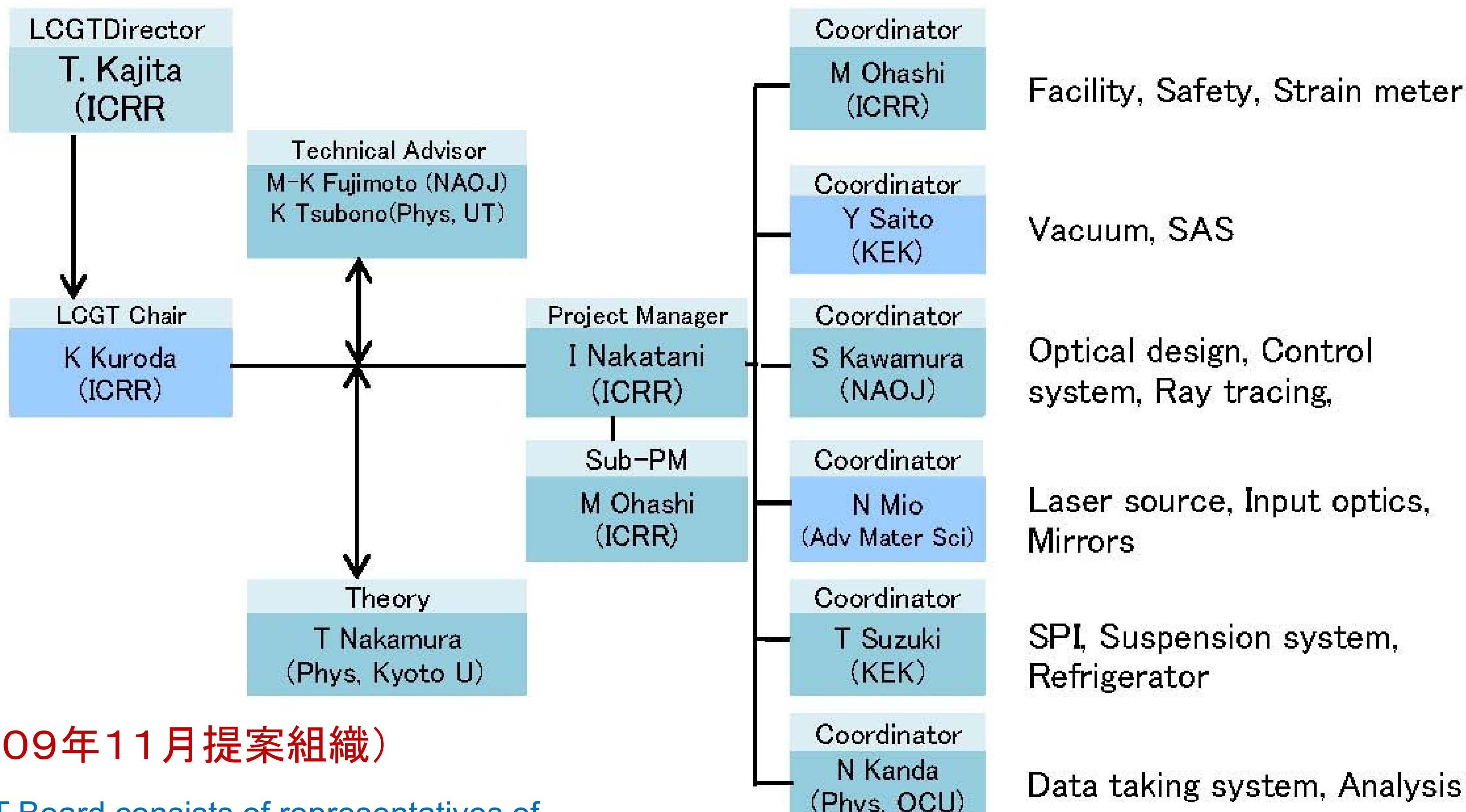
- RSE 制御系 NAOJ
  - Broadband RSE control scheme analysis
  - Well defined parameters
- 懸架系ファイバーの開発 KEK
  - Sapphire rod deformation
  - Thermal conductivity measurement
- 高出力レーザー光源 東大新領域
  - 110W出力を達成（2007年）

LCGT実現に向けた感度向上の様子



LCGT推進組織の充実

LCGT is hosted by ICRR under MOU with NAOJ and KEK.
Its organization consists of 87 domestic researchers belonging to 17 universities or research institutes and 28 oversea members belonging to 14 universities or research institutes (115 researchers in total).



（2009年11月提案組織）

LCGT Board consists of representatives of ICRR, NAOJ, and KEK with other senior members

研究者コミュニティからの支援

- 1993: Gravitational wave telescope was nominated as one of future projects by the report of subcommittee of ICRR.
- 1994: Early realization of Gravity wave detectors were described in the Astronomical subcommittee of Science Council of Japan.
- 1994: MOU promoting GW research among directors of NAOJ, KEK, and ICRR, being renewed every two years hereafter.
- 2000: Space Science subcommittee of the academic council of MEXT nominated LCGT as one of projects in a fund waiting list with recommending the reinforcement of R&D.
- 2005: Special report of the Astronomical subcommittee of Science Council of Japan strongly requested the prompt funding of LCGT on behalf of the whole astronomical community.
- 2007: ICRR was nominated as the host institute for LCGT under revised MOU originally exchanged in 1994.
- 2007: Future research plan committee of ICRR exclusively pushed LCGT.
- 2008: GWIC under IUPAP・PaNAGIC strongly supported the funding of LCGT that made the beginning of observation in 2015 possible.
- 2008: Astronomy & Astrophysics subcommittee of Science Council of Japan raised the resolution to promote early LCGT funding.
- 2009: Combined subcommittee (IAU, Astronomy & Astrophysics) in Science Council of Japan made a resolution to endorse LCGT.

結論

- LCGTの干渉計技術(power recycling, Fabry-Perot Michelson, control system)は、TAMA や CLIO によるR&Dで確立されている。
- もし LCGT が予算化されれば、世界に先駆け重力波を検出できる。
- 初検出の後には、adv. LIGO、adv. Virgo、GEO HF などとともに国際観測網の一翼を担う。
- 重力波検出のための長いR&Dがようやく日の目を見ようとしている。