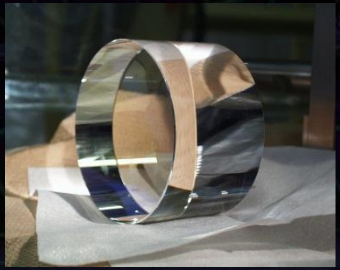
Commissioning of TAMA

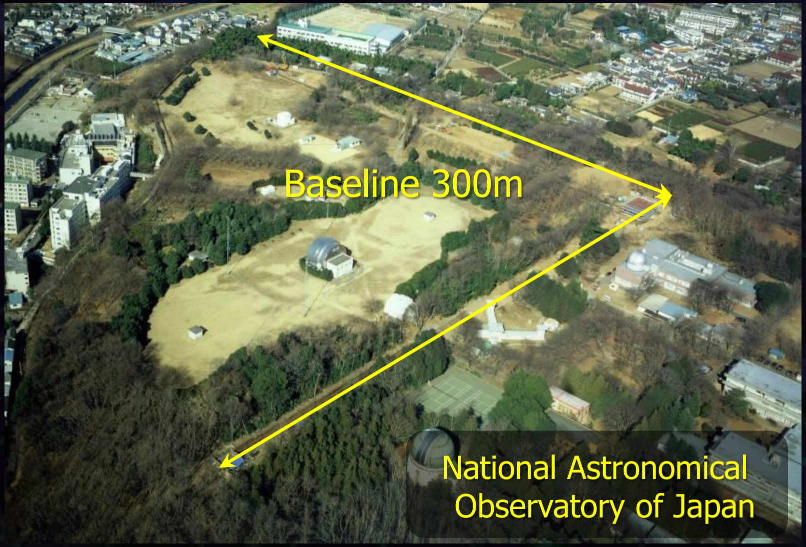


Masaki Ando

(National Astronomical Observatory of Japan)

TAMA300

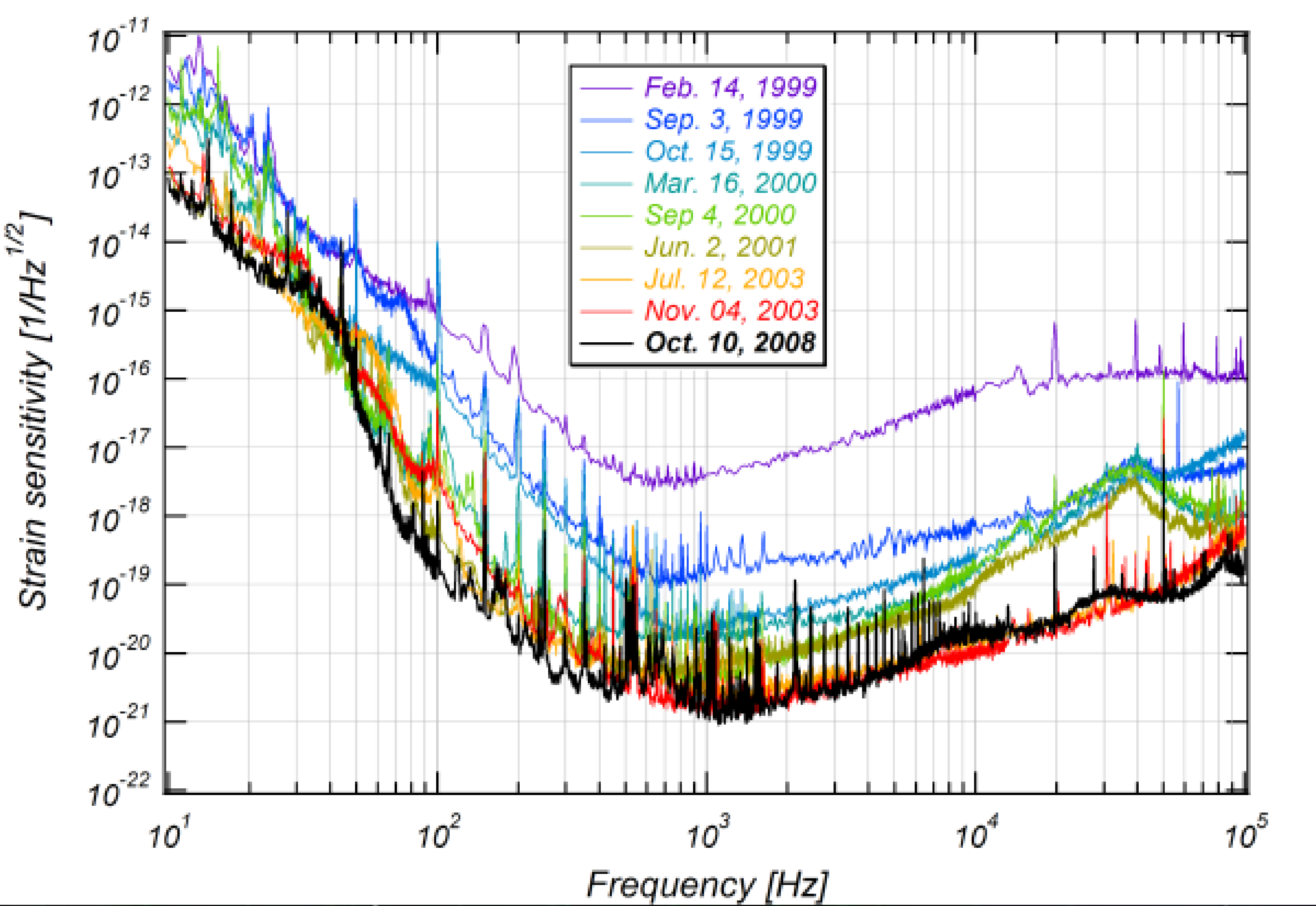
- Power-recycled FP Michelson interferometer with 300m arms.
- Built at NAOJ in Mitaka, Tokyo.



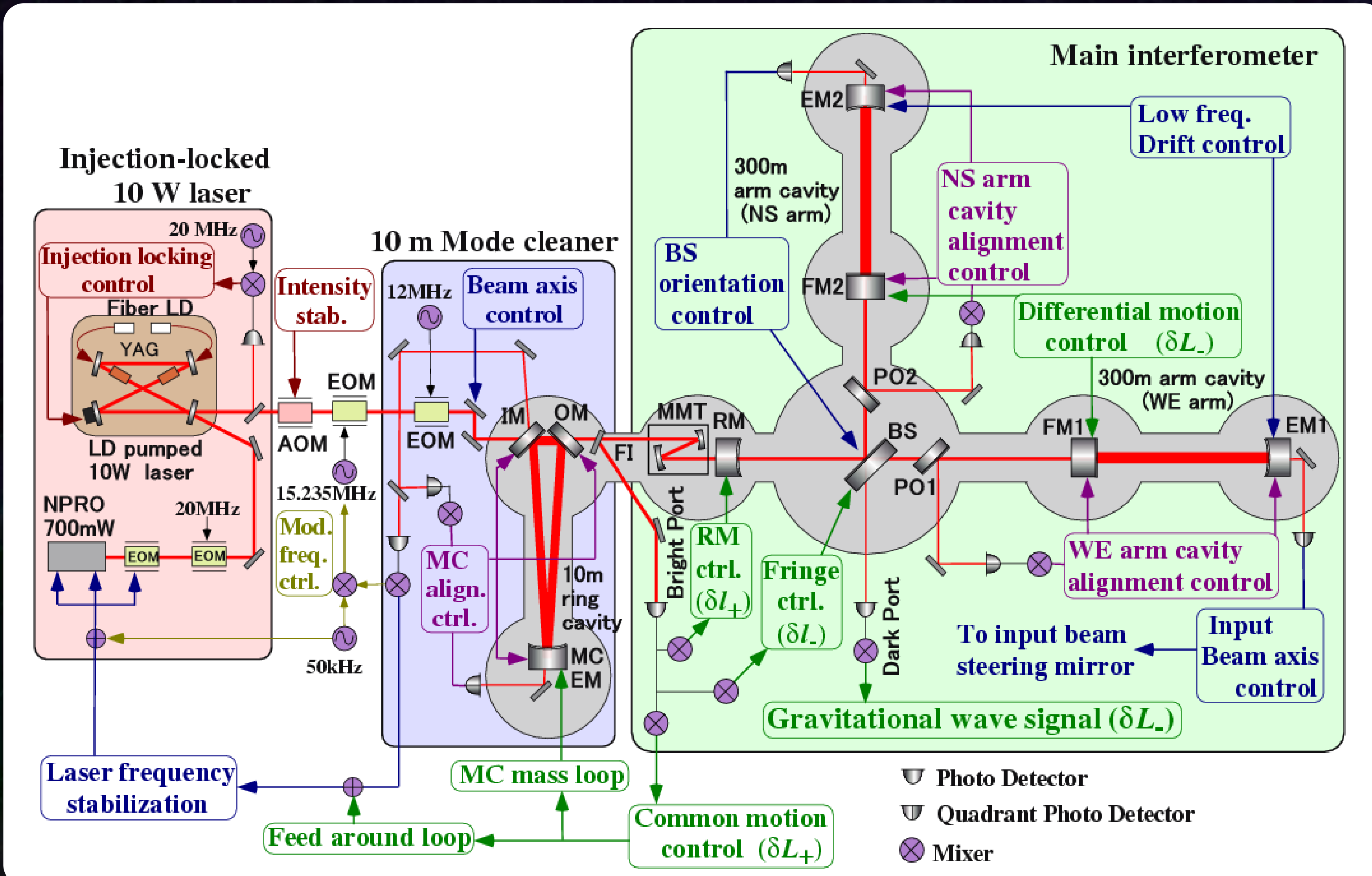
- Purpose
  - Intermediate step for a larger-scale GW antenna.
  - Observation of lucky events in our and nearby galaxies.

- Sufficient sensitivity to observe Galactic events
  (Worlds best sensitivity in 2000-2002)
- Earlier observation start in 1999.
  (Over 3000 hours' data)

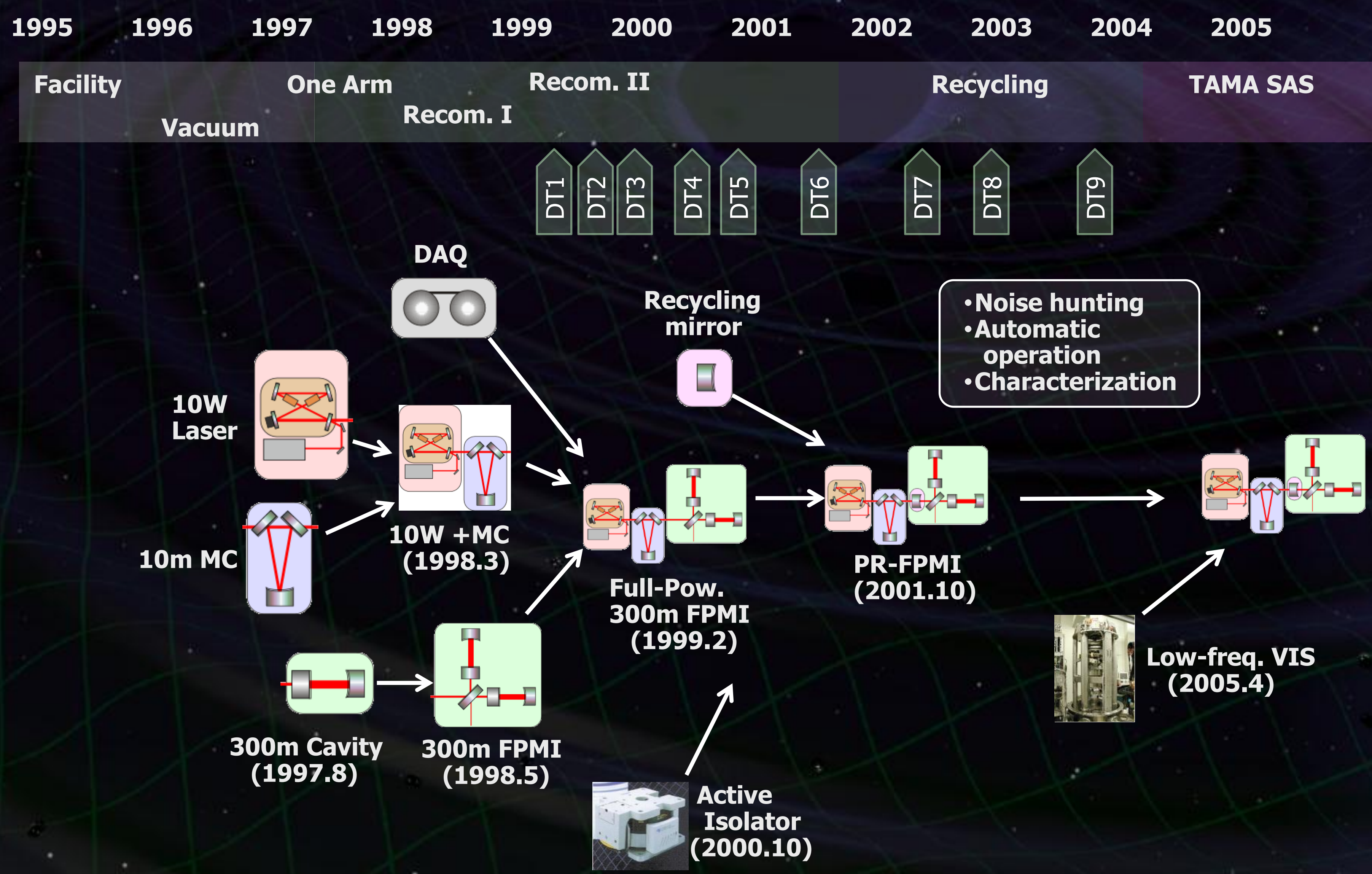
Sensitivity History



TAMA Optical Configuration



TAMA Commissioning History



TAMA Data Taking

Data Taking		Objective	Observation time	Typical strain noise level	Total data (Longest lock)
DT1	August, 1999	Calibration test	1 night	3×10^{-19} /Hz $^{1/2}$	10 hours (7.7 hours)
DT2	September, 1999	First Observation run	3 nights	3×10^{-20} /Hz $^{1/2}$	31 hours
DT3	April, 2000	Observation with improved sensitivity	3 nights	1×10^{-20} /Hz $^{1/2}$	13 hours
DT4	Aug.-Sept., 2000	100 hours' observation data	2 weeks (night-time operation)	1×10^{-20} /Hz $^{1/2}$ (typical)	167 hours (12.8 hours)
DT5	March, 2001	100 hours' observation with high duty cycle	1 week (whole-day operation)	1.7×10^{-20} /Hz $^{1/2}$ (LF improvement)	111 hours
DT6	Aug.-Sept., 2001	1000 hours' observation data	50 days	5×10^{-21} /Hz $^{1/2}$	1038 hours (22.0 hours)
DT7	Aug.-Sept., 2002	Full operation with Power recycling	2 days		25 hours
DT8	Feb.-April., 2003	1000 hours Coincidence	2 months	3×10^{-21} /Hz $^{1/2}$	1157 hours (20.5 hours)
DT9	Nov. 2003 - Jan., 2004	Automatic operation	6 weeks	1.5×10^{-21} /Hz $^{1/2}$	558 hours (27 hours)

Personal Opinions (1/3)

- Commissioning speed was very important in TAMA. TAMA was the smallest-scale detector in the 1st-generation detectors. So, earlier start of observation and first scientific results were crucial for TAMA. Hard works were required and steadiness was rather slighted.

- TAMA may be the maximum-scale laboratory experiment. Quick decision and flexible scheduling were made in a rather small commissioning team. Less documents, meetings and reviews were required.

- Contributions by graduate students were critical. On the other hand, the project schedule was sometimes constrained by thesis schedule.

Personal Opinions (2/3)

- TAMA commissioning method were successful in some aspects, and unsuccessful in the other aspects.
- Step-by-step commissioning procedure will be also valid in 2nd-generation antennae. Data-taking (or engineering run) is important for full-system test at that step.
- In 2nd-generation antennae, the required resources are larger by ~10 times. Project method with a solid organization is required, while we should accept some ineffectiveness due to overhead.

Personal Opinions (3/3)

- Commissioning of large GW antenna takes time. In particular for underground and cryogenic interferometers.

- The amount of on-site commissioning tasks should be minimized. For that, careful scheduling, pre-installation tests and risk management are important. Ideally, all the subsystem specifications and functions should be tested before brought into the tunnel, and before cooling. Steadiness is the key issue for speedy commissioning. The balance of steadiness and effectiveness is important.

Current Status

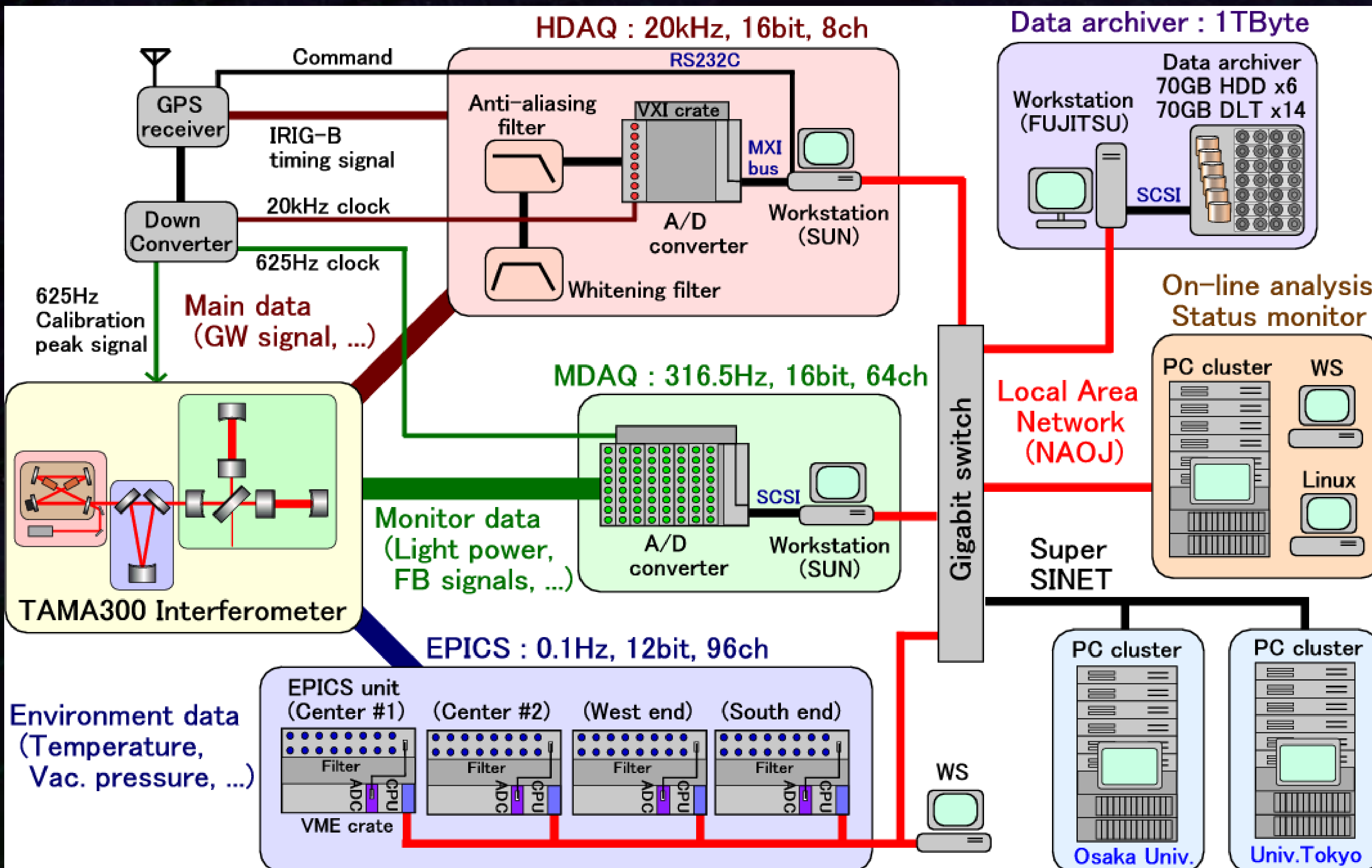
- TAMA interferometer is not in operation
  - Man power
  - Damages in earthquake on May 11th 2010

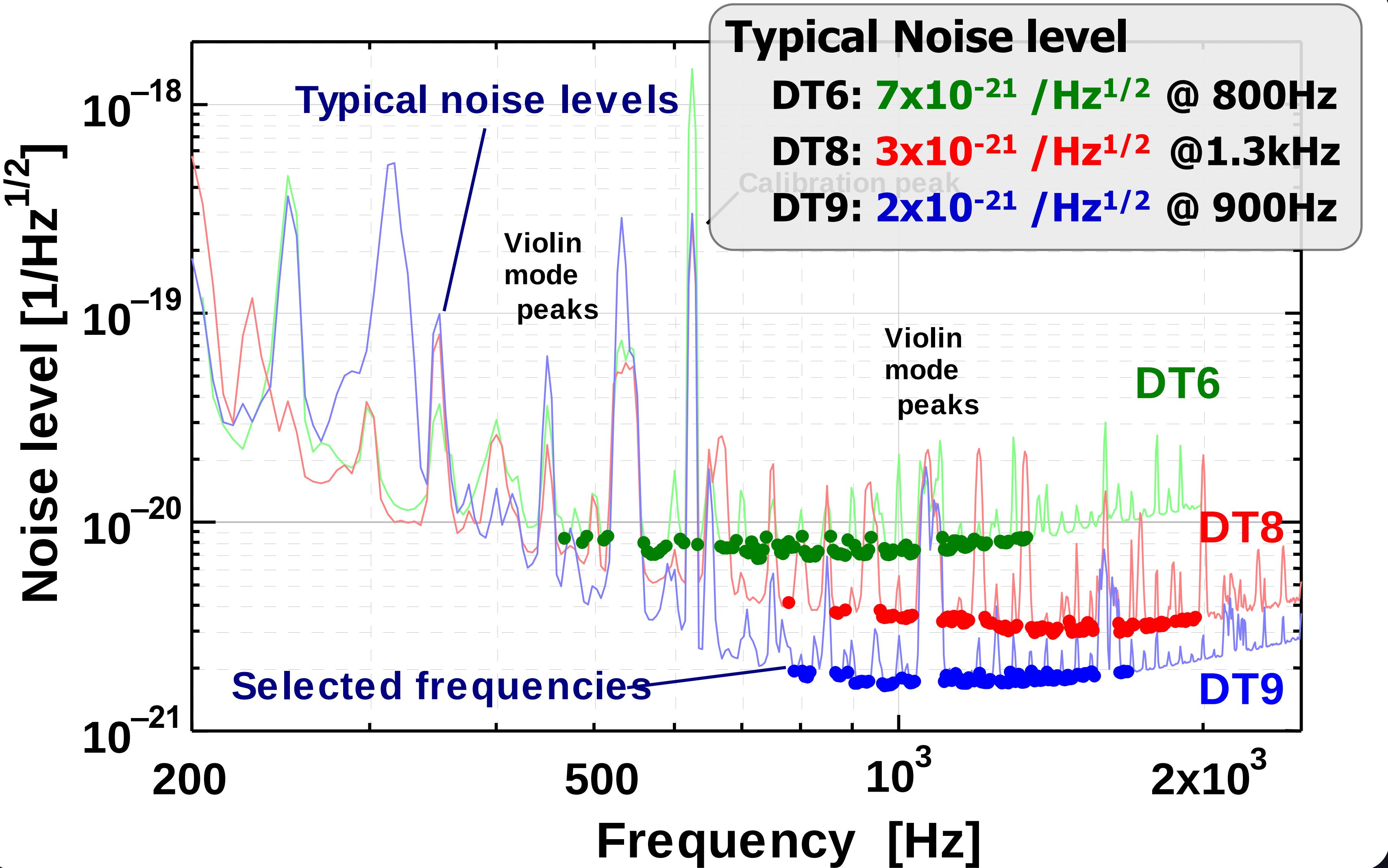
- TAMA will be a test facility for KAGRA
  - Mirror evaluation, VIS test, and IFO control.
  - Two vacuum chambers will be moved to site.
  - 10m MC, 300m arms will be kept for large IFO test

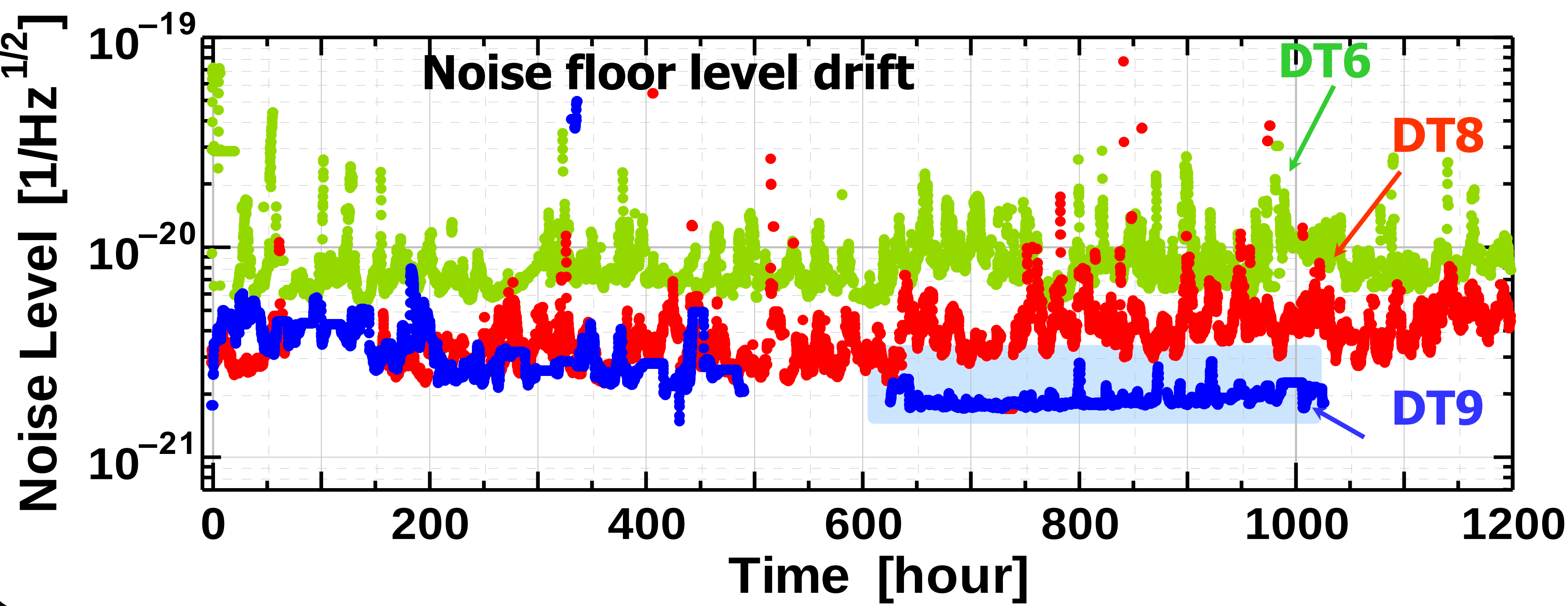
End

Appendix

TAMA300 DAQ System



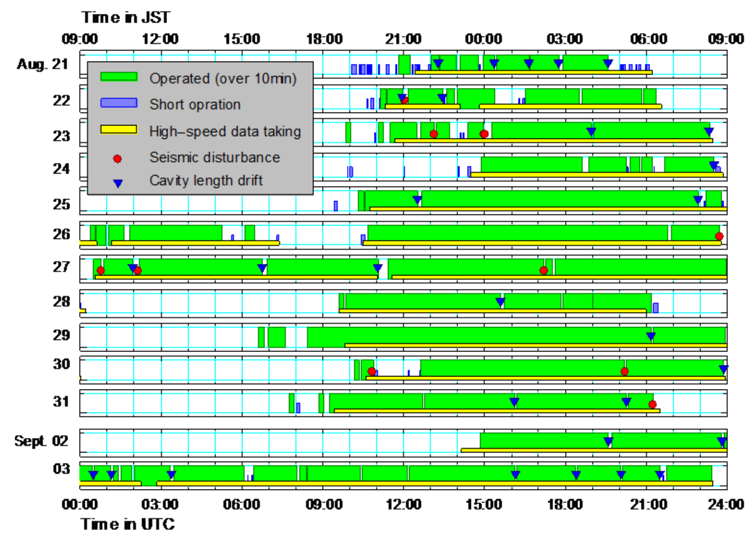

Typical Noise level
DT6: 7x10-21 /Hz1/2 @ 800Hz
DT8: 3x10-21 /Hz1/2 @1.3kHz
DT9: 2x10-21 /Hz1/2 @ 900Hz
Typical noise levels
Calibration peak
Violin mode peaks
Violin mode peaks
DT6
DT8
DT9
Selected frequencies
Noise level [1/Hz1/2]
Frequency [Hz]
10–18
10–19
10–20
10–21
200
500
10³
2x10³



Noise floor level drift
DT6
DT8
DT9
Noise Level [1/Hz^1/2]
10^−19
10^−20
10^−21
0
200
400
600
800
1000
1200
Time [hour]

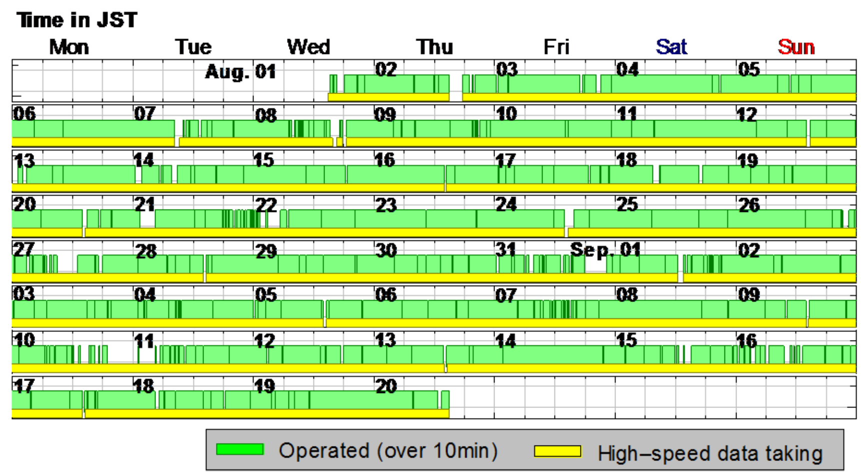
- **Data Taking 4**
  - Aug.-Sept., 2000 (2 weeks)
  - Sensitivity : 1×10^{-20} /Hz$^{1/2}$ @900Hz

  Over 100-hour observation



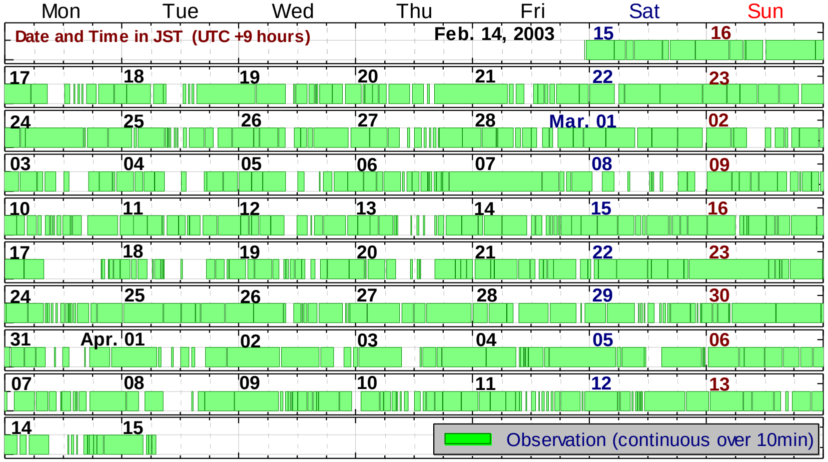
- **Data Taking 6**
  - Aug. 1- Sept.20, 2001 (50 days)
    → Obs. Time 1038 hours

  Over 1000-hour observation



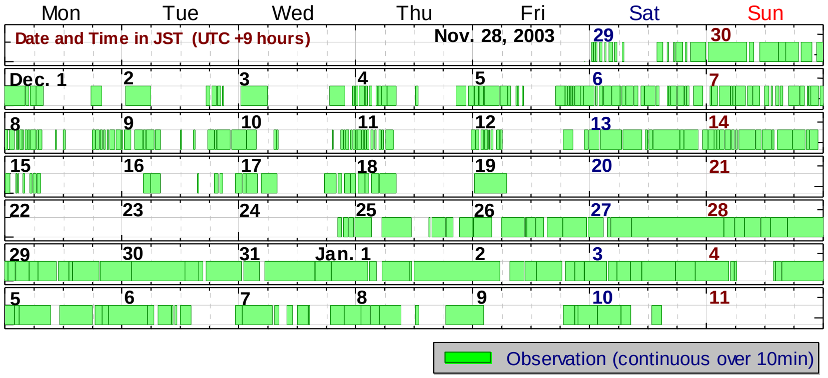
- **Data Taking 8**
  - Feb. 14 – April 14, 2003 (2 months)
  - 1157 hours' data (Duty 81%)
  - Sensitivity : 3×10^{-21} /Hz$^{1/2}$ @1.3kHz

Long obs. With High Duty factor



- **Data Taking 9**
  - Nov. 28, 2003 – Jan. 10, 2004
  - 558 hours' data
  - Sensitivity : 2×10^{-21} /Hz$^{1/2}$ @900Hz

Better sensitivity
New- year holidays → good stability



Data taking runs (3)

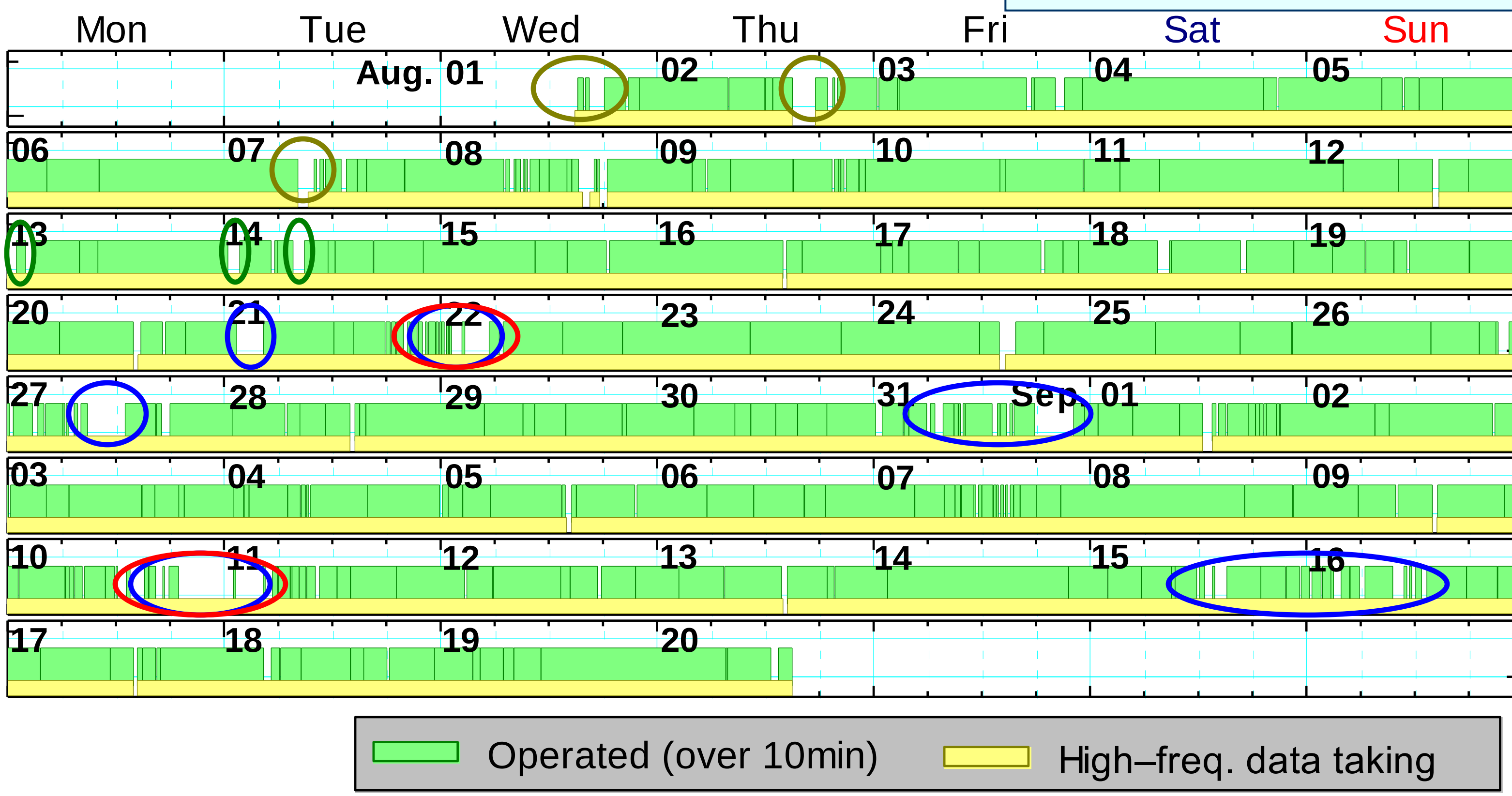
- Detector operation status in DT6 -

- **Operation status calendar**

Total observation : 1038 hours

Typhoon
Laser instability
Measurement+adjustment
Human error

Date in JST



KAGRA サイト

岐阜県・神岡町 の地下サイトに建設

Facility of the Institute of Cosmic-Ray Research (ICRR), Univ. of Tokyo.

Landsat photo data
NASA altitude data
Cashmir 3D

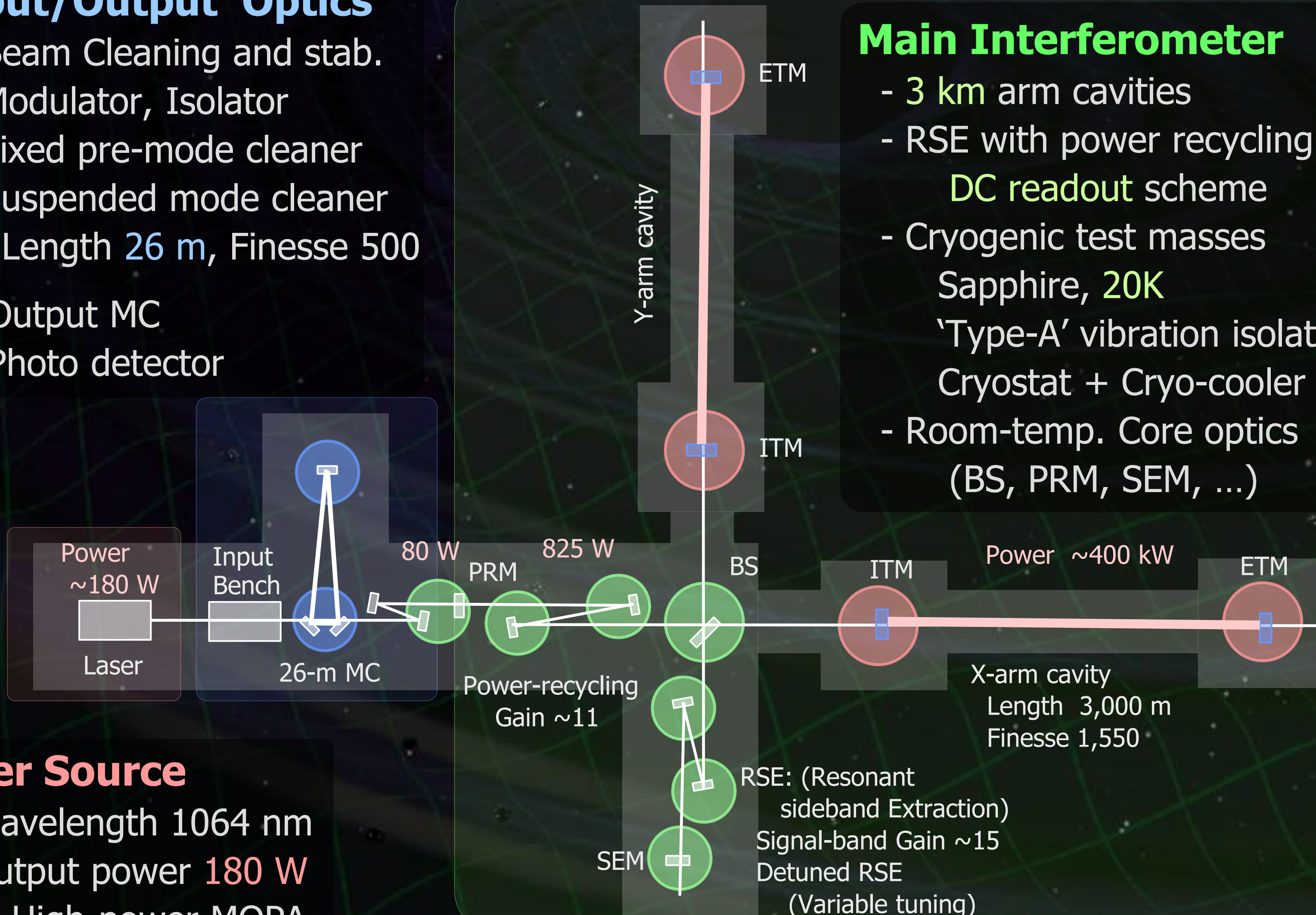
- Neutrino
  - Super Kamiokande, Kamland
- Dark matter
  - XMASS
- Gravitational wave
  - CLIO, KAGRA
- Geophysics
  - Strain meter

- 220km away from Tokyo
- 1000m underground from the top of the mountain. (Near Super Kamiokande)
- 360m altitude
- Hard rock of Hida gneiss (5 [km/sec] sound speed)

KAGRA 干渉計構成

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
  DC readout scheme
- Cryogenic test masses
  Sapphire, 20K
  'Type-A' vibration isolator
  Cryostat + Cryo-cooler
- Room-temp. Core optics
  (BS, PRM, SEM, …)

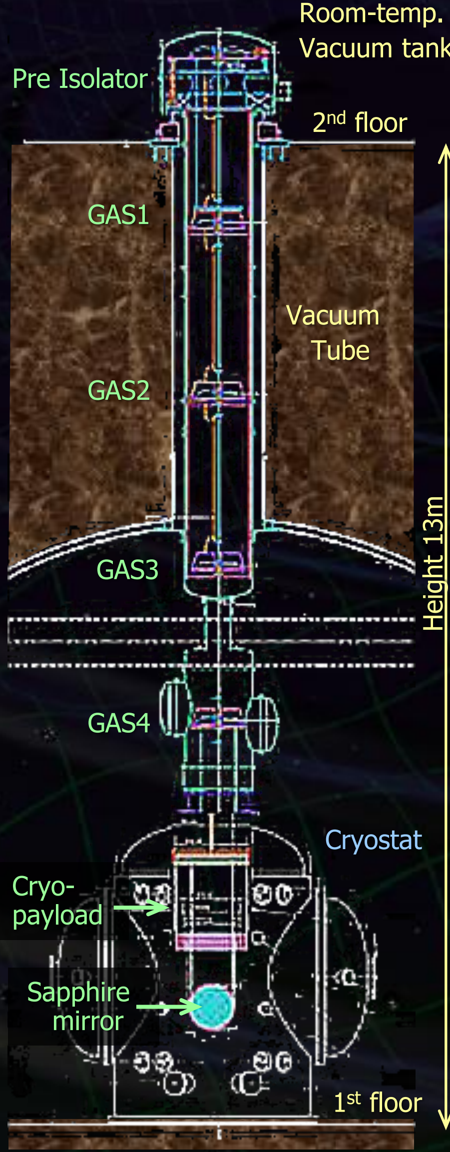


Laser Source
- Wavelength 1064 nm
- Output power 180 W
  High-power MOPA

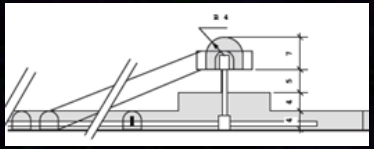
KAGRA鏡懸架・冷却系

- **高性能防振装置** (Type-A SAS)
  - 上層部の岩盤より懸架された 多段の受動防振装置.
  - 常温の真空槽内に収められる.
  - ローカル制御とダンピング機構.
  - 最下段に低温ペイロード, サファイヤ鏡を懸架.

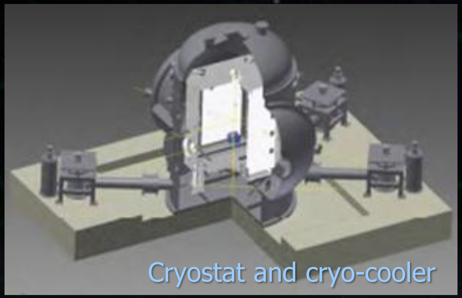
- **低温ペイロード**
  - サファイヤ鏡を懸架する2段振り子.
    - サファイヤ鏡　20K
    - 振り子部　16K
  - 鏡の変位・角度用アクチュエータ.
  - 低温シールド部とヒートリンク接続.



- **トンネル**： 2層構造
  - 上部　高さ 7m
  - 中間岩盤　厚さ 5m
  - 下部　高さ 8m



- **クライオスタット・冷却系**
  - 外形：Φ2.4m, 高さ 3.8m
  - 二重の輻射シールド (80K, 8K)
  - 4台の低雑音PT冷凍機
    - 1^{st} stage　36 W at 50K
    - 2^{nd} stage　0.9 W at 4K

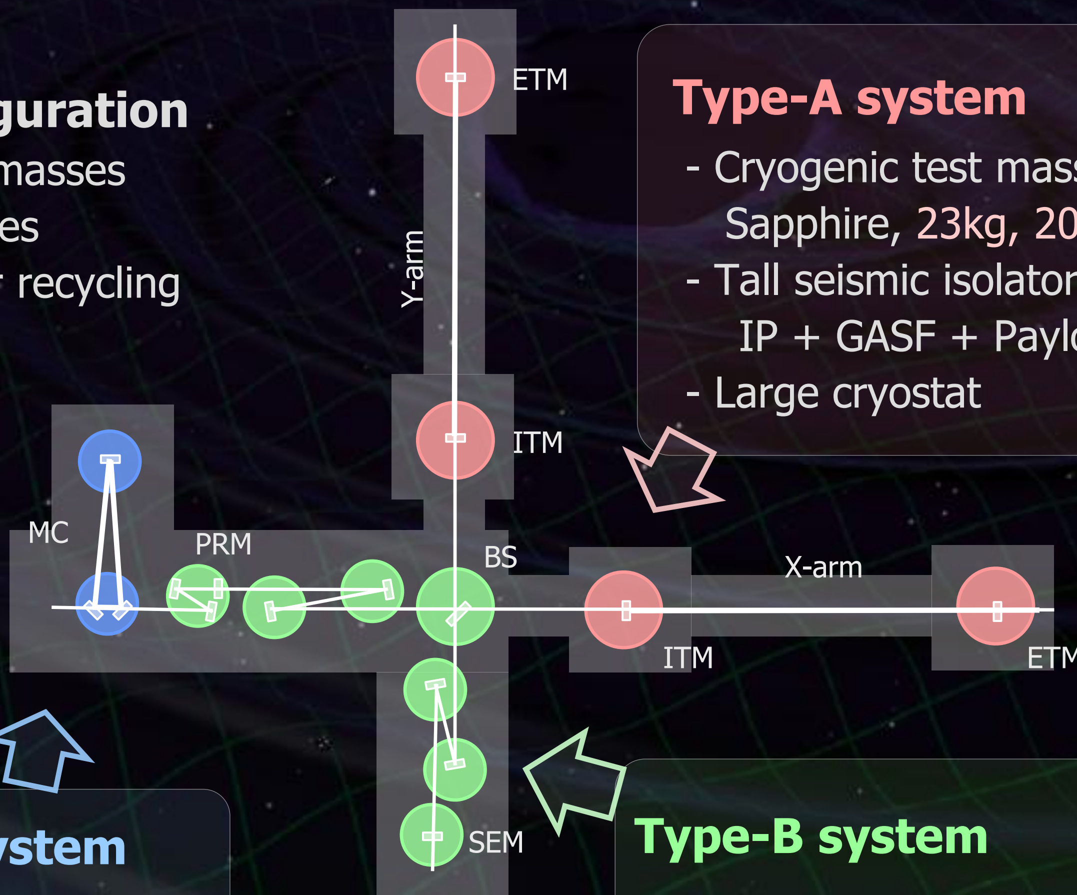


Master Schedule

bKAGRA final configuration

bKAGRA configuration

- Cryogenic test masses
- 3 km arm cavities
- RSE with power recycling



Type-A system

- Cryogenic test mass
  Sapphire, 23kg, 20K
- Tall seismic isolator
  IP + GASF + Payload
- Large cryostat

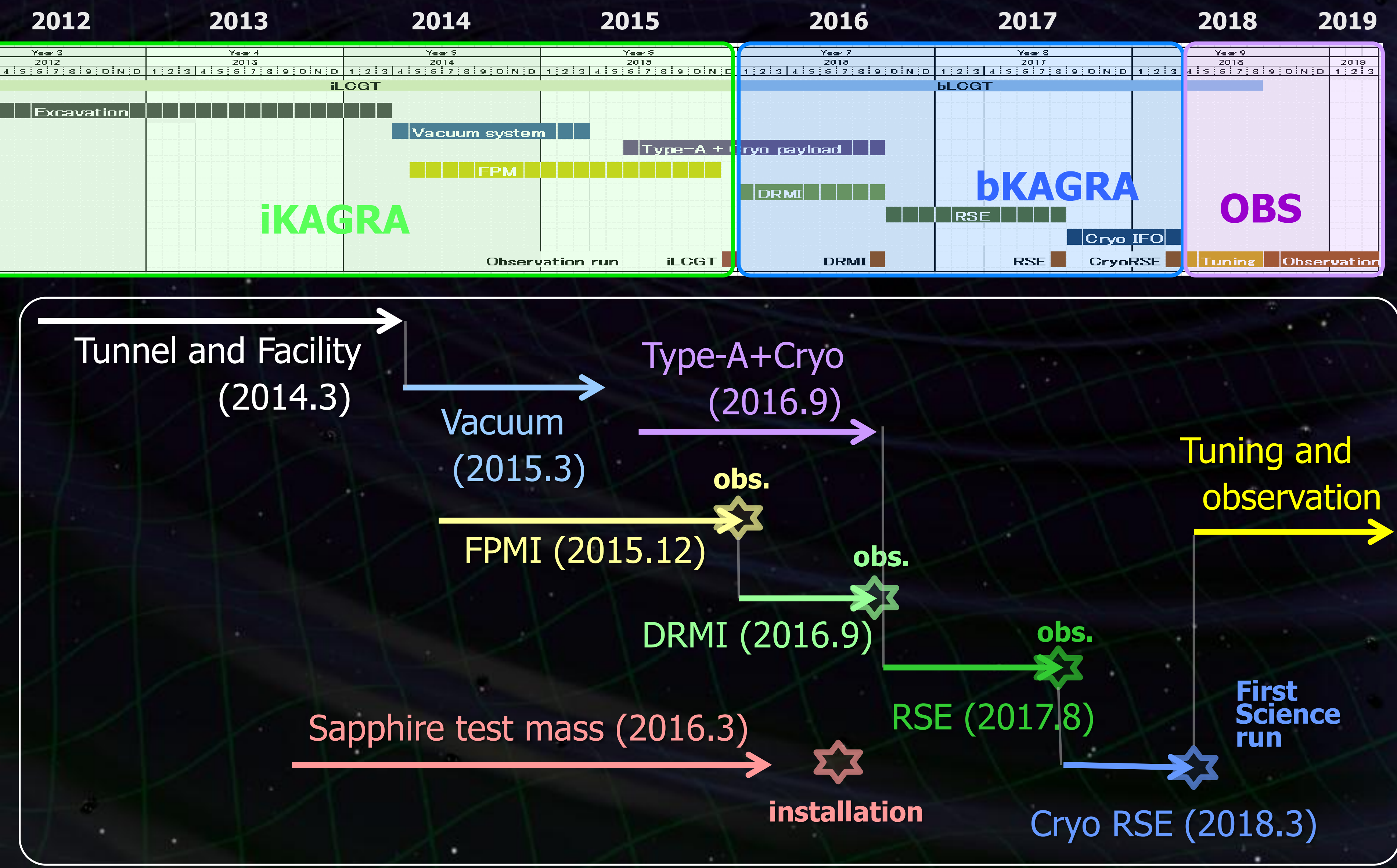
Type-C system

- Mode cleaner
  Silica, 1kg, 290K
- Stack + Payload

Type-B system

- Core optics (BS, RM ,…)
  Silica, 10kg, 290K
- IP + GASF + Payload
- Stack for aux. optics

Major milestones of KAGRA



Vacuum systems (- 2015.3)

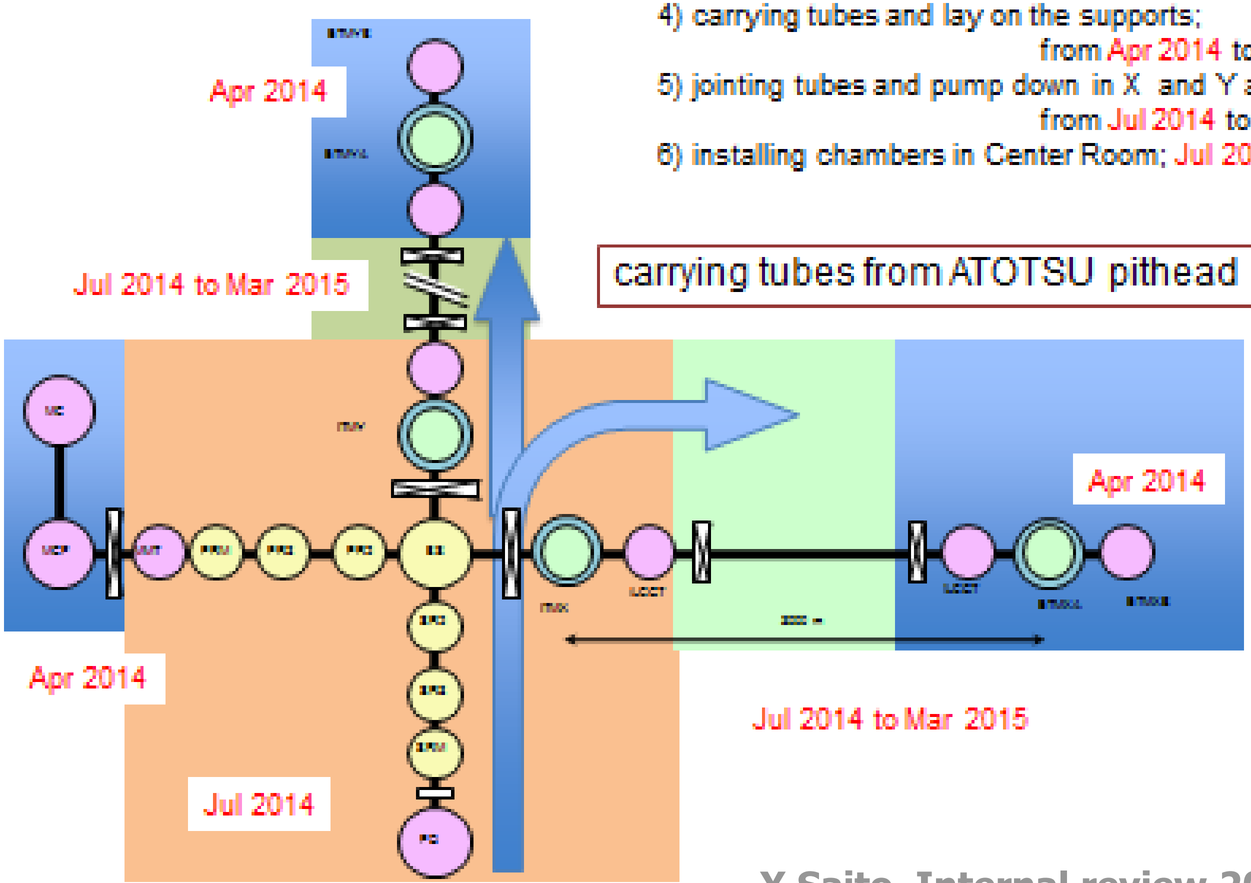
LCGT Vacuum System

120123 VAC (YS)

3. Schedule

expected schedule for installing (2)

1) manufacturing 478 of tubes; from Apr 2011 to Mar 2013
2) manufacturing chambers; from Sep 2012 to Mar 2014
3) installing chambers in X and Y ends; Apr 2014
4) carrying tubes and lay on the supports; from Apr 2014 to Jun 2014
5) jointing tubes and pump down in X and Y arm from Jul 2014 to Mar 2015
6) installing chambers in Center Room; Jul 2014



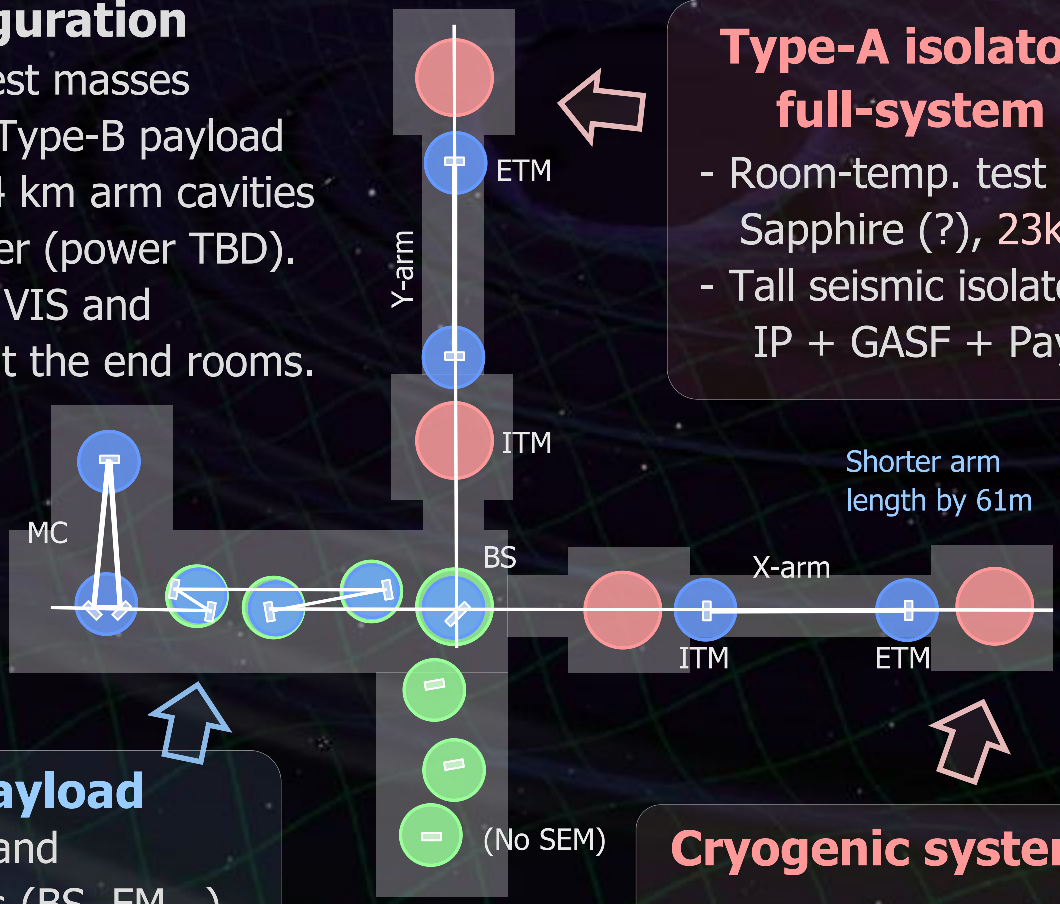
Y.Saito, Internal review 2012

22

iKAGRA commissioning (- 2015.12)

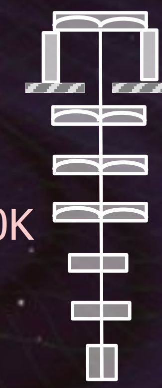
iKAGRA configuration

- Room-temp. test masses suspended by Type-B payload
- FPMI with 2.94 km arm cavities
- Low laser power (power TBD).
- On-site test of VIS and Cryo-system at the end rooms.



Type-A isolator full-system test

- Room-temp. test
  Sapphire (?), 23kg, 290K
- Tall seismic isolator
  IP + GASF + Payload



iLCGT obs. run
in Dec. 2015
~1 month

Type-B payload

- Test mass and
  Core optics (BS, FM,..)
  Silica, 10kg, 290K
- Seismic isolator
  Table + Type-B Payload
  or Fixed Type-B

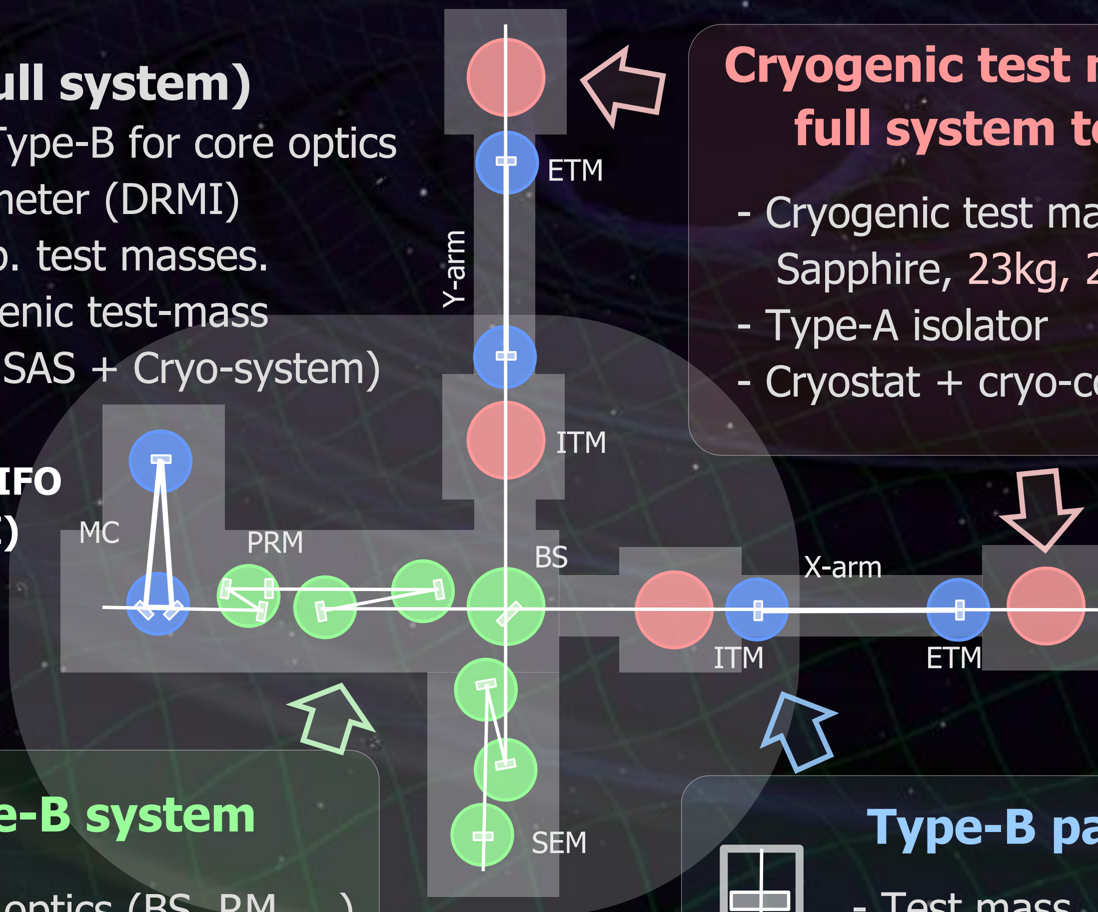
Cryogenic system test

- Cryostat + Rad. shield duct
- Cryo-cooler
- Cryogenic payload
- Fixed Type-ASAS

bKAGRA commissioning 1 (- 2016.9)

bKAGRA1
(DRMI, Cryo full system)
- VIS upgrade to Type-B for core optics
- Center interferometer (DRMI) with room-temp. test masses.
- Full test of cryogenic test-mass system (Type-A SAS + Cryo-system)

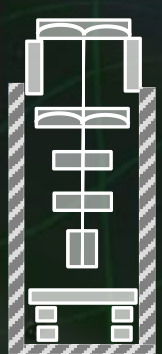
Center IFO (DRMI)



Cryogenic test mass full system test

- Cryogenic test mass
  Sapphire, 23kg, 20K
- Type-A isolator
- Cryostat + cryo-cooler

Type-B system



- Core optics (BS, RM ,…)
  Silica, 10kg, 290K
- IP + GASF + Payload
- Stack for aux. optics

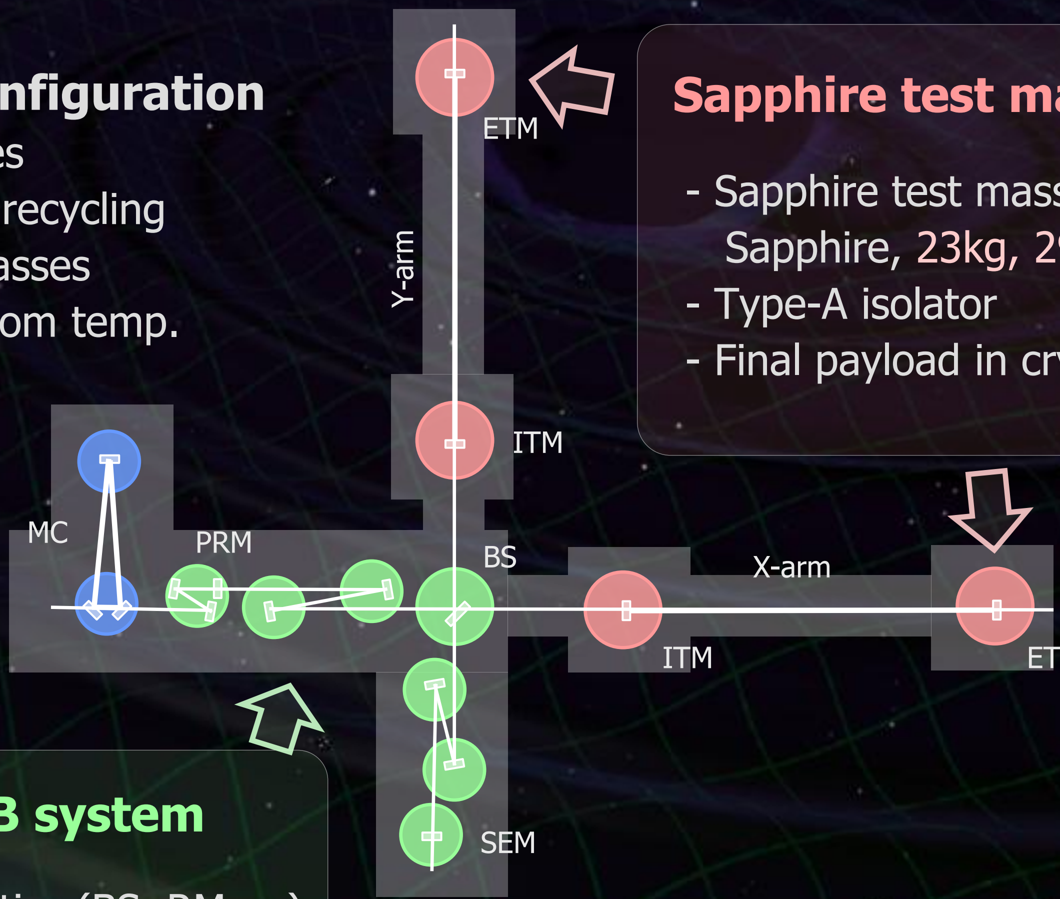
Type-B payload

- Test mass
  Silica, 10kg, 290K
- Seismic isolator
  Table + Type-B Payload

bKAGRA commissioning 2 (- 2017.8)

bKAGRA full configuration

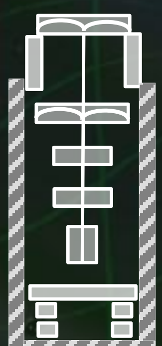
- 3 km arm cavities
- RSE with power recycling
- Sapphire test masses
  operated at room temp.



Sapphire test mass

- Sapphire test mass
  Sapphire, 23kg, 290K
- Type-A isolator
- Final payload in cryostat

Type-B system

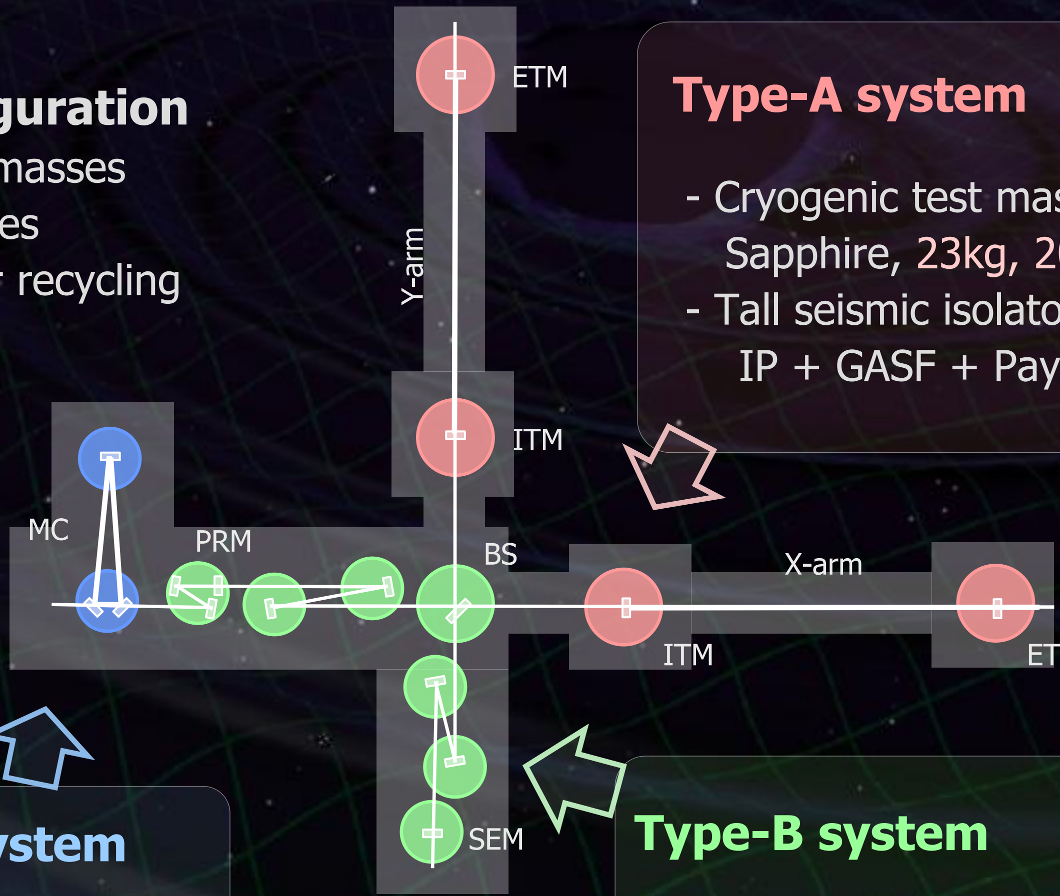


- Core optics (BS, RM ,…)
  Silica, 10kg, 290K
- IP + GASF + Payload
- Stack for aux. optics

Cryogenic operation (- 2018.3)

bKAGRA configuration
- Cryogenic test masses
- 3 km arm cavities
- RSE with power recycling

first science run
in Mar. 2018
~1 month



Type-A system

- Cryogenic test mass
  Sapphire, 23kg, 20K
- Tall seismic isolator
  IP + GASF + Payload

Type-C system

- Mode cleaner
  Silica, 1kg, 290K
- Stack + Payload

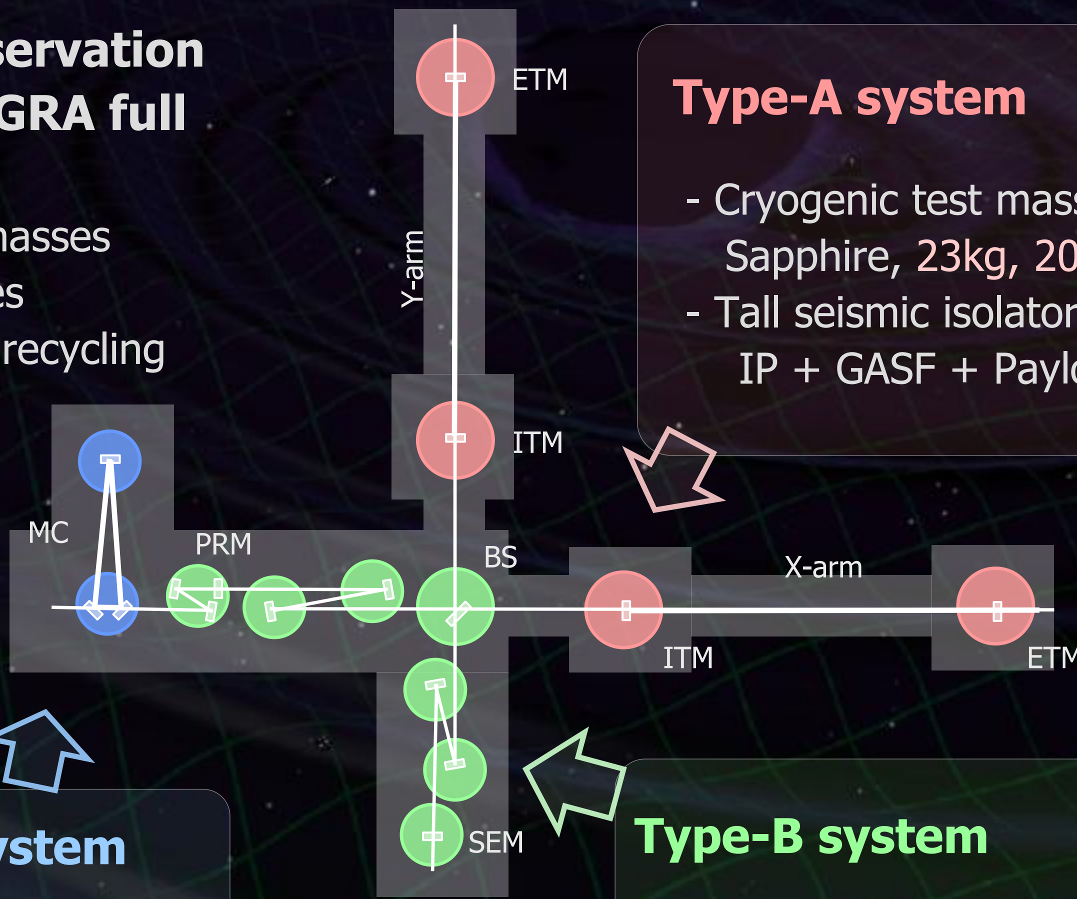
Type-B system

- Core optics (BS, RM ,...)
  Silica, 10kg, 290K
- IP + GASF + Payload
- Stack for aux. optics

Tuning and observation (2018.4 -)

Tuning and observation run with bKAGRA full configuration

- Cryogenic test masses
- 3 km arm cavities
- RSE with power recycling



Type-A system

- Cryogenic test mass
  Sapphire, 23kg, 20K
- Tall seismic isolator
  IP + GASF + Payload

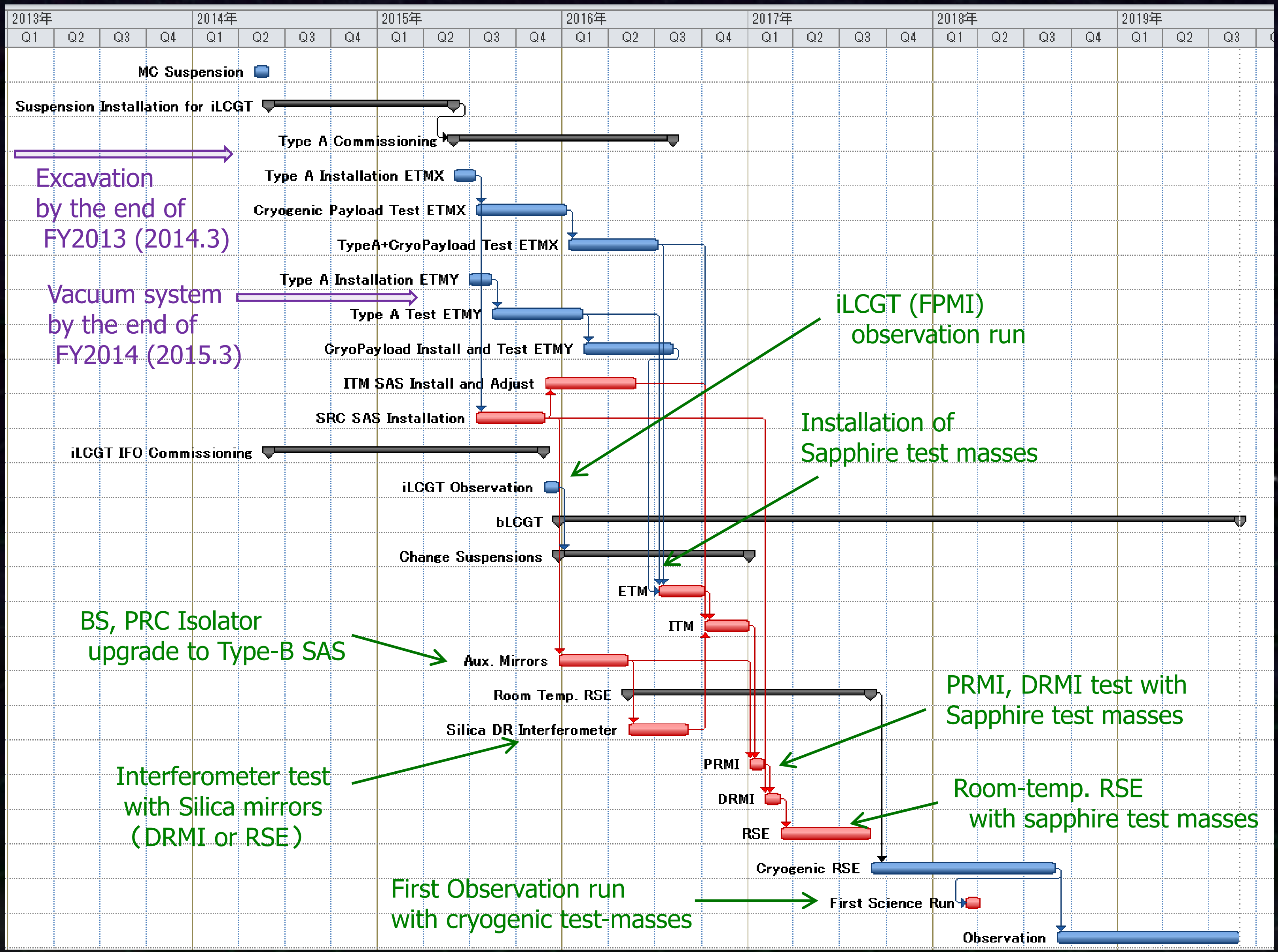
Type-B system

- Core optics (BS, RM ,…)
  Silica, 10kg, 290K
- IP + GASF + Payload
- Stack for aux. optics

Type-C system

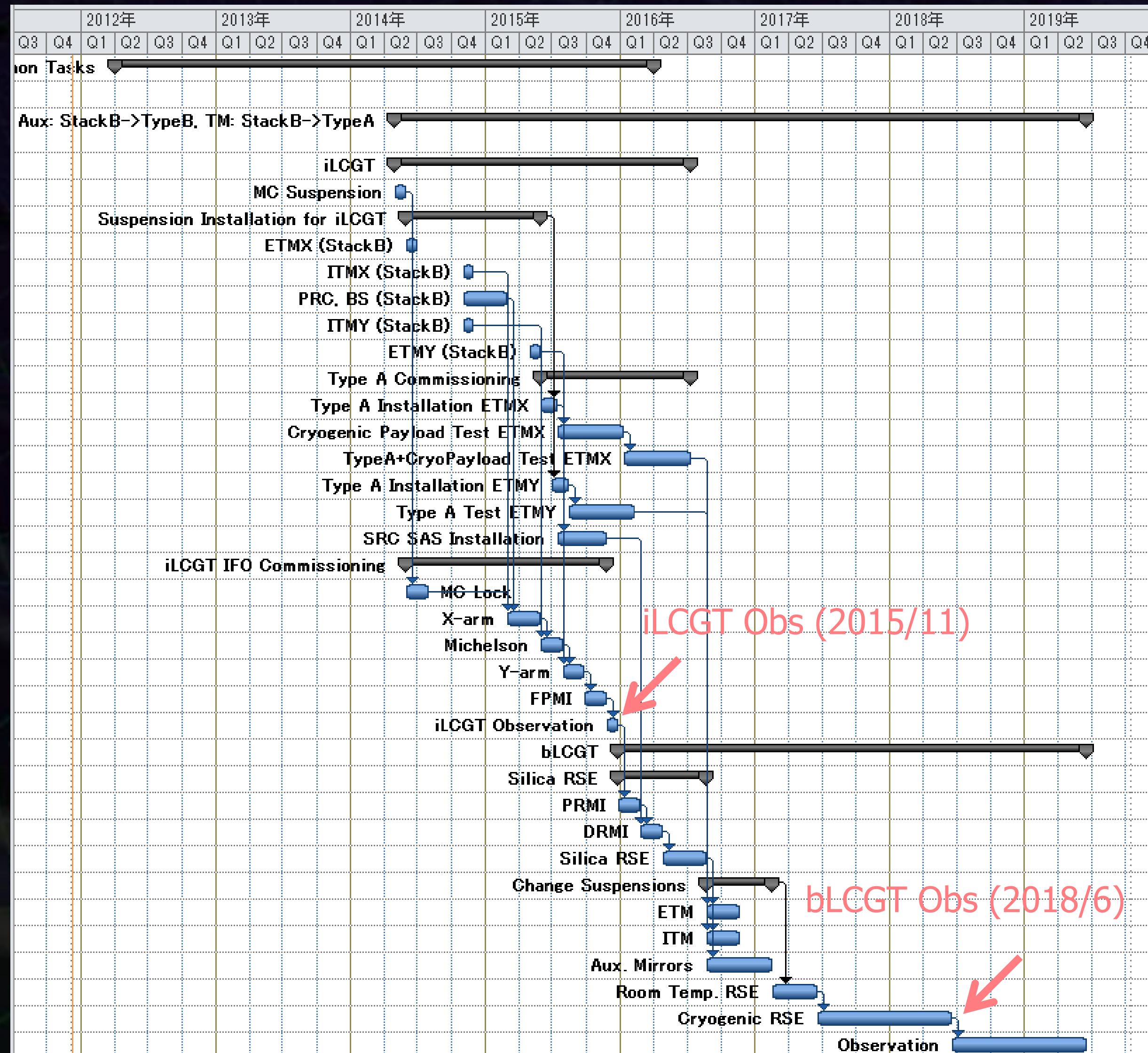
- Mode cleaner
  Silica, 1kg, 290K
- Stack + Payload

Example of Detailed Schedule



Bottom-up Schedule Consideration

An example
for plan-1 →



Bottom-up plan