Observation runs of an interferometric gravitational wave detector TAMA300

National Astronomical Observatory of Japan

Koji Arai (TAMA project)

MG10 Plenary

Overview of this talk

- ***Introduction of TAMA300***
  a 300-m Fabry-Perot Michelson interferometer
  8 observations since 1999

- ***Long-term observations: Data Taking 6 & 8***
  DT6: 50 days' observation in the summer of 2001
  DT8: 59 days' observation in the winter-spring of 2003
  (LIGO-TAMA joint observation)

- ***TAMA Data Analysis***
  Results with DT6 data
  Preliminary result of NS inspiral search with DT8 data

- ***Future Plans***
  LCGT: 3km cryogenic interferometer in a mine

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TAMA300

- ***Laser interferometric GW detector***
  with arm length of 300m

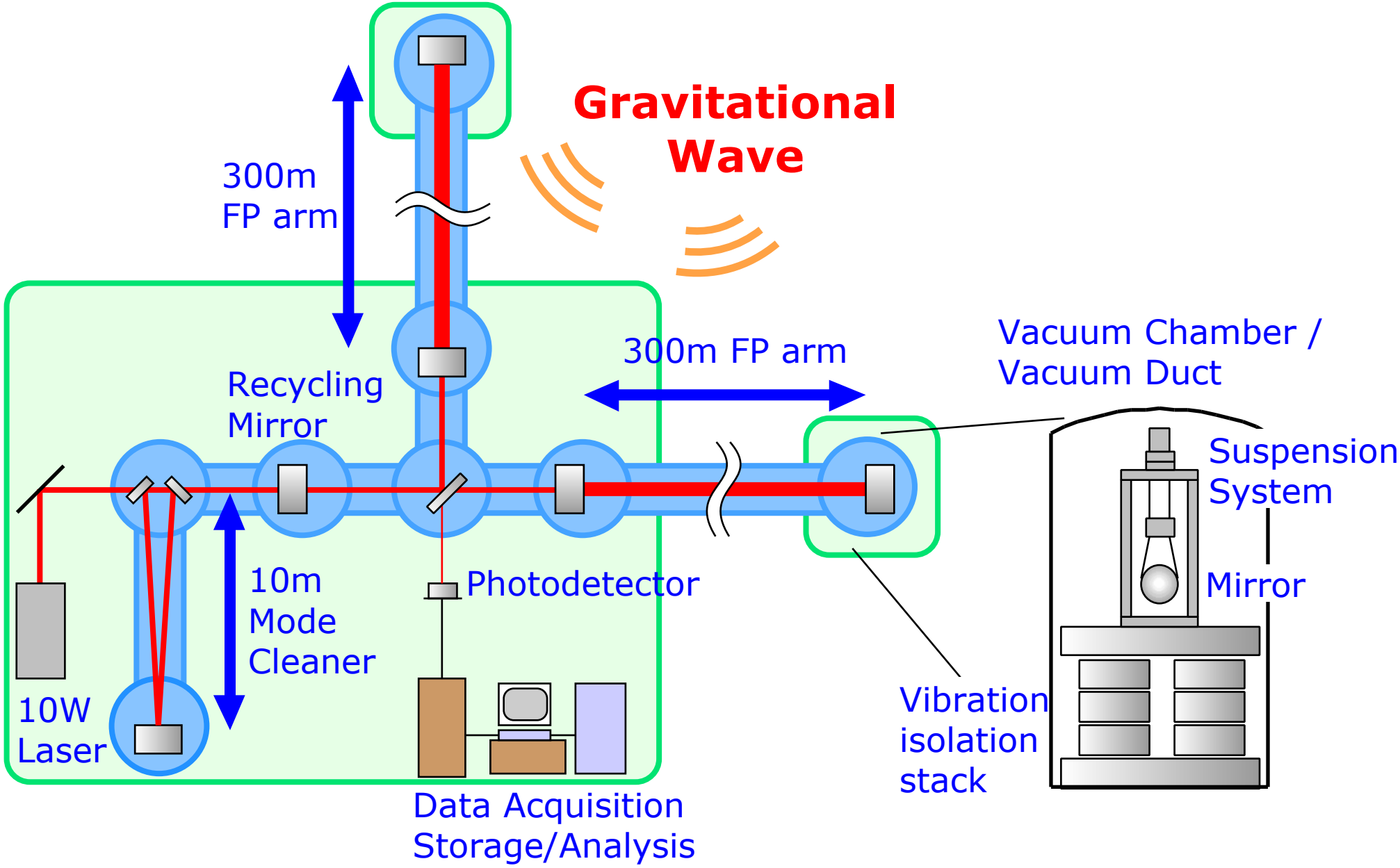
  Site: National Astronomical Observatory of Japan,
  (Mitaka, Tokyo)

- ***Object of the project***

  To develop a detector capable to detect GW events
  in nearby galaxies.
  To establish techniques for a future km-class interferometer

Designed sensitivity ~ $h_{RMS} = 3 \times 10^{-21}$ @300Hz (BW300Hz)

TAMA300 detector ~ overview



TAMA300 detector overview

- **Aerial view**
- Light source
- Center room
- 300-m tubes
- Vibration isolation
- Mirrors
- Control electronics

National Astronimical Observatory of Japan

(Tokyo, Mitaka Campus (E139.32.21 N35.40.25)

Middle of the city area ~ convenient for detector development

~ heavy traffic

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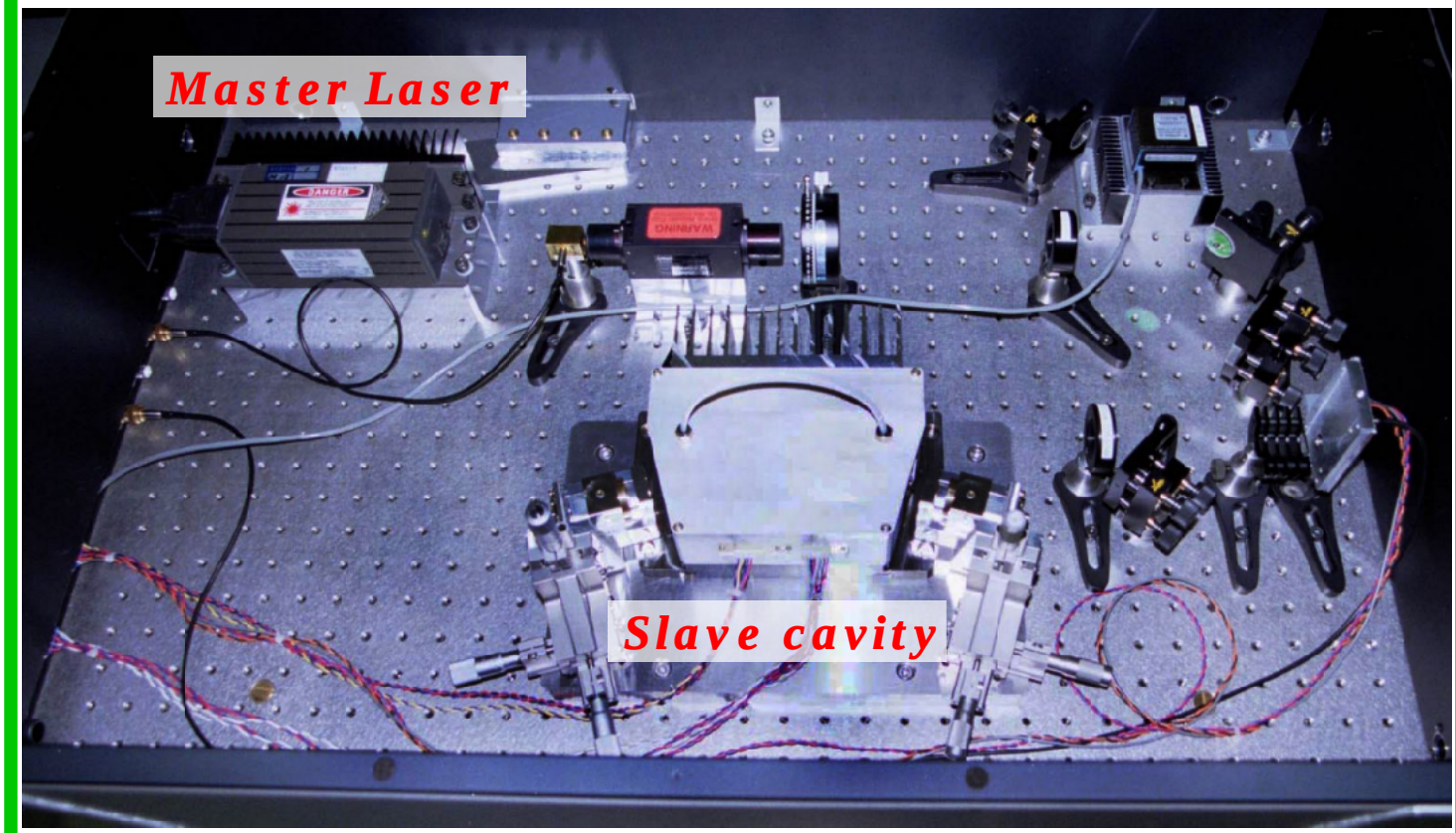

Injection locked Nd:YAG laser

λ=1064nm, Output of 10W

Pre-stabilized by 10-m mode cleaner

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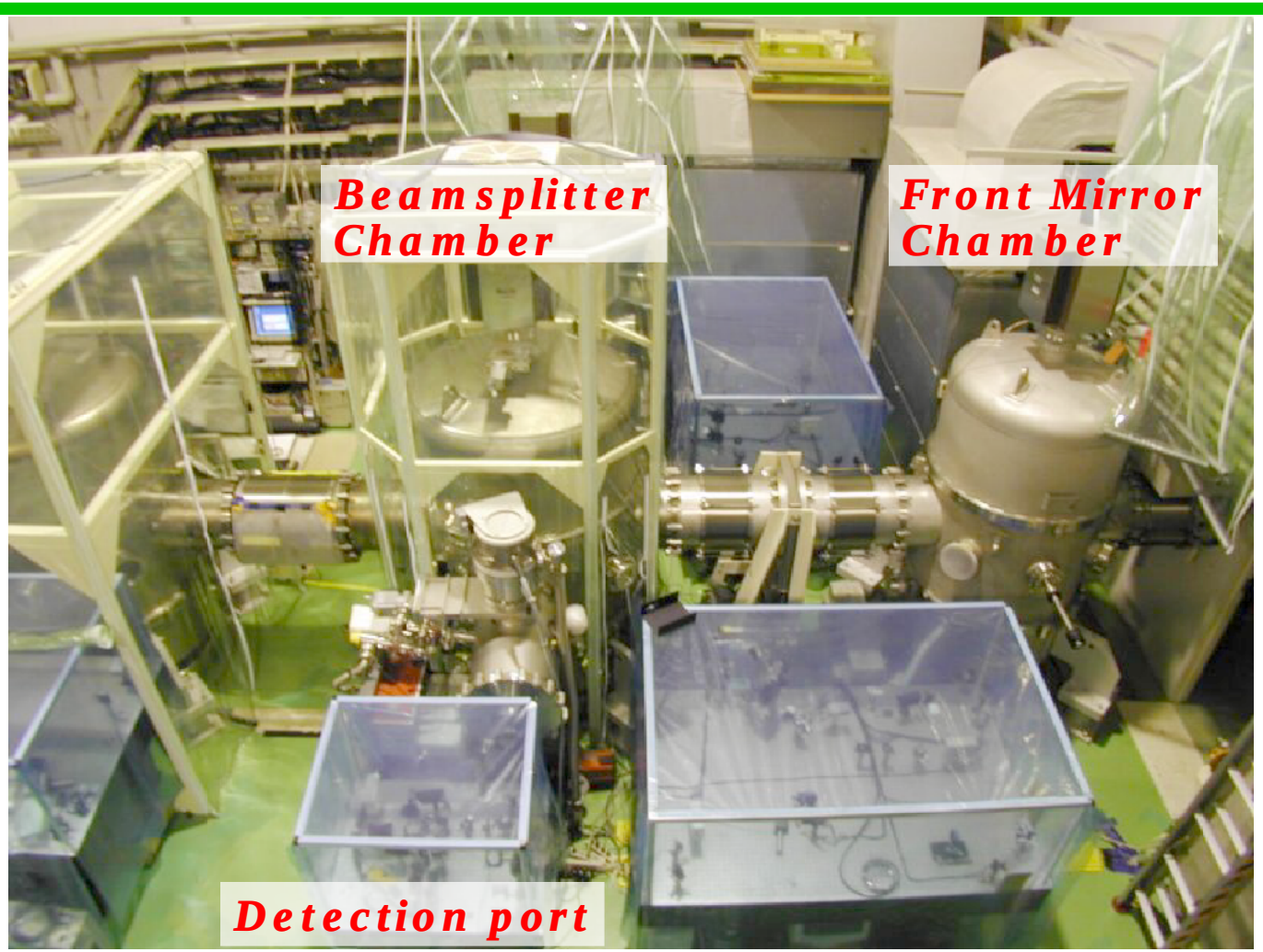

Beamsplitter

~ divides the incident beams into two beams

~ recombines the two reflected beams

Photodetectors receive recombined beam at the detection port

TAMA300 detector overview

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- ▷ **300-m tubes**
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300-m arms:
Electro-Chemical Polishing of internal surface

~ realizes vacuum pressure of 10^{-8} Pa without baking

TAMA300 detector overview

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- ▷ **Vibration isolation**
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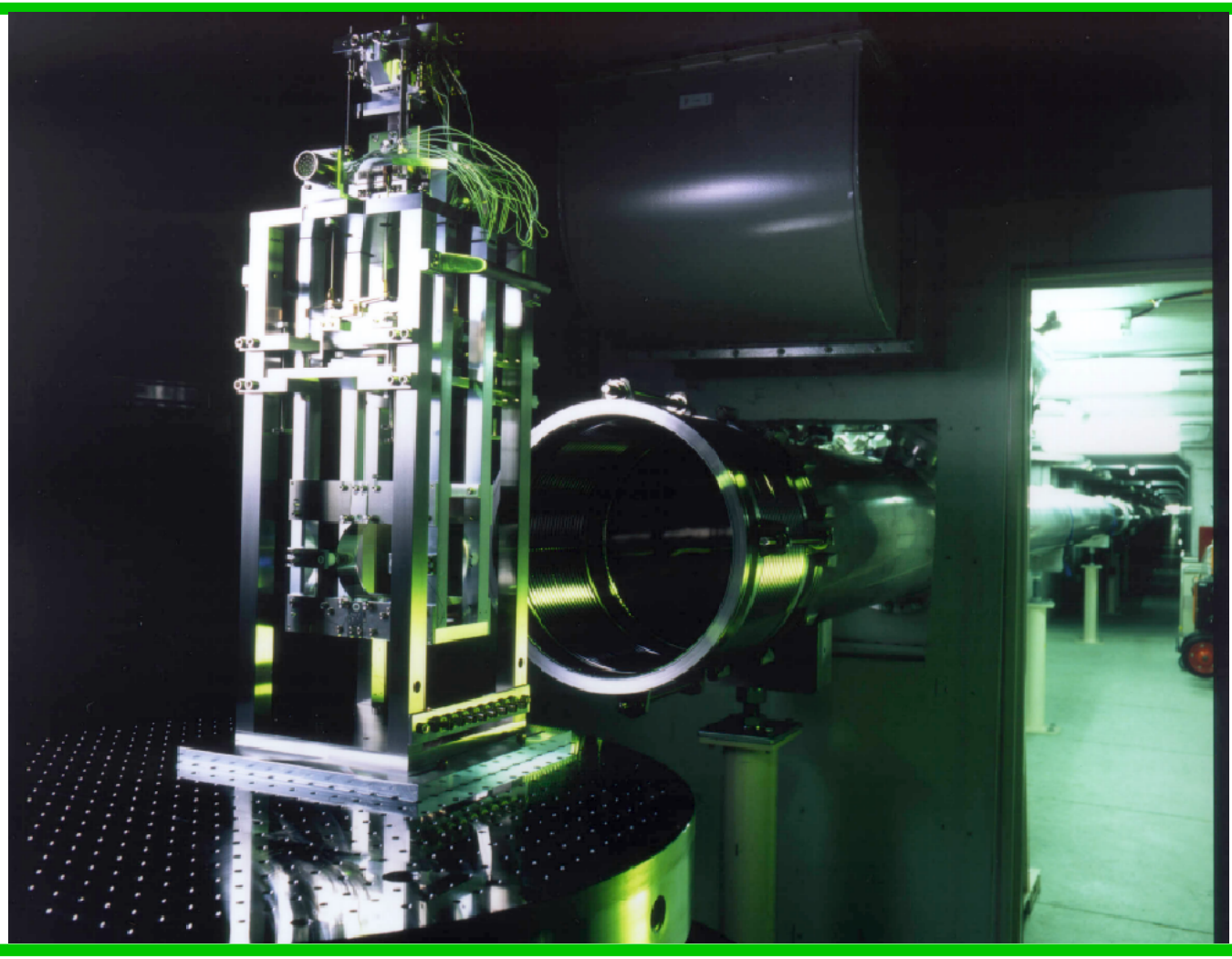

3-layer system:

Active air spring + Stack + Double pendulum suspension

Achieved performance

~ better than 10^{-8} at 150Hz

TAMA300 detector overview

- Aerial view
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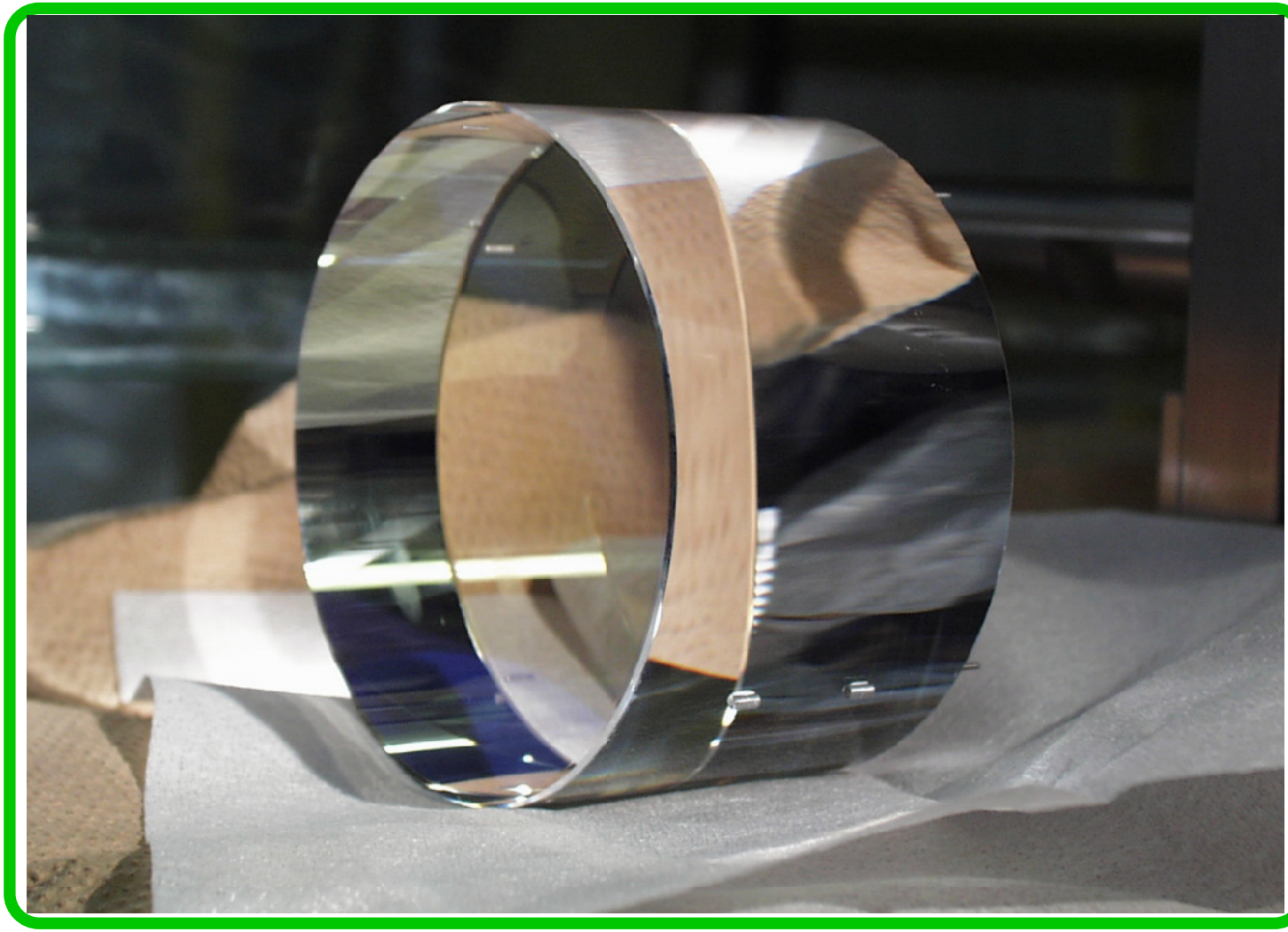
- 300-m tubes
- Vibration isolation
- ▷ **Mirrors**
- Control electronics

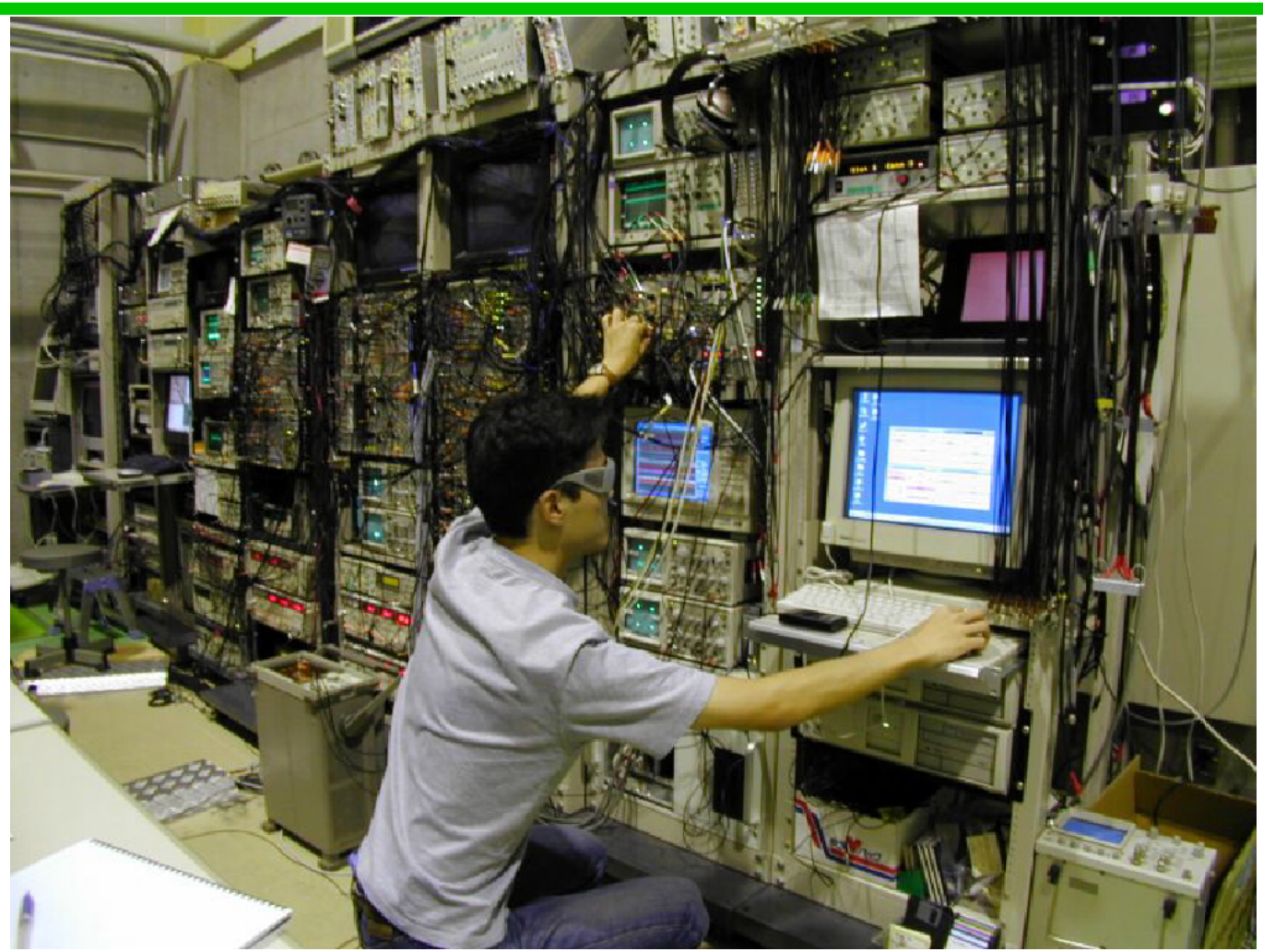


Fused Silica ϕ100mm x 60mm, m=1kg

Polished / Dielectric coating

TAMA300 detector overview

- Aerial view
- Light source
- Center room
- 300-m tubes
- Vibration isolation
- Mirrors
- ▷ **Control electronics**



Analog control circuits
with capability of digital switching for automatic operation

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  LCGT: 3km cryogenic interferometer in a mine

Data taking (DT) runs in past

6 observations without power recycling
2 observations with power recycling

[Without power recycling]

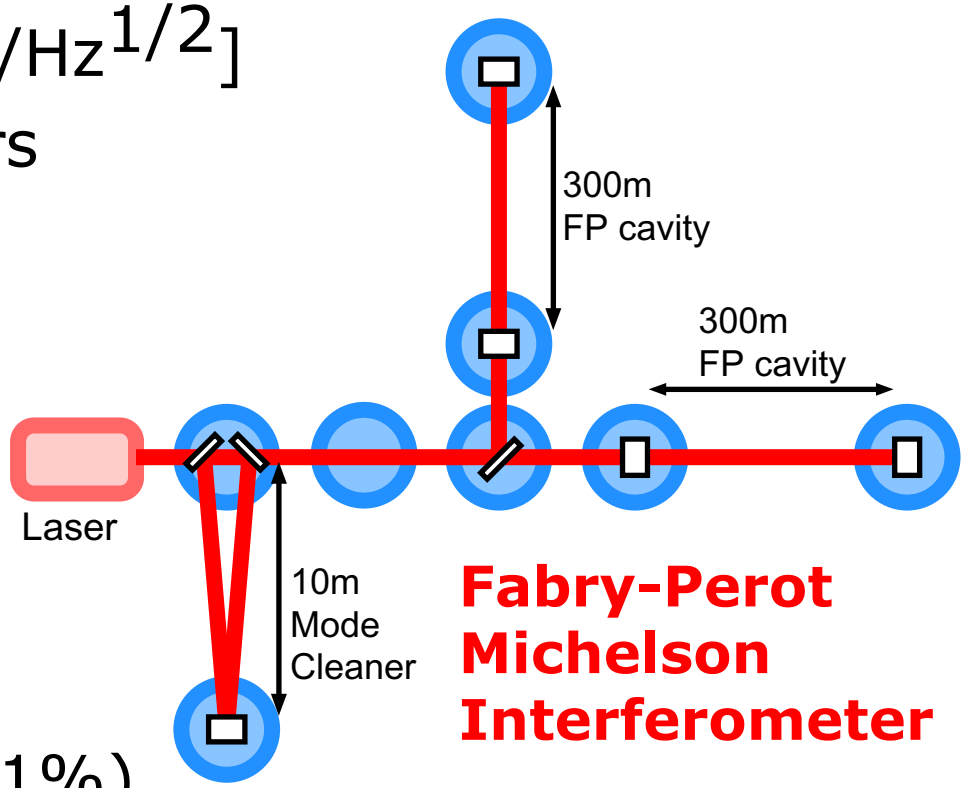
DT1	1999 Aug. 6~ 7	1 night	11 hours	
DT2	1999 Sep. 17~20	3 nights	31 hours	
DT3	2000 Apr. 20~23	3 nights	13 hours	
DT4	2000 Aug. 21~Sep. 4	13 nights	167 hours	
DT5	2001 Mar. 2~ 8	6 days	111 hours	
DT6	2001 Aug. 1~Sep. 20	50 days	1038 hours	***LISM(20m)***

[With power recycling]

DT7	2002 Aug, 31~Sep. 2	1 day	25 hours	***LIGO & GEO***
DT8	2003 Feb. 14~Apr. 15	59 days	1158 hours	***LIGO***

Interferometer on Data Taking 6

- **DT6 ~ 50 days run (2001/8/1~9/20)**
  - IFO configuration: Fabry-Perot Michelson (w/o power recycling)
  - Enough sensitivity to detect Galactic NS merger events
    Enough stability for long-term operation
    - ☐ Best sensitivity: 5×10^{-21} [/Hz$^{1/2}$]
    - ☐ Accumulated data: 1038 hours
    - ☐ Duty Cycle: 86.5%
      Longest lock: 22 hours
  - Coincidence with LISM 20m IFO at Kamioka mine
    - ☐ Lock overlapping 709 h (59.1%)



Interferometer on Data Taking 8

● DT8 ~ 2 months run (2003/2/14~4/15)

First full-time joint observation with LIGO (Called S2 in LIGO)

First long-term observation with power recycling

Power recycling of TAMA300 (2001/10~Present)

Power recycling gain of 4.5

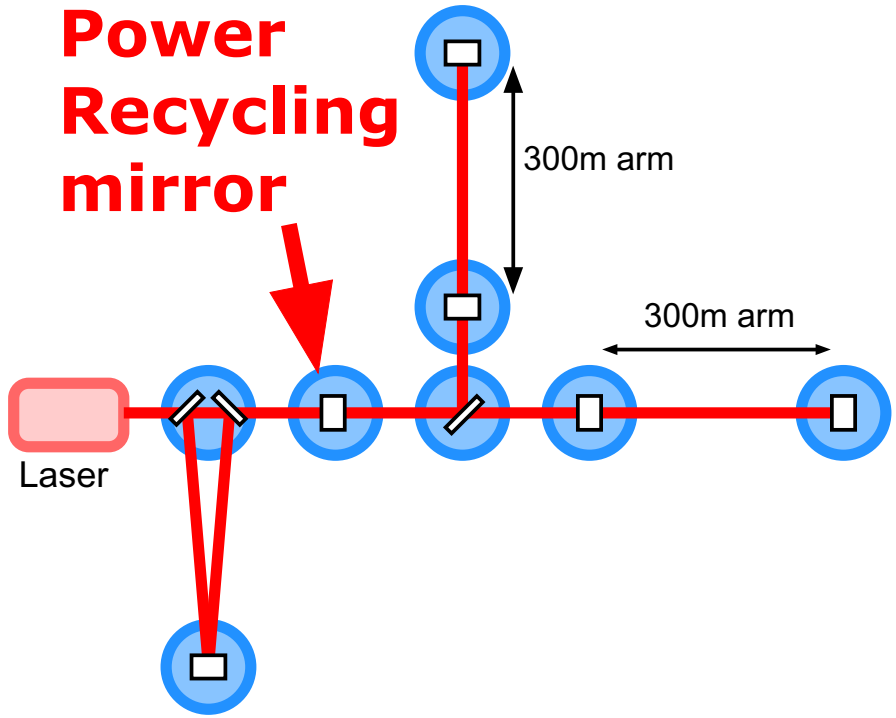
Best sensitivity: 2.7×10^{-21} [/Hz$^{1/2}$]

IFO operation

Accumulated data: 1158 hours

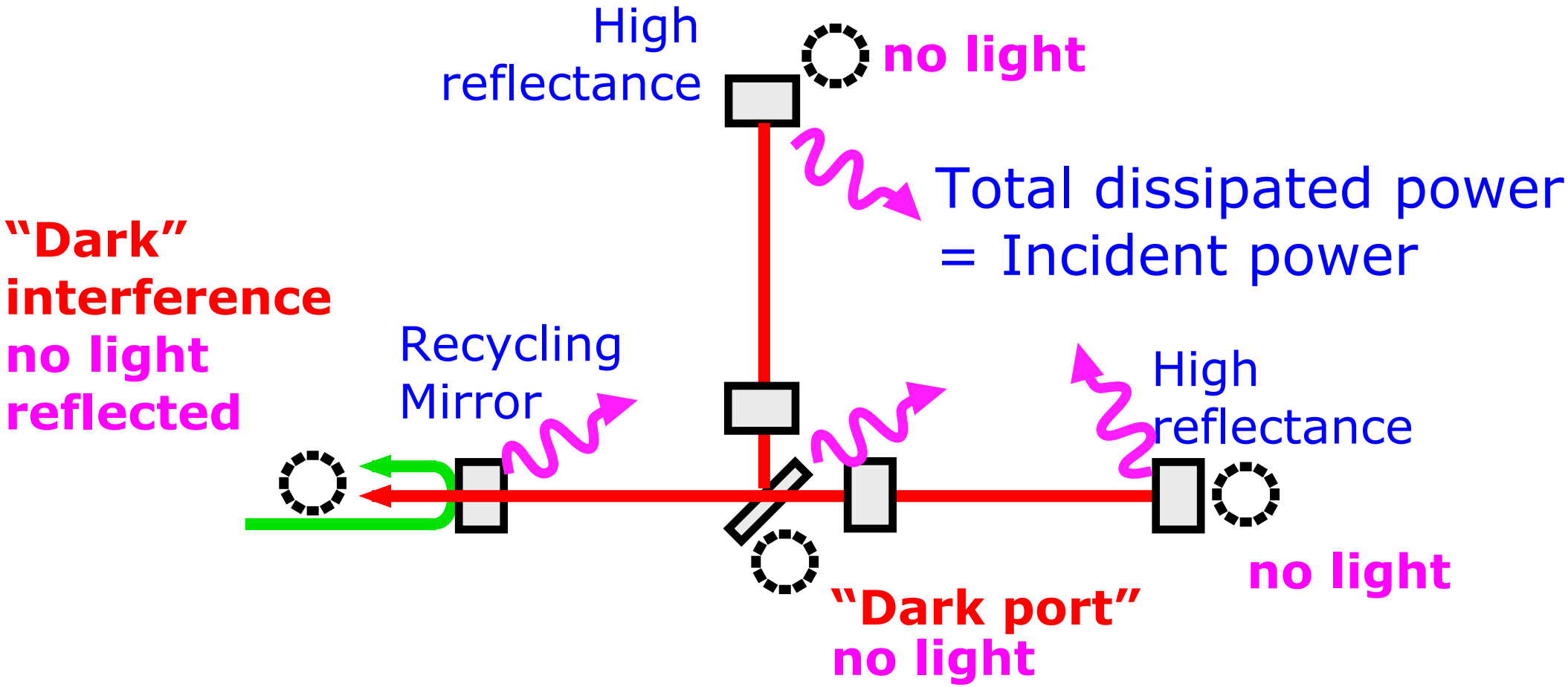
Duty cycle: 81.3 %

Longest lock: 20.5 hours



Principle of power recycling

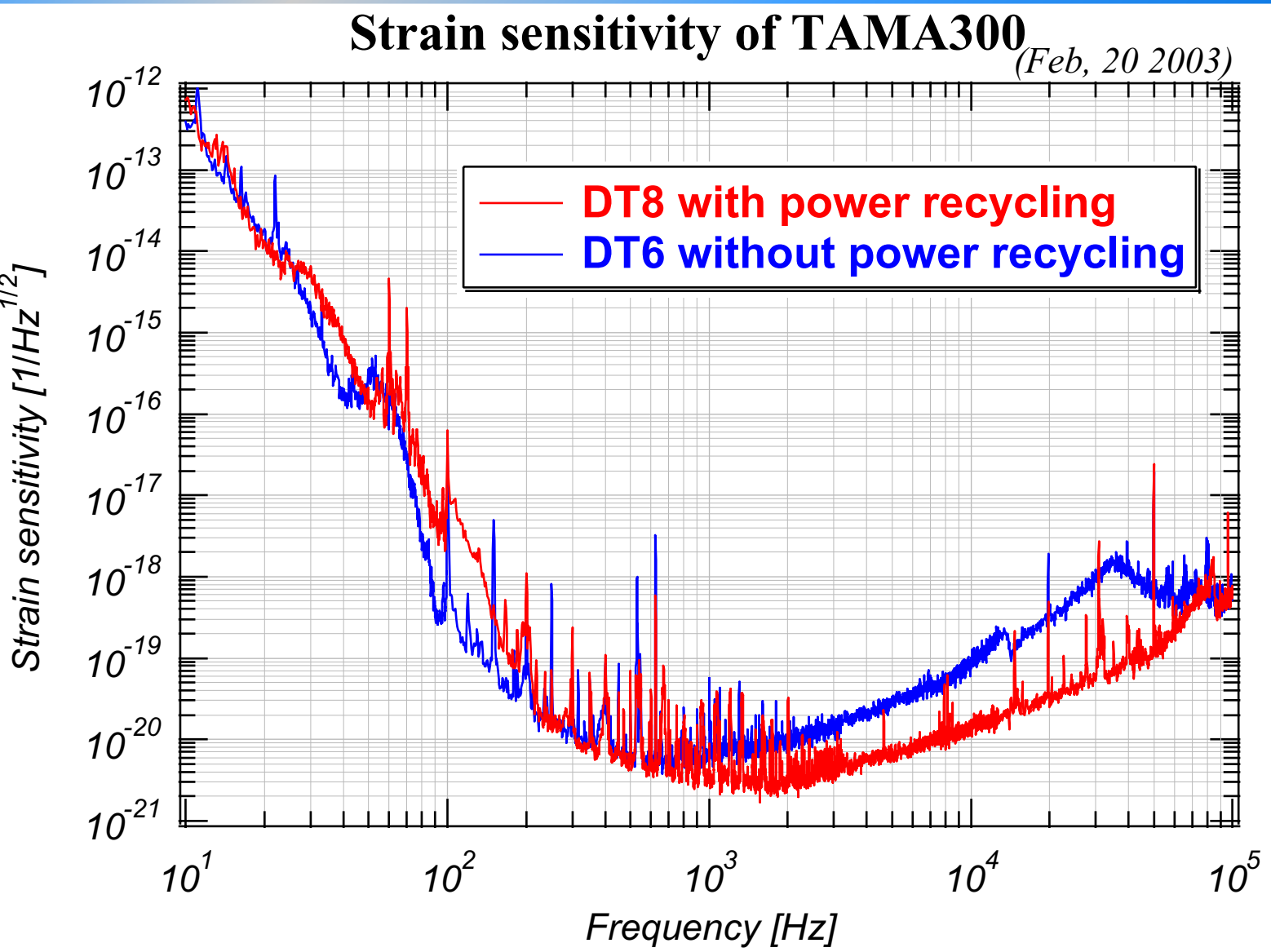
- Laser light is enclosed in the interferometer



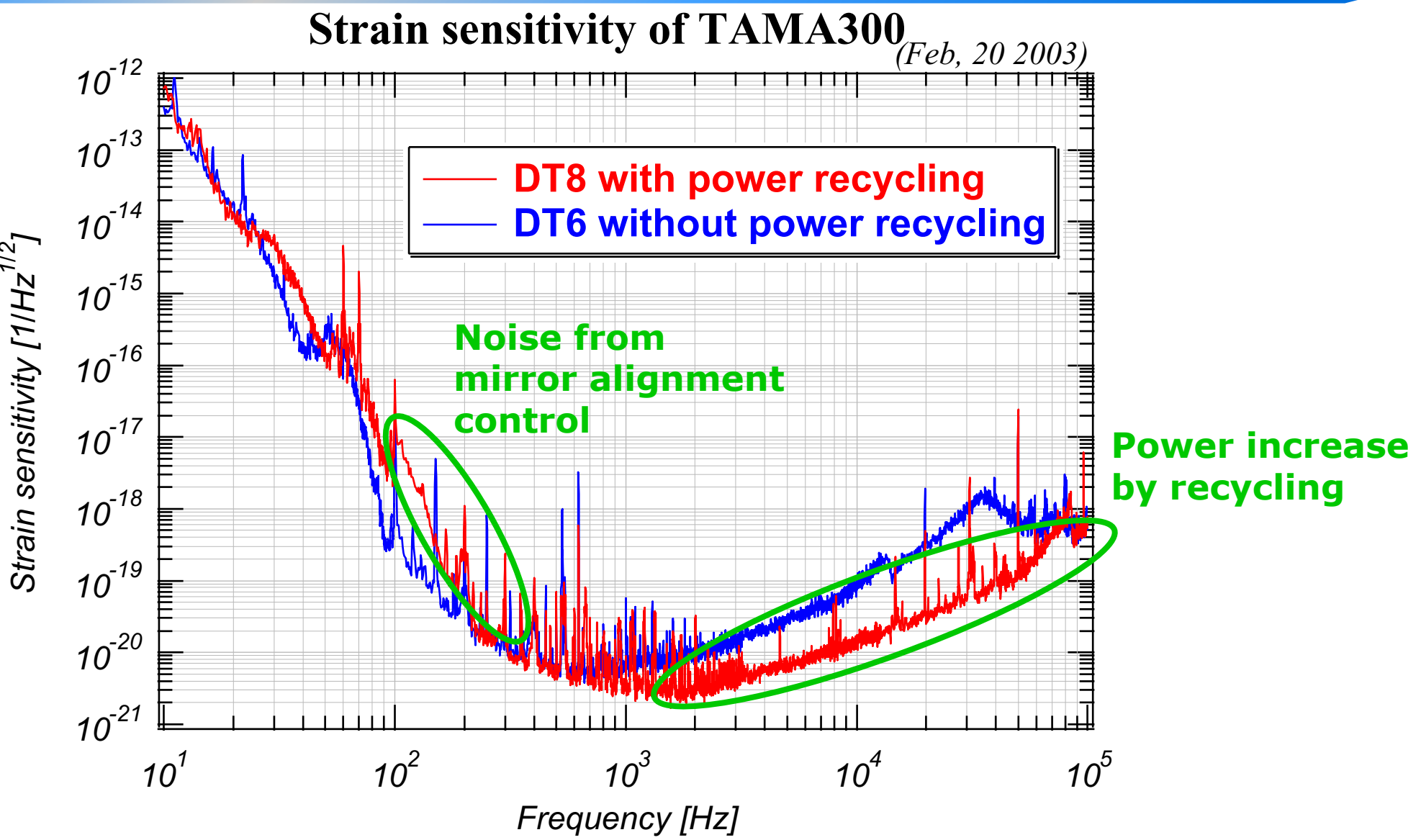
$$P_{\mathrm{inc}} = \varepsilon_{\mathrm{loss}} P_{\mathrm{internal}} \rightarrow P_{\mathrm{internal}} = \frac{P_{\mathrm{inc}}}{\varepsilon_{\mathrm{loss}}} \equiv G\, P_{\mathrm{inc}}$$

$$(G_{\mathrm{TAMA}}=4.5)$$

Sensitivty in DT6 & DT8

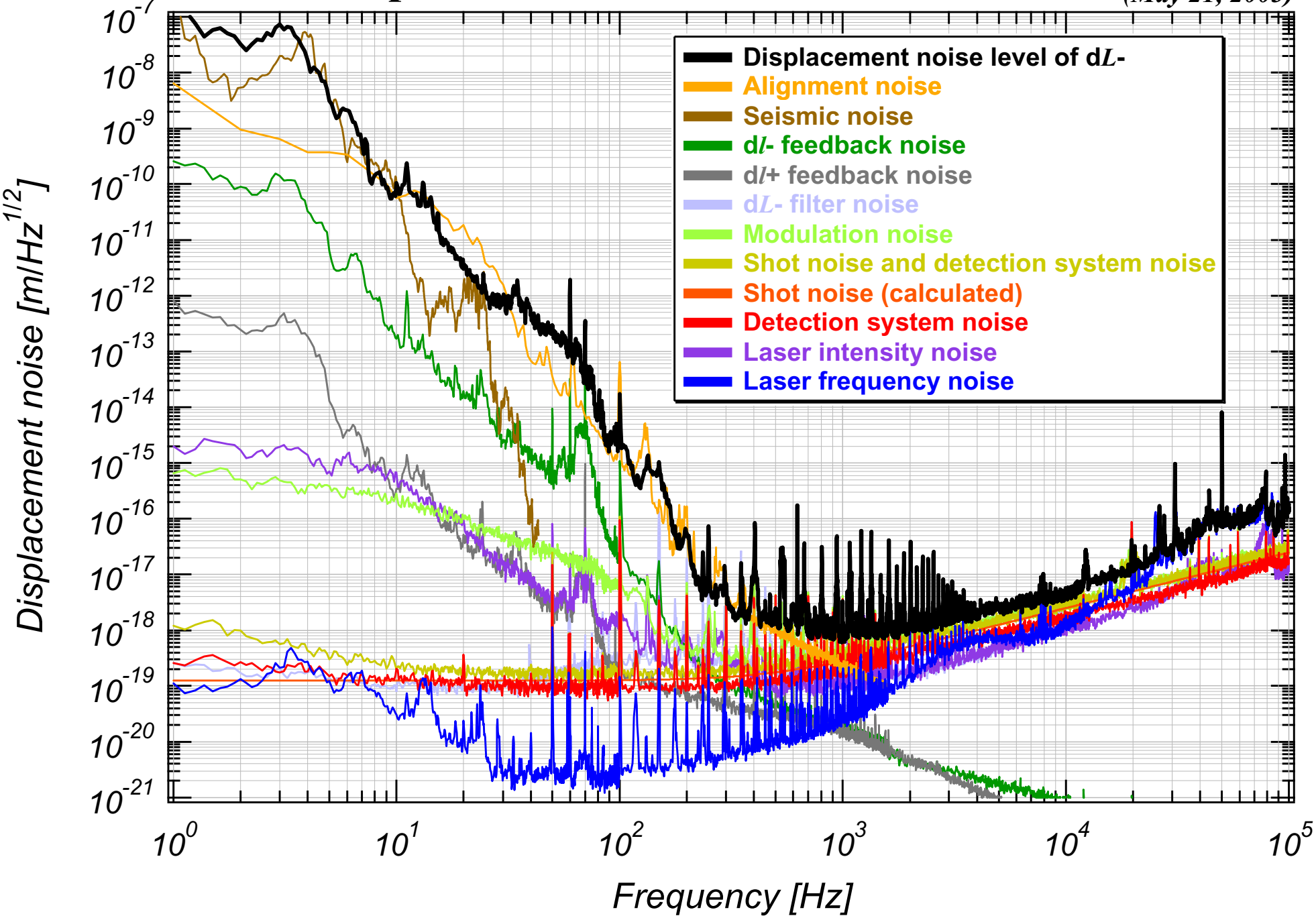


Sensitivty in DT6 & DT8



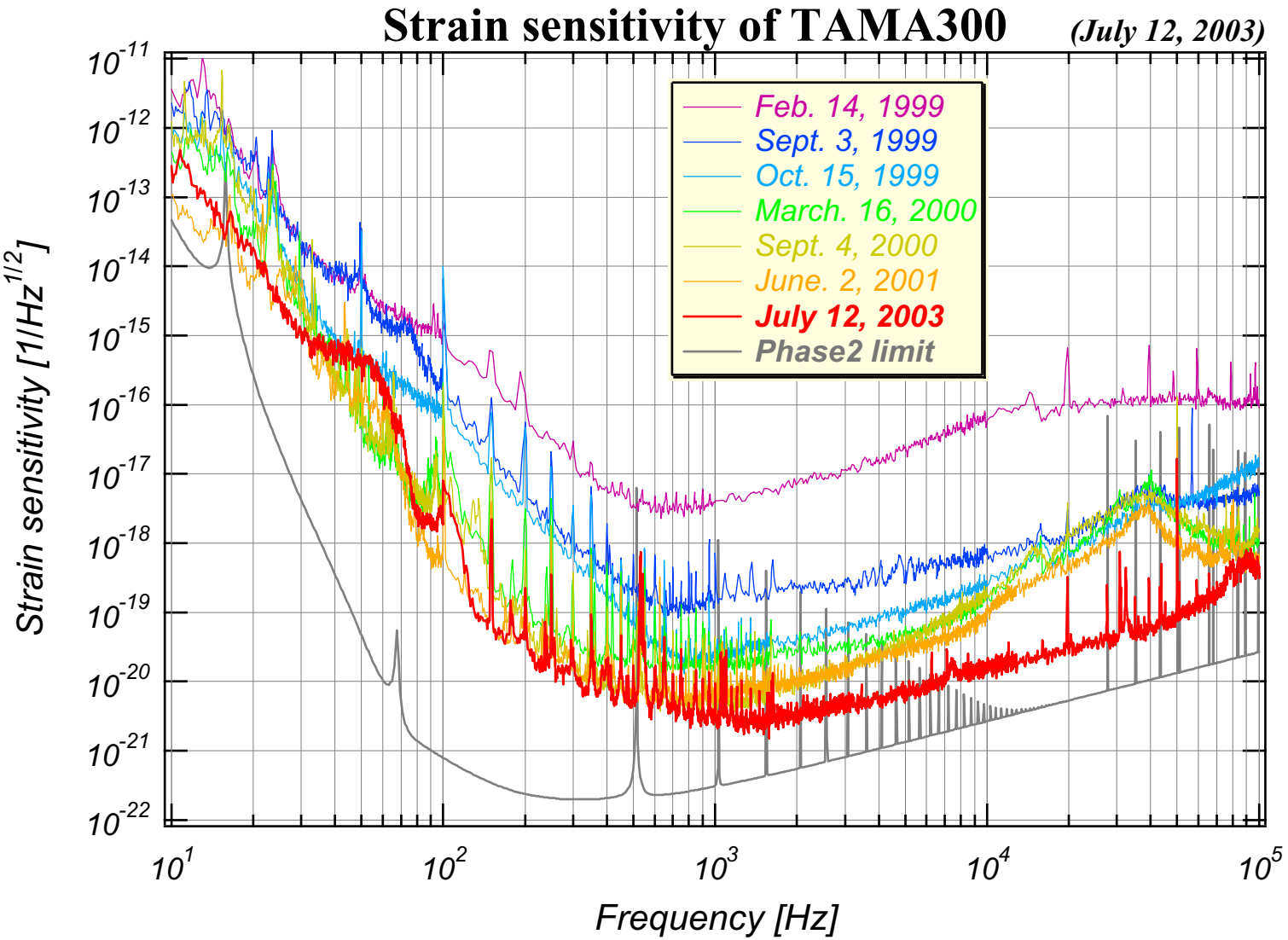
Floor level: DT6 5 x10^{-21} /Hz$^{1/2}$

DT8 2.7x10^{-21} /Hz$^{1/2}$


Displacement noise level of TAMA300
(May 21, 2003)
Displacement noise level of dL-
Alignment noise
Seismic noise
dl- feedback noise
dl+ feedback noise
dL- filter noise
Modulation noise
Shot noise and detection system noise
Shot noise (calculated)
Detection system noise
Laser intensity noise
Laser frequency noise
Displacement noise [m/Hz^1/2]
Frequency [Hz]
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
10^0
10^1
10^2
10^3
10^4
10^5

History of the sensitivity

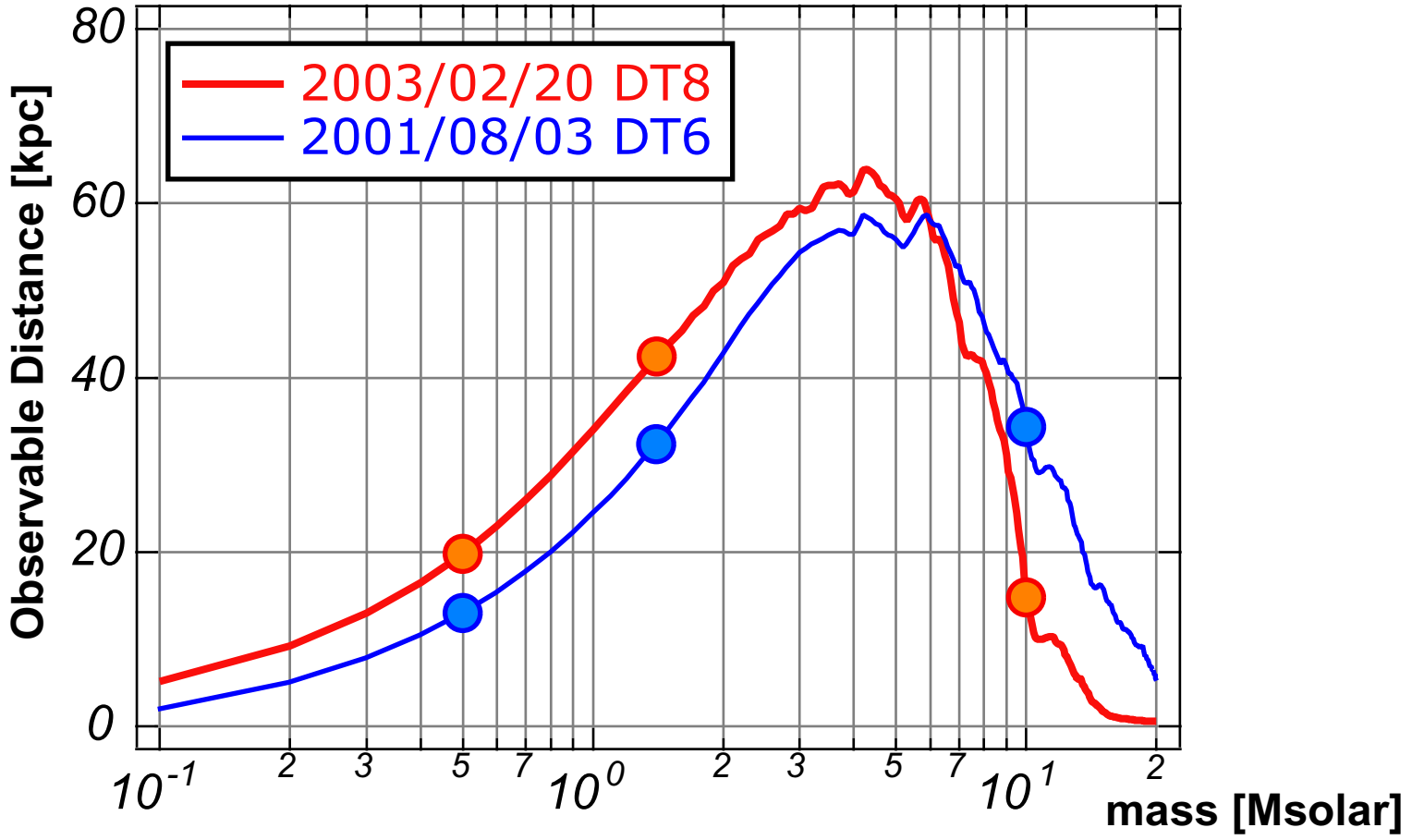
- ***Improvement by a factor of 10^3 ~ 10^4***
  ~ operation since 1999



Observable distance

Distance for an optimally oriented m+m system, to yield SNR=10

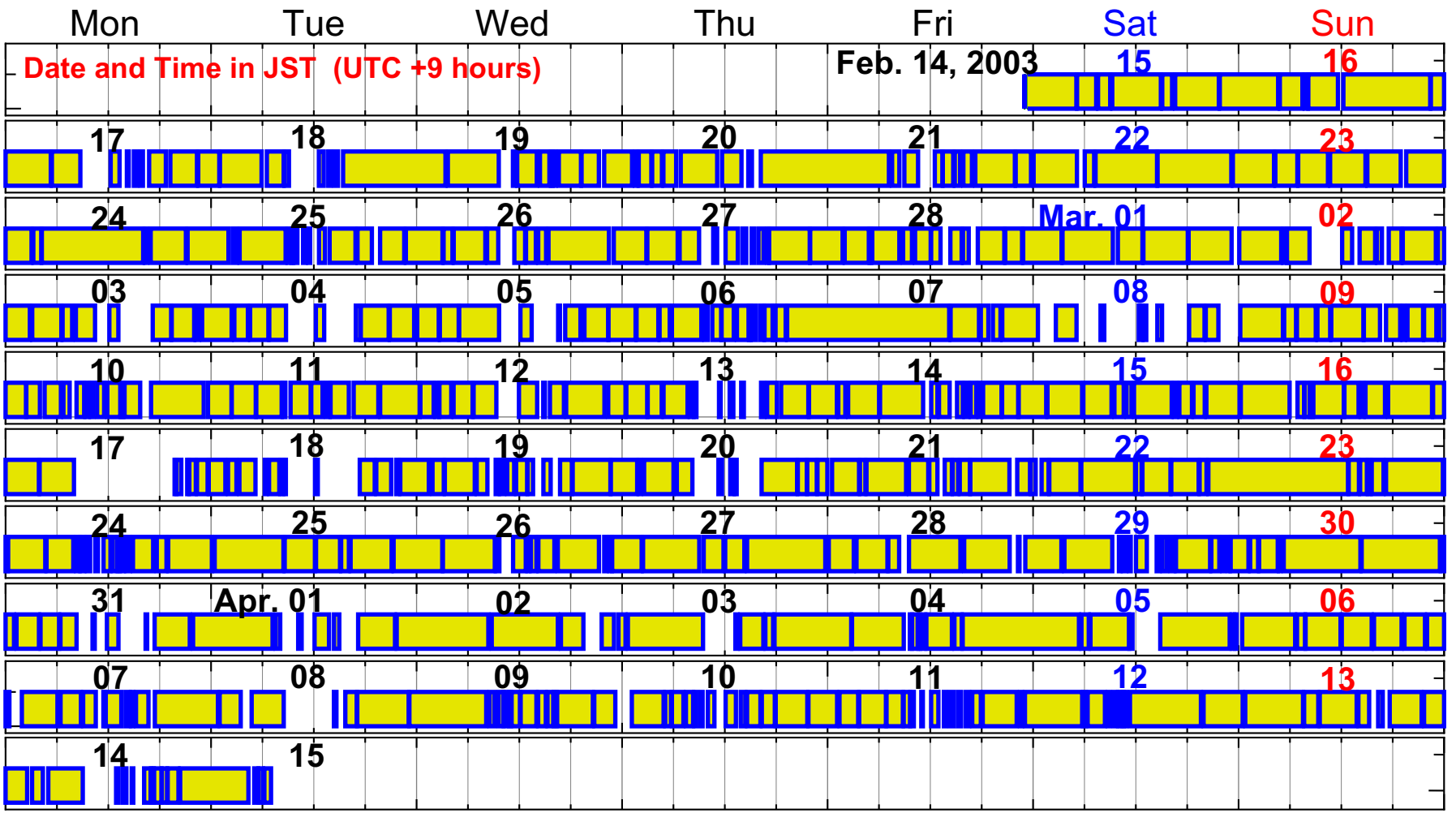
	DT6	DT8
m=0.5 (Macho BH):	14 kpc	20 kpc
m=1.4 (NS):	33 kpc	42 kpc
m=10 (BH):	34 kpc	15 kpc



Duty cycle

- DT6: 1038h07m (out of 1200 hours, duty cycle 86.5%)
- DT8: 1157h51m (out of 1424 hours, duty cycle 81.3%)

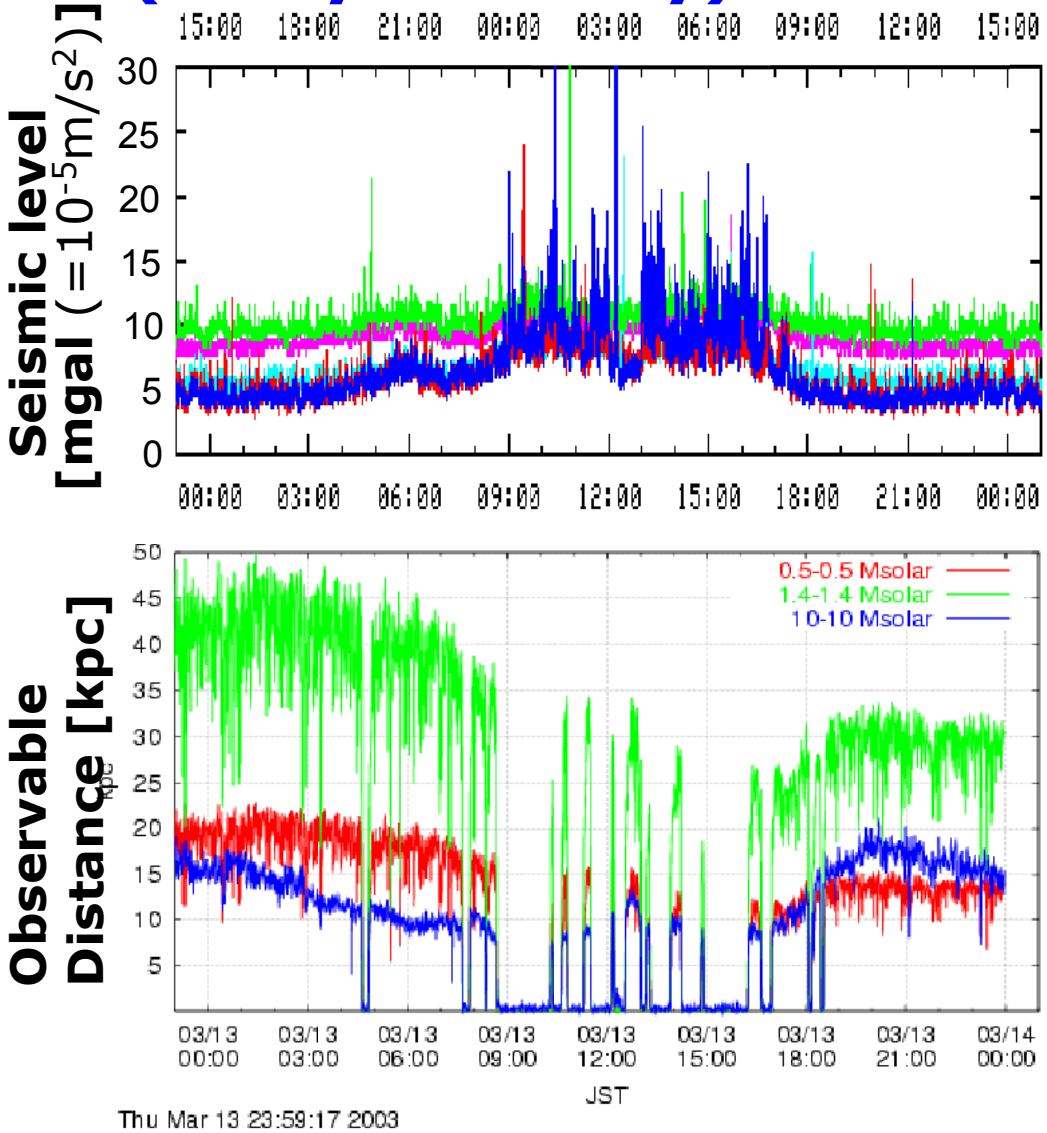
Observation Calendar for DT8



DT8: Disturbance by construction

13rd May, 2003 (Thu)

(Noisy weekday)



Construction works near the site

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- ***Future Plans***
  LCGT: 3km cryogenic interferometer in a mine

Data analysis activities

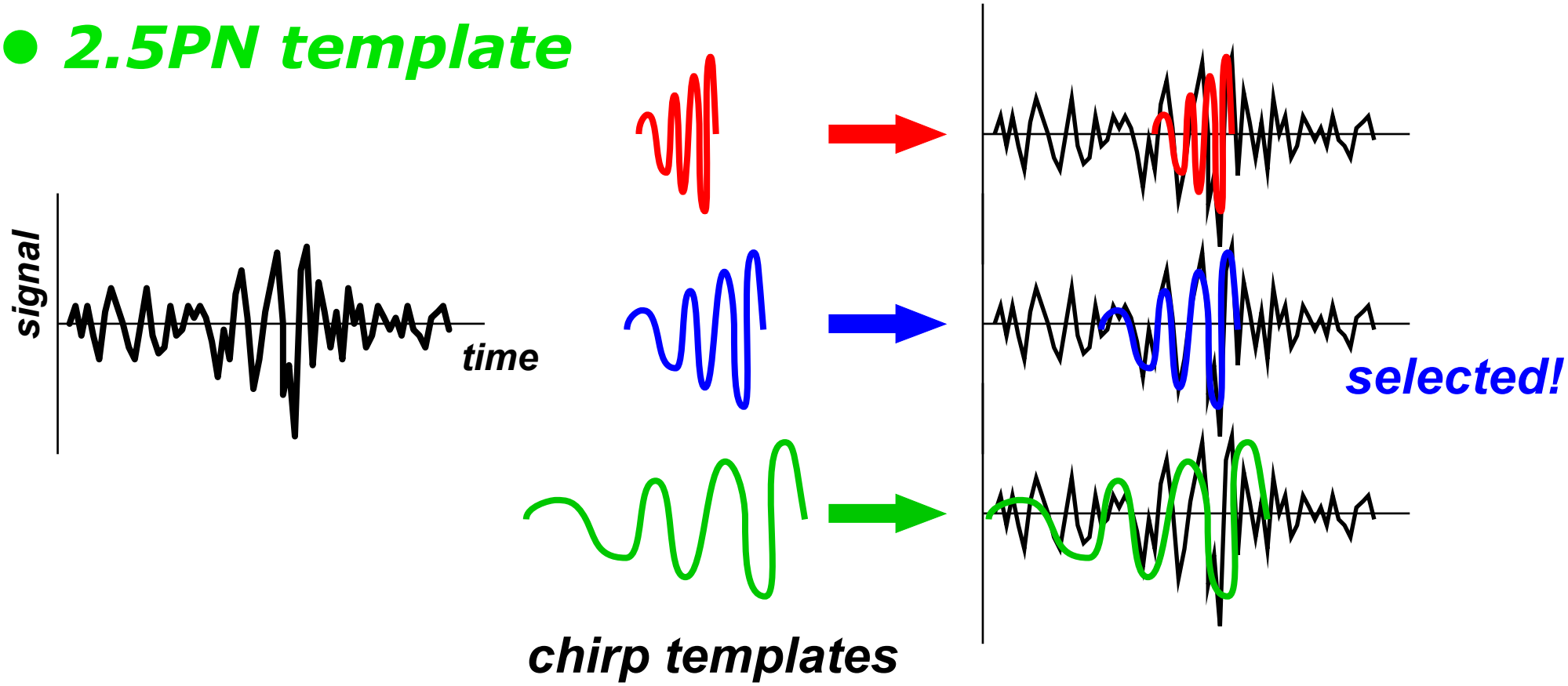
- **Matched filtering analysis**
  - > *NS binary inspirals*
  - > *Coincidence analysis between multiple detectors*
  - > *0.5Msolar Macho BH binary inspirals*
  - > *BH ringdown analysis*

- **Burst analysis**
  - > *Rejection of non-gaussian noise by time-scale selection*

- **Continuous wave**
  - > *Search for possible GW from SN1987a remnant*

NS ispirals: Matched Filtering

- **2.5PN template**

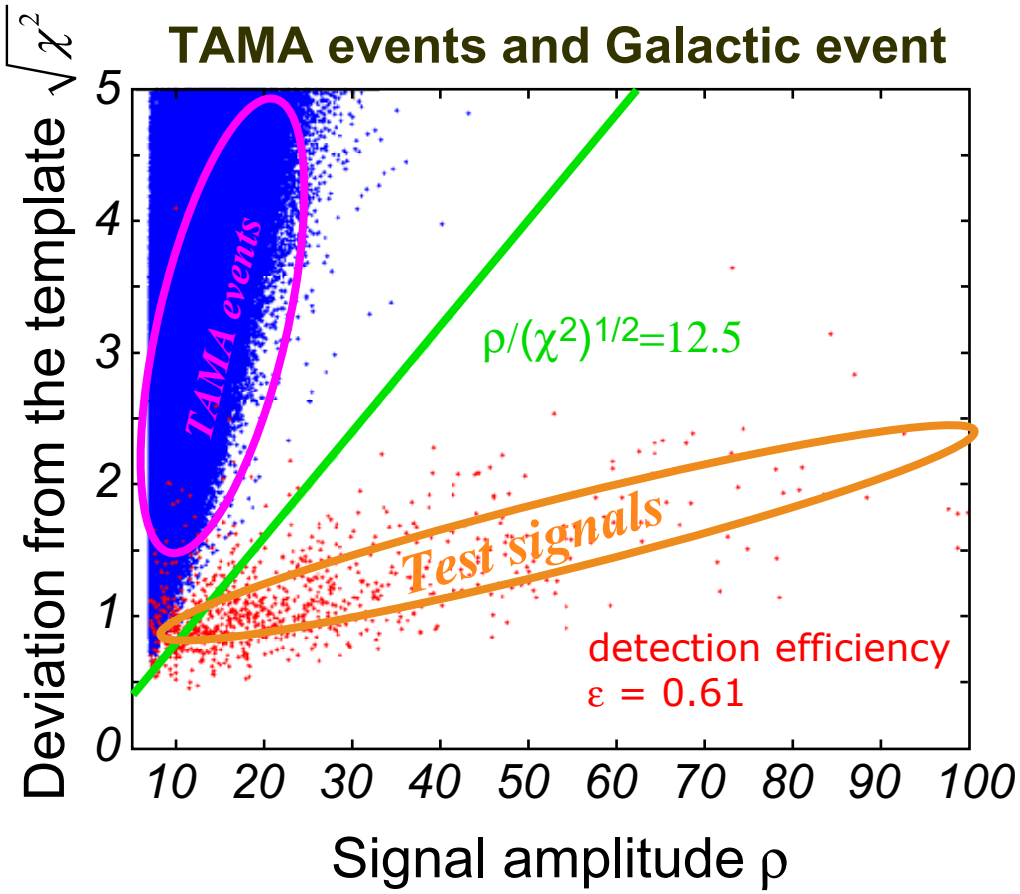


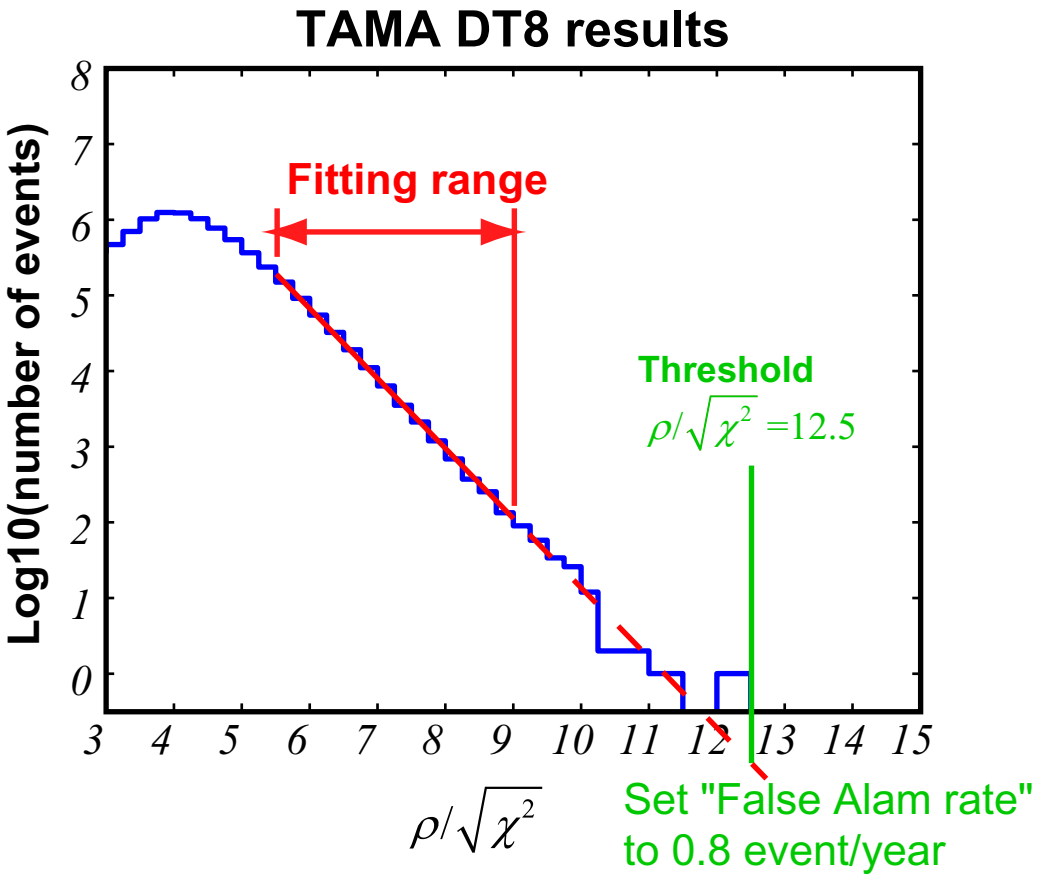
- **Each data segment has two outputs**

ρ: signal amplitude ~ correlation with the template

χ^2: deviation of the signal from the selected template

Event distrib. / detection efficiency





Upper limit to the Galactic NS merger

- **Observation time**

  T_{obs} = 1163 hours (for lock longer than 520sec)

- **Event threshold** 1039 hours for DT6

  $\rho/(\chi^2)^{1/2}$ = 12.5 (for false alerm rate = 0.8 / year)

- **Detection efficiency** $\rho/(\chi^2)^{1/2}$ = 16 for DT6

  ε = 0.61 (from Galactic event monte-carlo simulation)

- **Upper limit to the avg # of events** 0.23 for DT6

  Observed # of event = 0 **over the threshold**

  => N=2.3 (C.L.: 90%) (from standard Poisson statistics analysis)

Preliminary search result for DT8

=> $N / T_{obs} / \varepsilon$ = **0.0033** [event/hr]

= **2.9×10^1** [event/yr]

for 1.0 Msolar < m_1, m_2 < 3.0Msolar

For DT6

=**0.0095** [1/hr]

=**8.3×10^1** [1/yr]

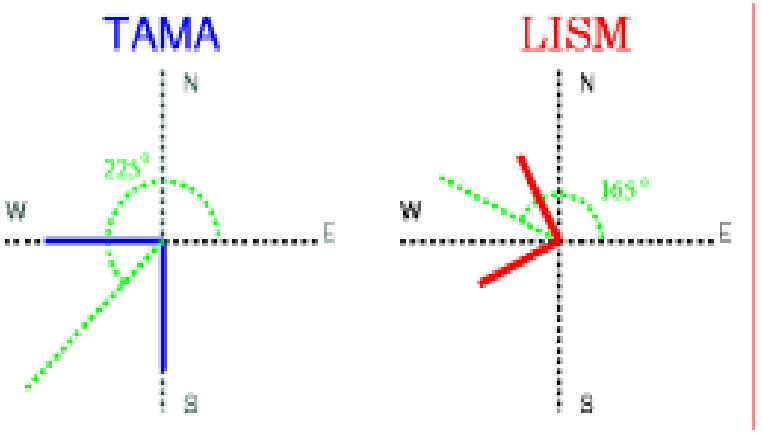
1 < m < 2Msolar

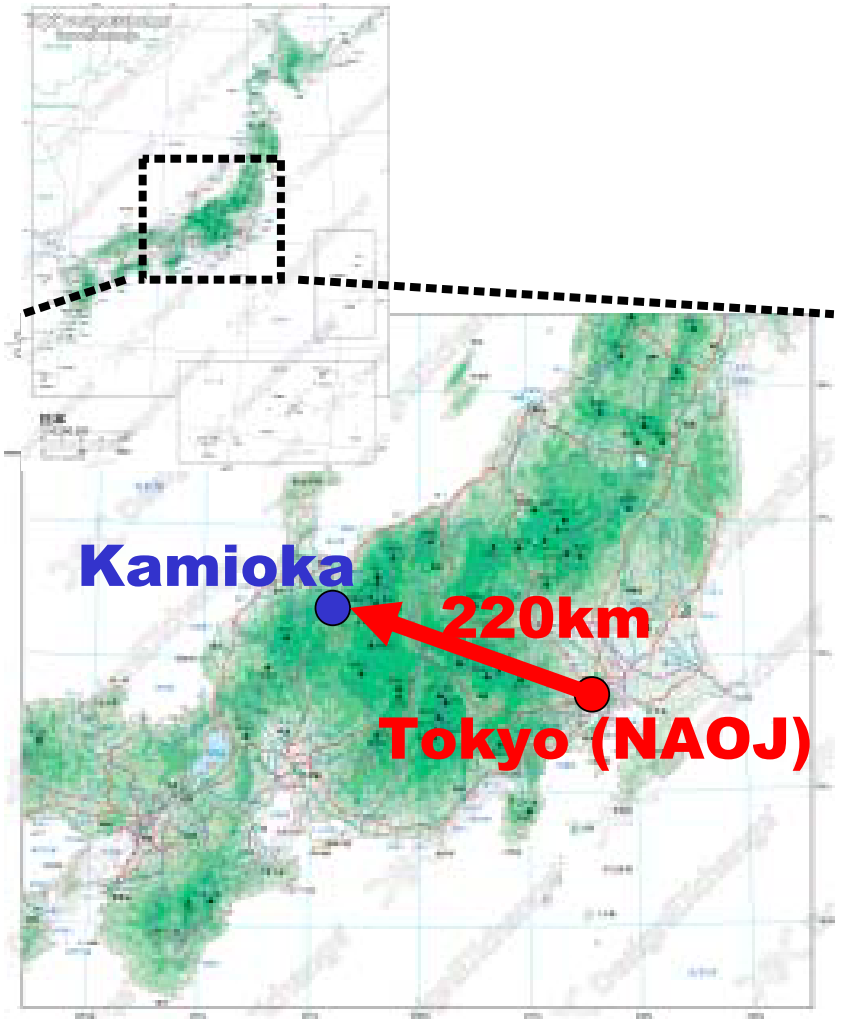
DT6: TAMA-LISM20m coincidence run

● Location of TAMA and LISM20m prototype

- **Distance between TAMA and LISM ～ 220km**
  => Max delay of signal arrival time = 0.73msec
- **Sensitivity $h = 8 \times 10^{-20}$ /Hz$^{1/2}$**
- **Analyzed 244 hours of commonly-locked data**
- **Relation between TAMA and LISM arms direction**

	orientation	latitude	longitude
TAMA	225°	35.68° N	139.54° E
LISM	165°	36.25° N	137.18° E





Results of coincident event search

Results of onestep search for common lock parts

TAMA	LISM
158437 events	142465 events

After t_c -coincidence

70 events

After t_c, M, η -coincidence

18 events

After t_c, M, η, ρ -coincidence

13 events

Results of coincident event search

Results of onestep search for common lock parts

TAMA	LISM
158437 events	142465 events

After t_c-coincidence	accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$
70 events	70.45 ± 8.53

After t_c, M, η-coincidence	accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$
18 events	17.55 ± 4.08

After t_c, M, η, ρ-coincidence	accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$
13 events	12.76 ± 3.51

Burst GW analysis

- **Distinguish burst signals with a certain time-scale using higher-order statistics**

The detector output:

Full of bursts ~ essentially indistingushable from GWs

=> assume time-scale of the GW bursts

(c.f. Supernova)

Two statistics of each data segment:

Averaged noise power: Averaged noise level

2nd-order moment of noise power: Gaussianity

Bursts with different time-scale have different behaviours

in terms of those two statistics

=> Select bursts only with target time-scale

Burst GW analysis

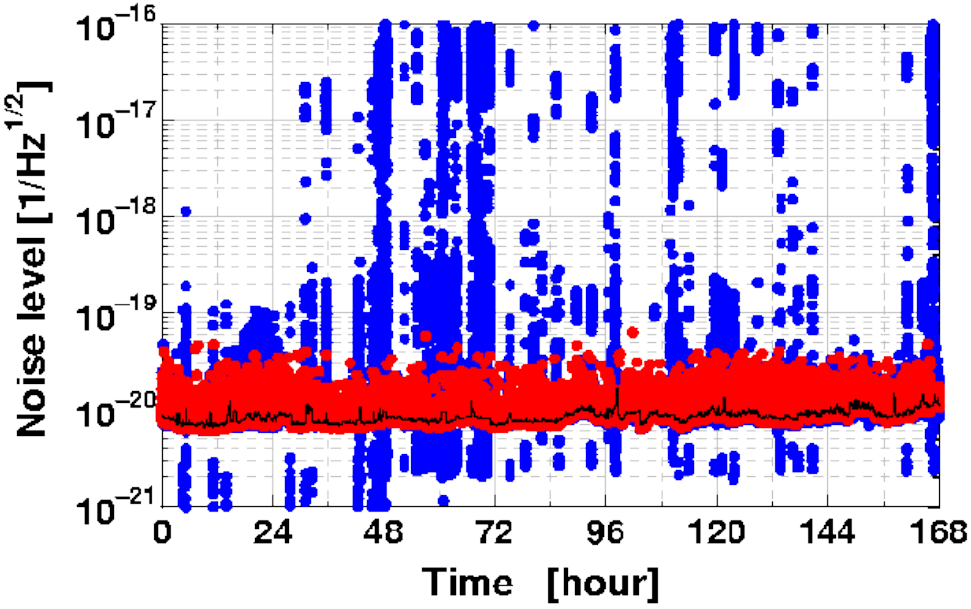
- **Analysis of DT6 data**

Rejected 10% of data by the time-scale filter

=> Improvement of

false event rate 1/1000

(False dismissal rate = 1ppm)



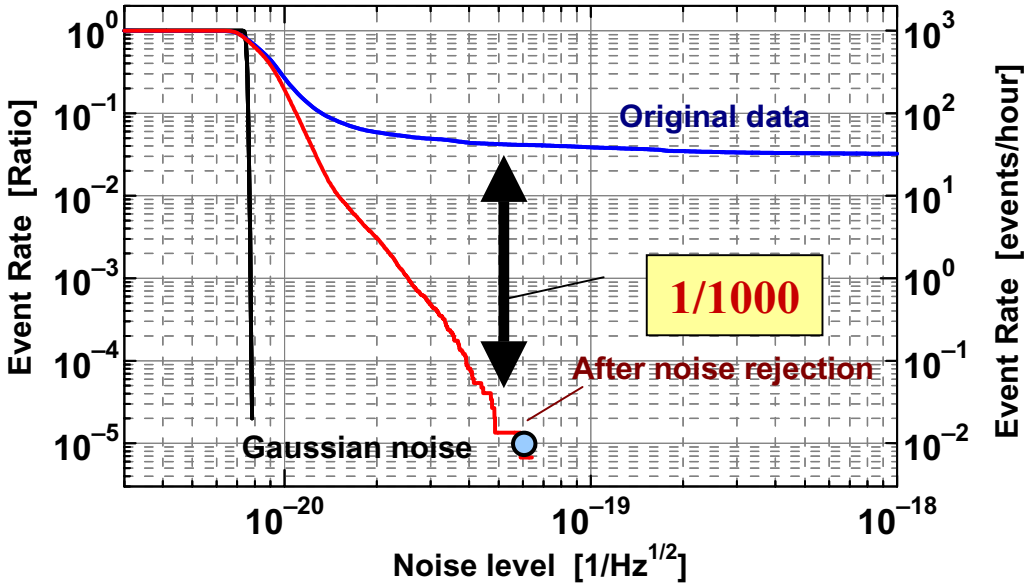
Event rate for 10msec GWs

hrms: ~ 1×10^{-17} : 1 ev/hr

~ 3×10^{-17} : 10^{-2} ev/hr

Event rate for 1msec GWs

hrms: ~ 3×10^{-17} : 4 ev/hr



Continuous wave from SN1987A

- **Target: possible SN1987a remnant**

(Middleditch, et al. New Astronomy, 5 (2000) 243)

o Expected Waveform: Sinusoidal (f=934.908Hz +/- 0.05Hz)

+ time dependence of the sensitivity

+ doppler correction

(the earth's daily/yearly round)

+ spindown correction

(assume spindown rate: $2\sim3\times10^{-10}$ [Hz/s])

o Search result: DT6 50days data

Upper limit: $h=5\times10^{-23}$ (C.L. 99%)

($h_{upperlimit}$ from the spindown: $h=9.4\times10^{-27}$)

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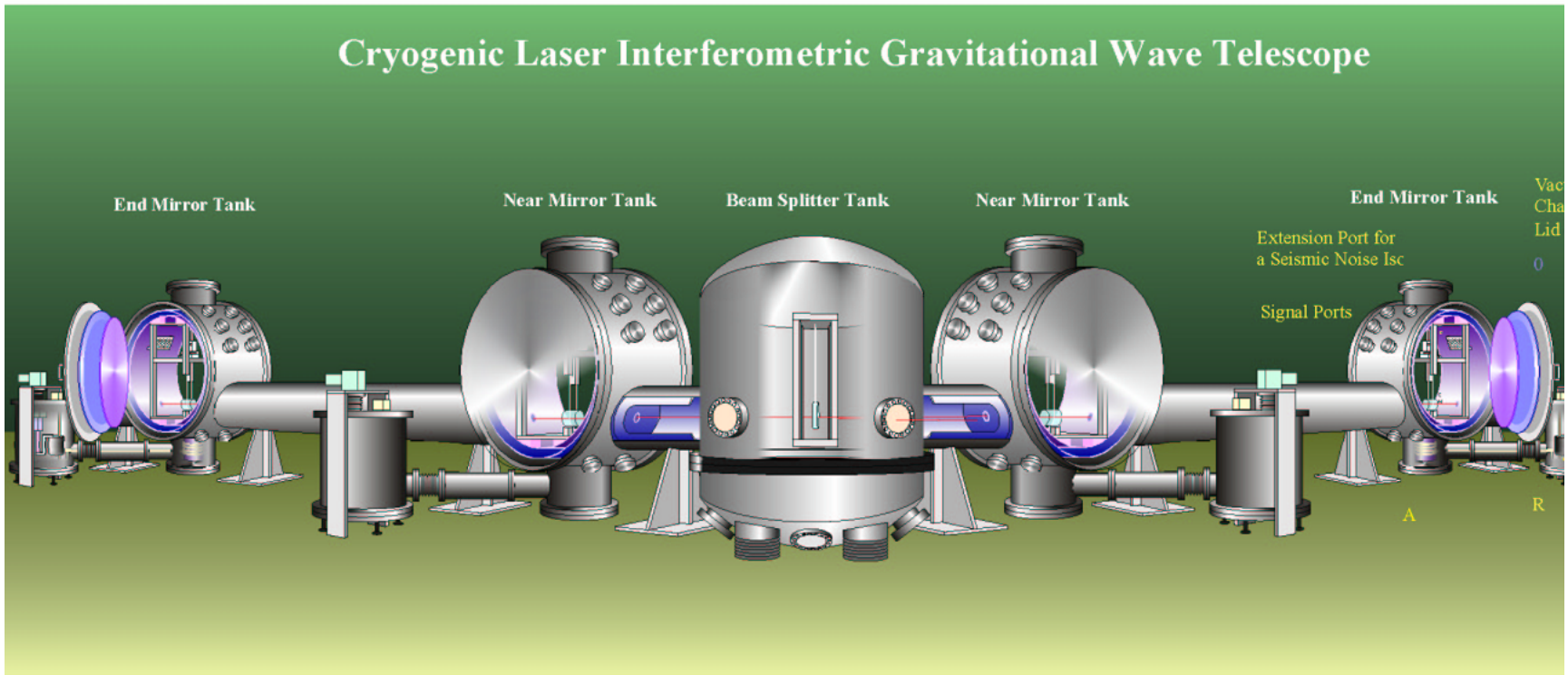
☞ - ***Future Plans***
  LCGT: 3km cryogenic interferometer in a mine

LCGT: Japanese future project

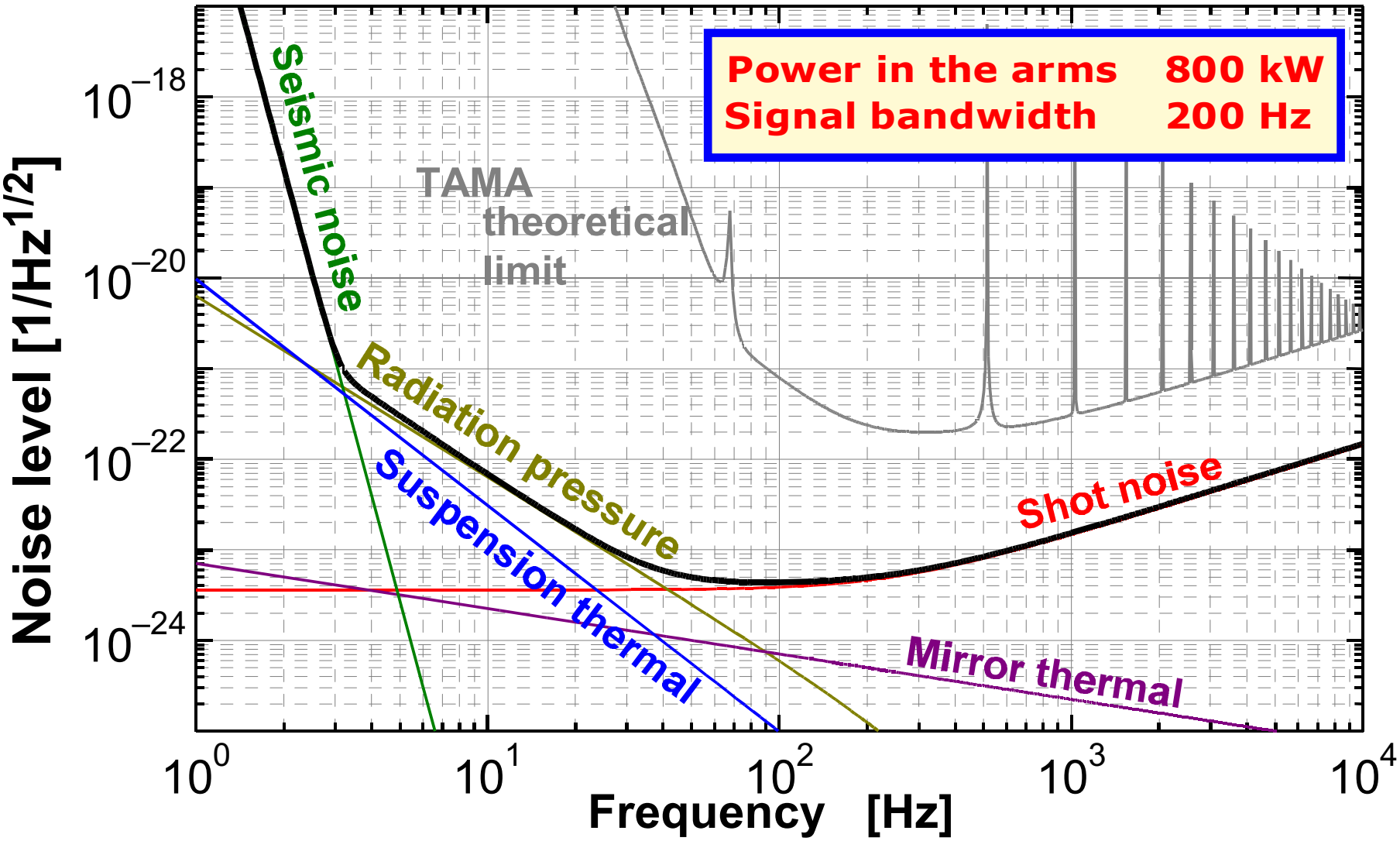
- ***Large-scale Cryogenic Gravitational wave Telescope***

3-km interferometer at Kamioka mine
Cryogenic (~20K) mirror to reduce thermal noise



Design sensitivity of LCGT

LCGT noise budget



Sensitivity of LCGT will be quantum-noise limited

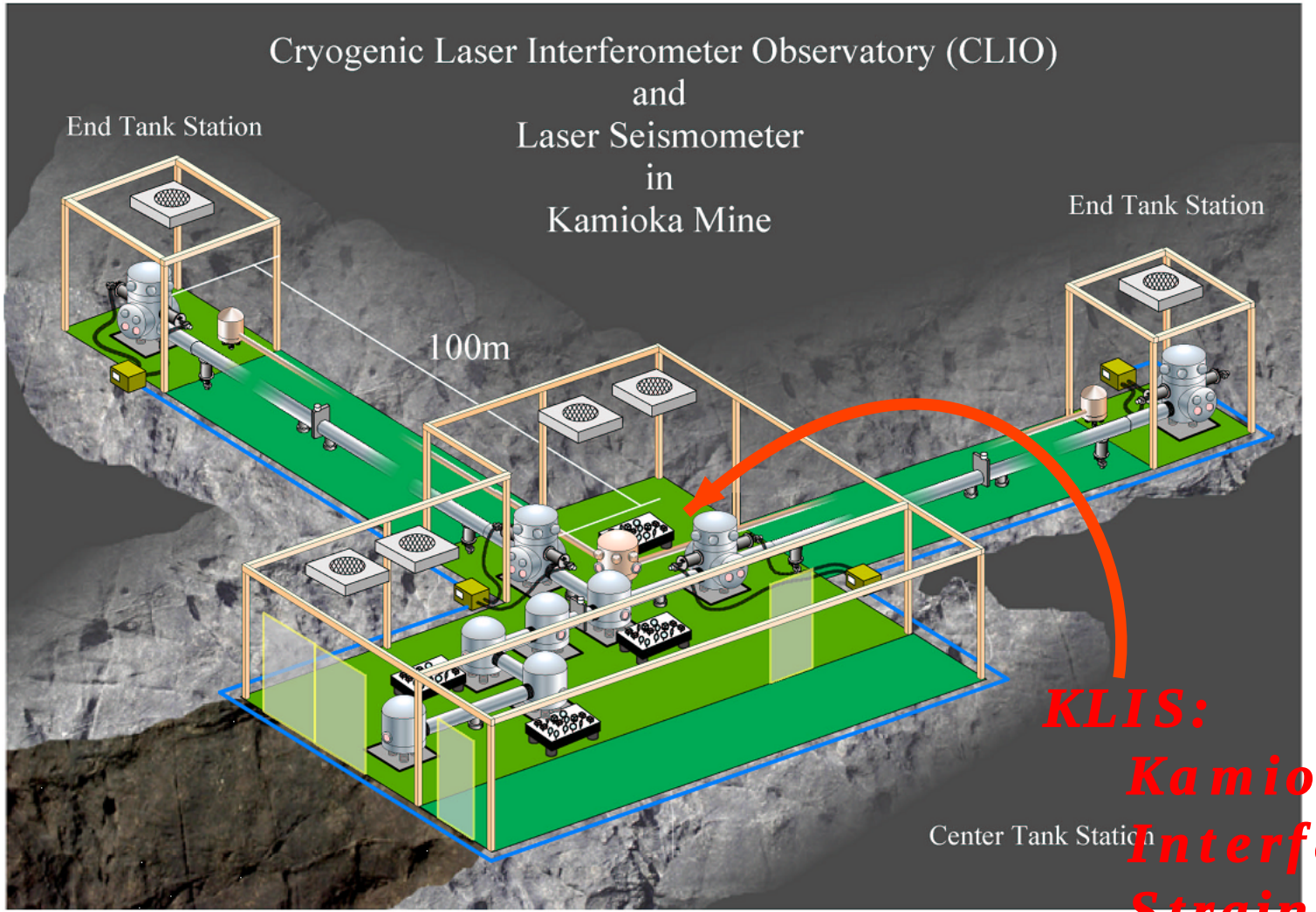
LCGT will be capable of detecting

- ***NS binary inspiral at 200Mpc with SNR of 10***

CLIO: Cryogenic laser interferometer Observatory

100-m cryogenic interferometer detector in Kamioka

Pilot program to demonstrate feasibility of LCGT technologies



The construction is underway

KLIS: Kamioka Laser Interferometric Strainmeter

~ for geophysical purposes

Summary

- ***Interferometric GW detector TAMA300***

  A 300-m Fabry-Perot Michelson interferometer

  8 observations from 1999 to 2003

- ***Long-term (>1000h) observation DT6 / DT8***

DT6: h= 5 x10^{-21}/sqrtHz

1038h => duty cycle 86.5%

DT8: First long-term operation with power recycling

Full-time joint observation with LIGO

h=2.7x10^{-21}/sqrtHz

1158h => duty cycle 81.3%

Summary

- ***Data Analysis using DT6 / DT8 data***

>NS ispirals: Galactic event rate

DT6 R < 0.0095 event/hr (C.L.90%) for 1<*m*<2Msolar

DT8 R < 0.0033 event/hr (C.L.90%) for 1<*m*<3Msolar

>Coincidence analysis between multiple detectors

TAMA300 & LISM (20m)

>Burst search

Rejection of non-gaussian noise by time-scale selection

R = 0.01 event/hr for $h_{rms}>3\times10^{-17}$ (10ms pulse)

>Continuous wave from possible SN1987a remnant

$h < 5 \times 10^{-23}$ (C.L. 90%)

- ***LCGT: Large-scale Cryogenic Gravitational wave Telescope***