Operation of TAMA300 detector

National Astronomical Observatory of Japan

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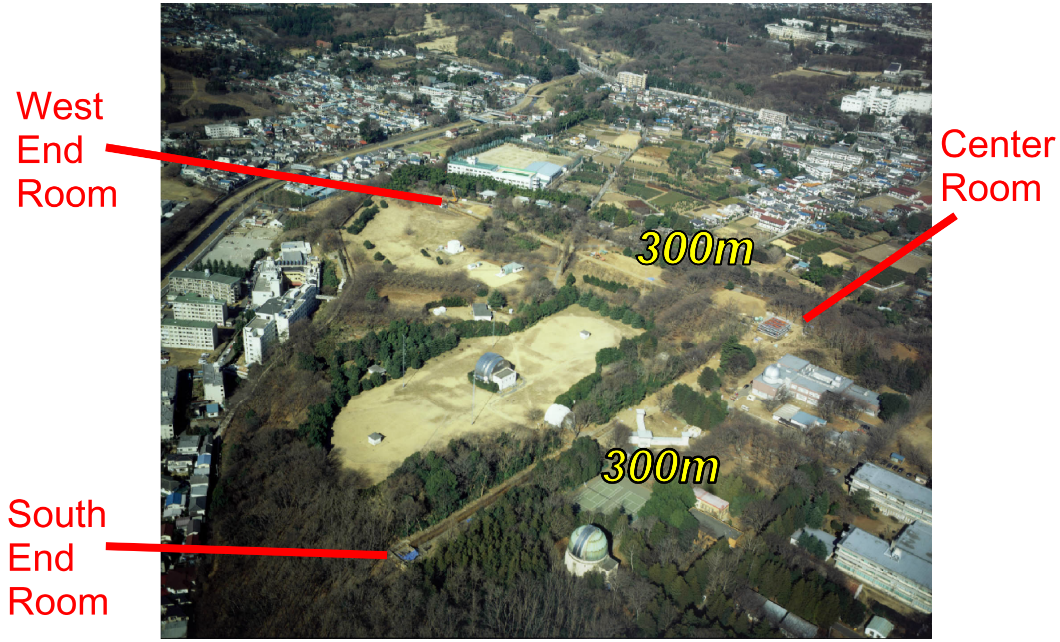
MG10 GW3 session

TAMA300

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

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



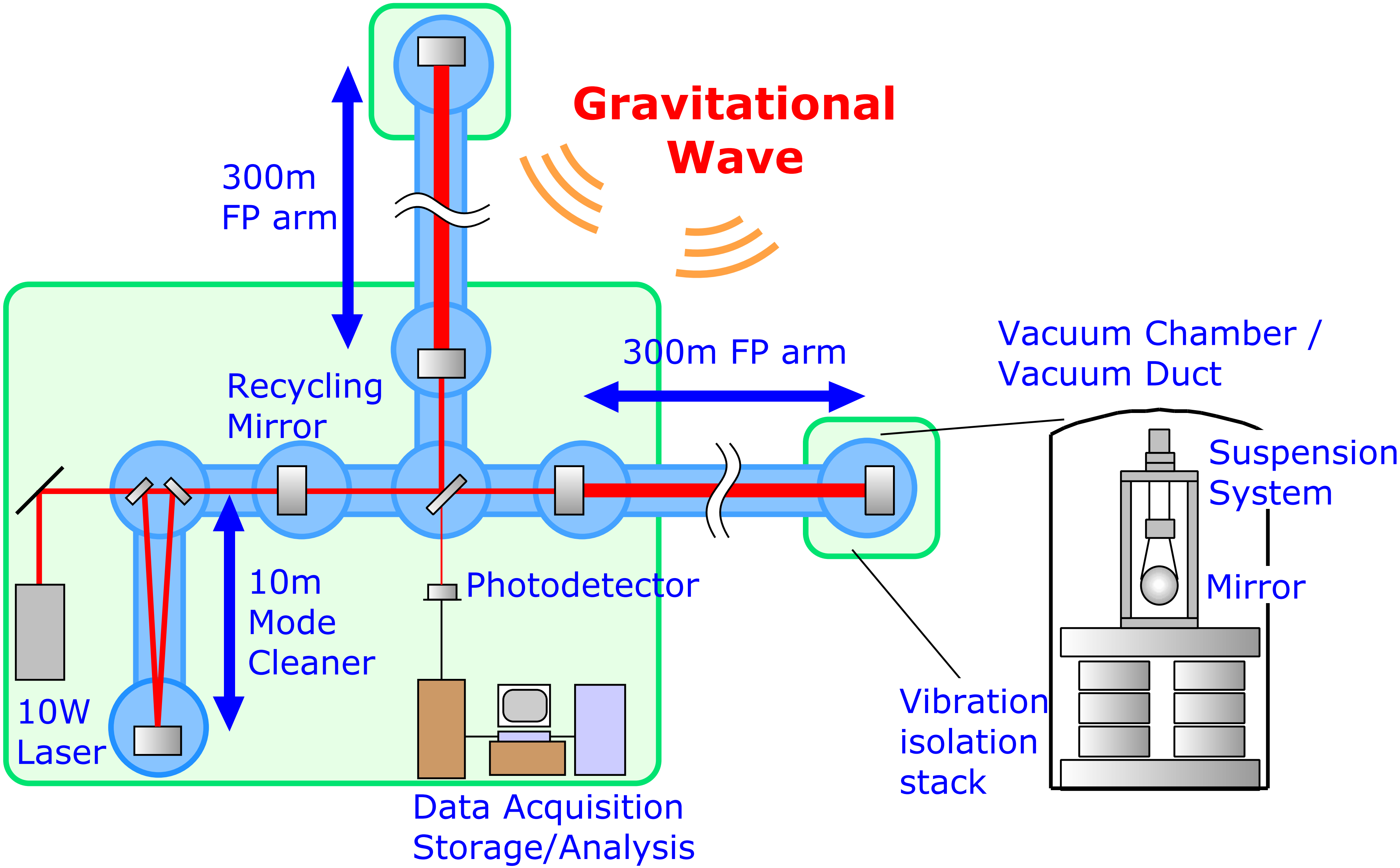
- ***Object of the project***

  To develop a detector capable
  □ to detect GW events
  □ in nearby galaxies.

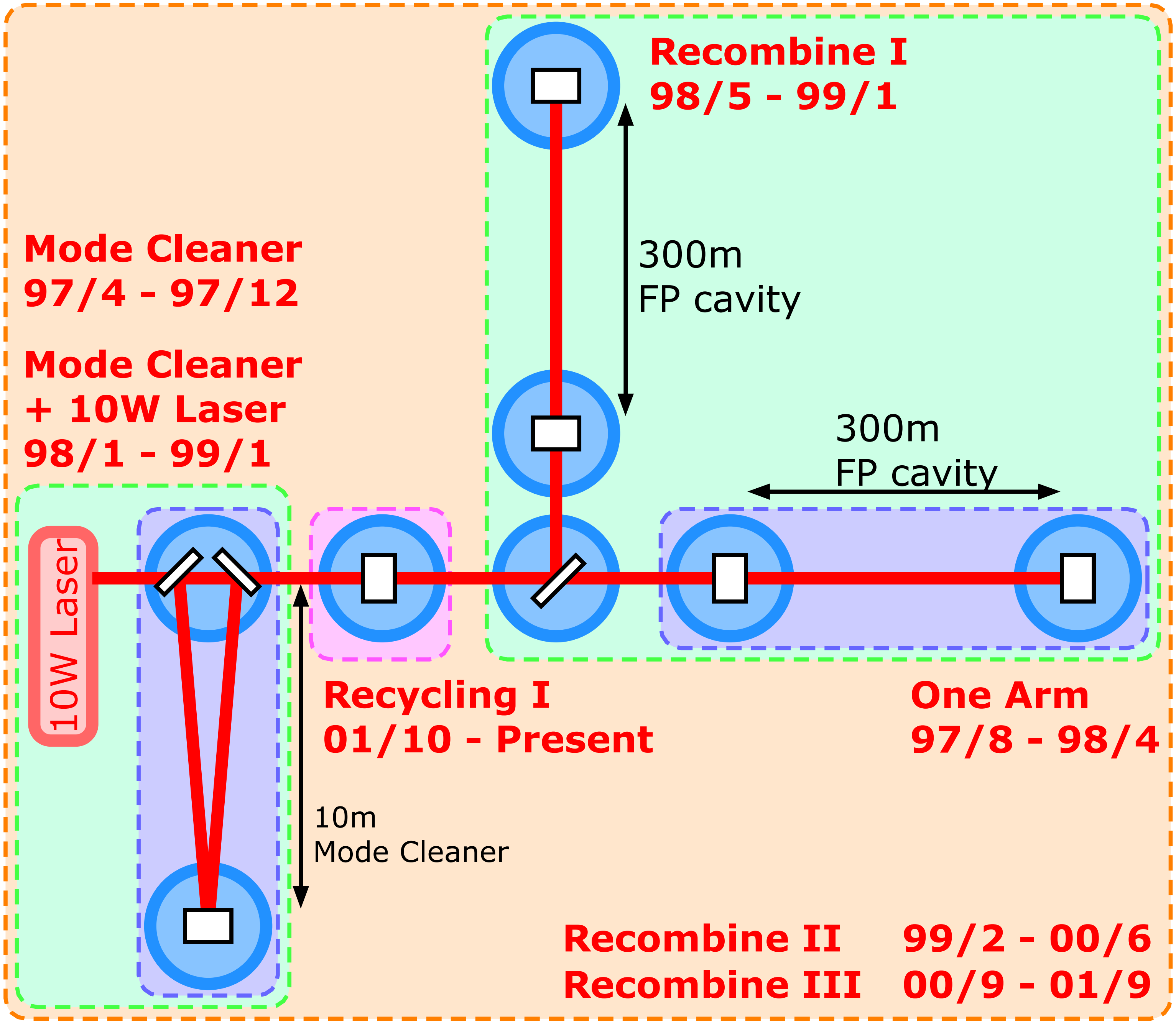
  To establish techniques
  for a future km-class interferometer

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

TAMA300 detector ~ overview



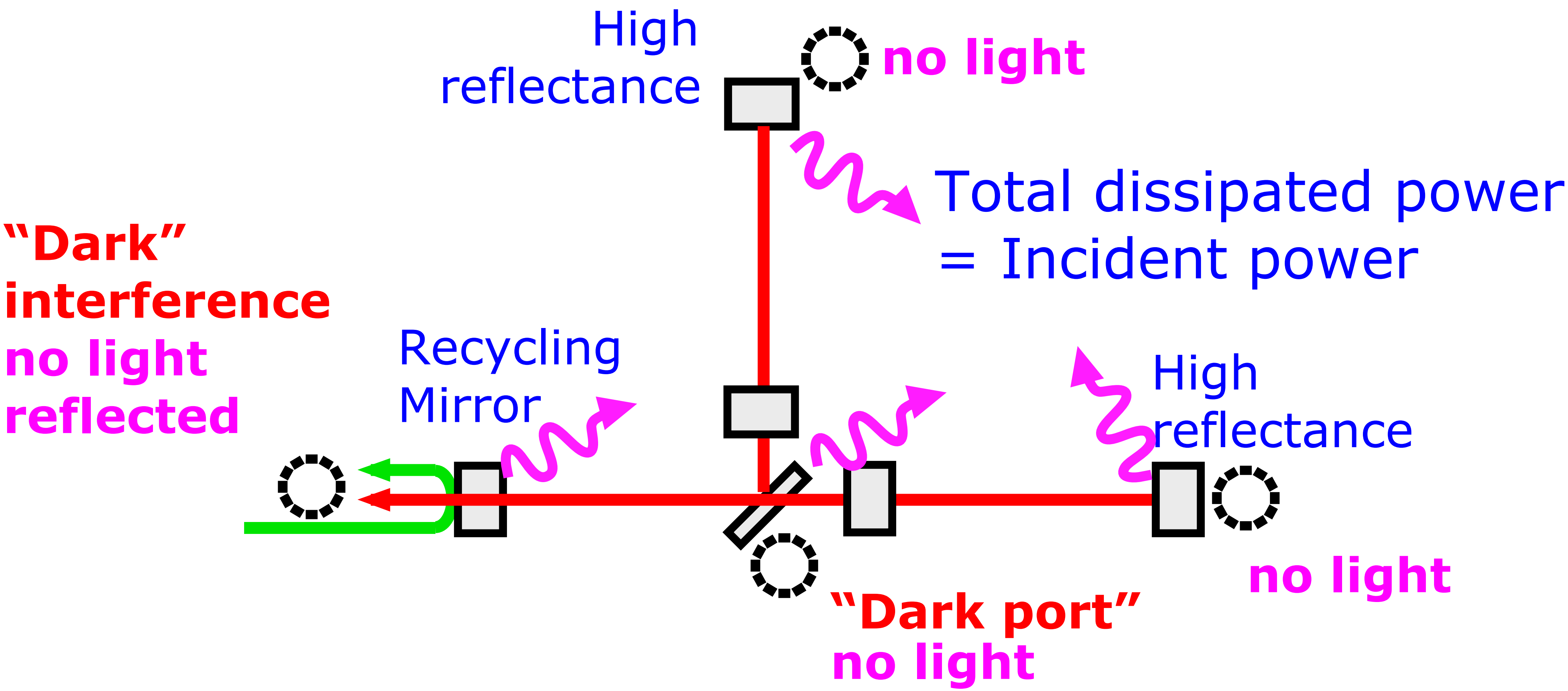
History of TAMA development



1995	Project started	
1996	Facility construction completed	
1997	Vacuum system completed	
1999/8	Data Taking 1	11h
1999/9	Data Taking 2	31h
2000/4	Data Taking 3	13h
2000/8, 9	Data Taking 4	167h
2001/3	Data Taking 5	111h
2001/8,9	Data Taking 6	1038h
2001/10-	Recycling experiment	
2002/8-9	Data Taking 7	25h
2003/2-4	Data Taking 8	1158h

Principle of power recycling

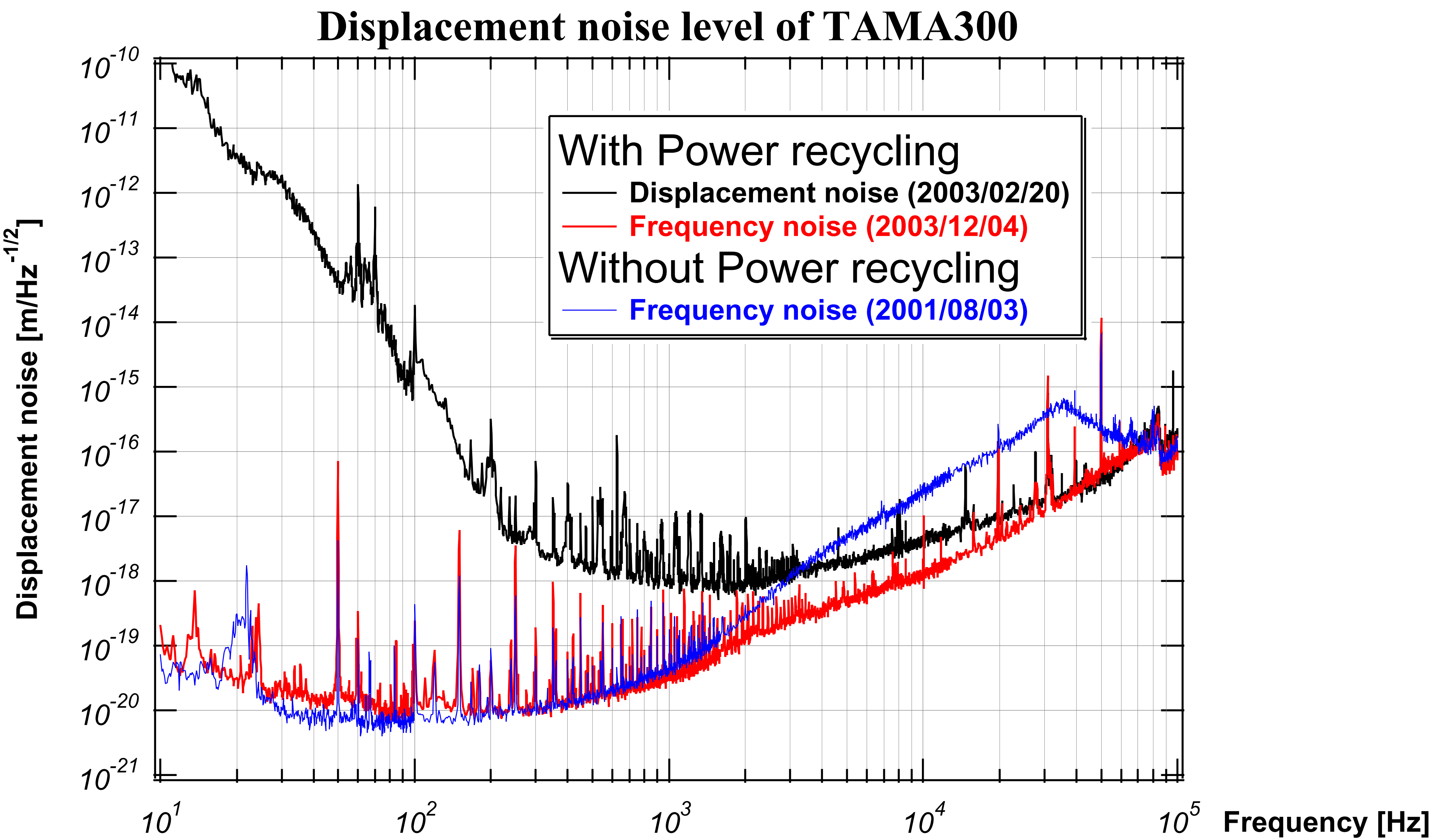
- **Laser light is enclosed in the interferometer**



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

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

Frequency Stabilization



Control bandwidths extended:

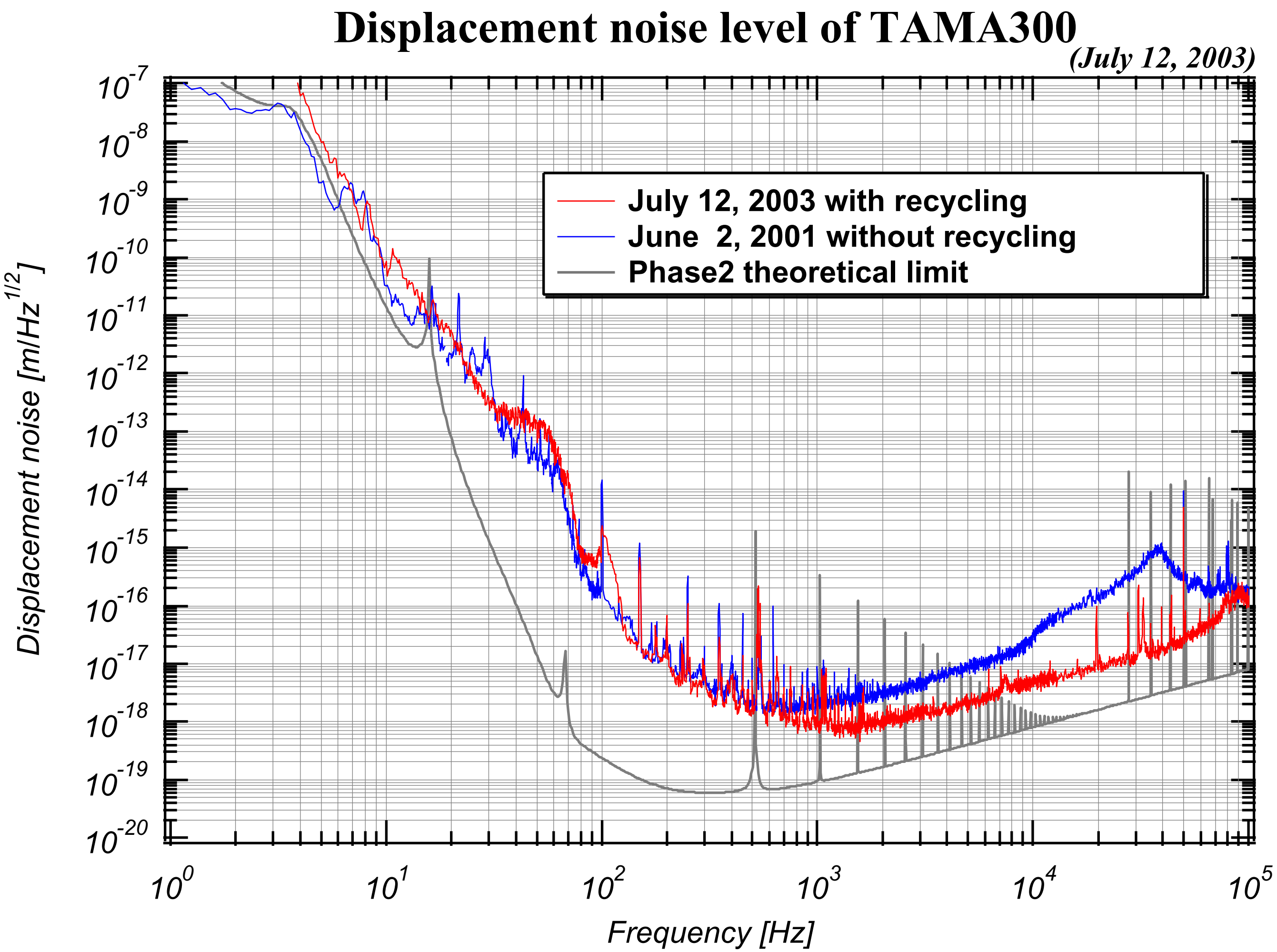
MC servo (300kHz -> 600kHz)

Common-mode servo (20kHz -> 40kHz)

Power recycling

- **Sensitivity improved by power recycling**

Reduction of detector noise, shot noise, and frequency noise

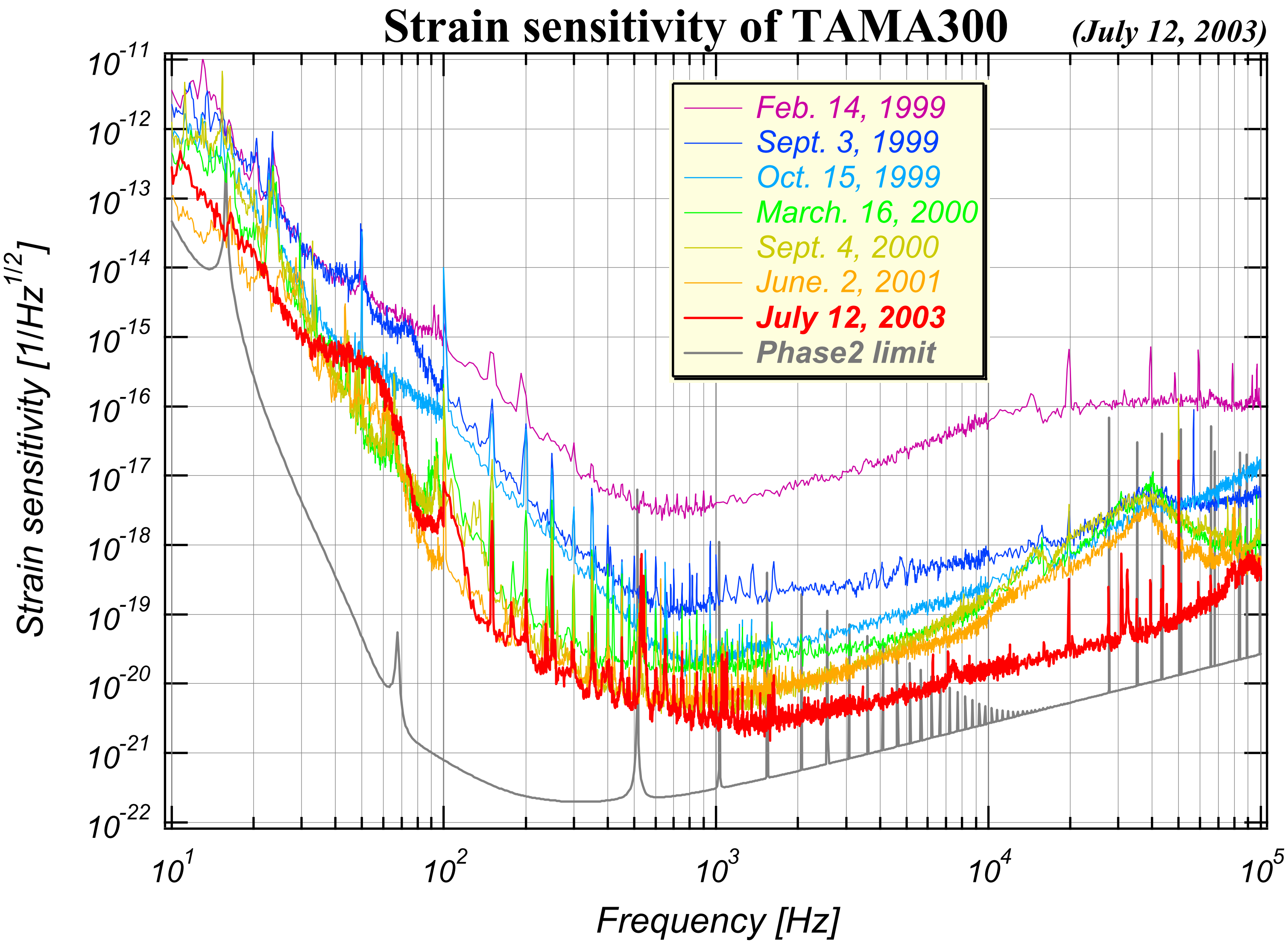


Floor level: 8×10^{-19} m/Hz$^{1/2}$□ (in displacement)

□ □ □ □ 2.7×10^{-21} /Hz$^{1/2}$□□ (in strain)

History of the sensitivity

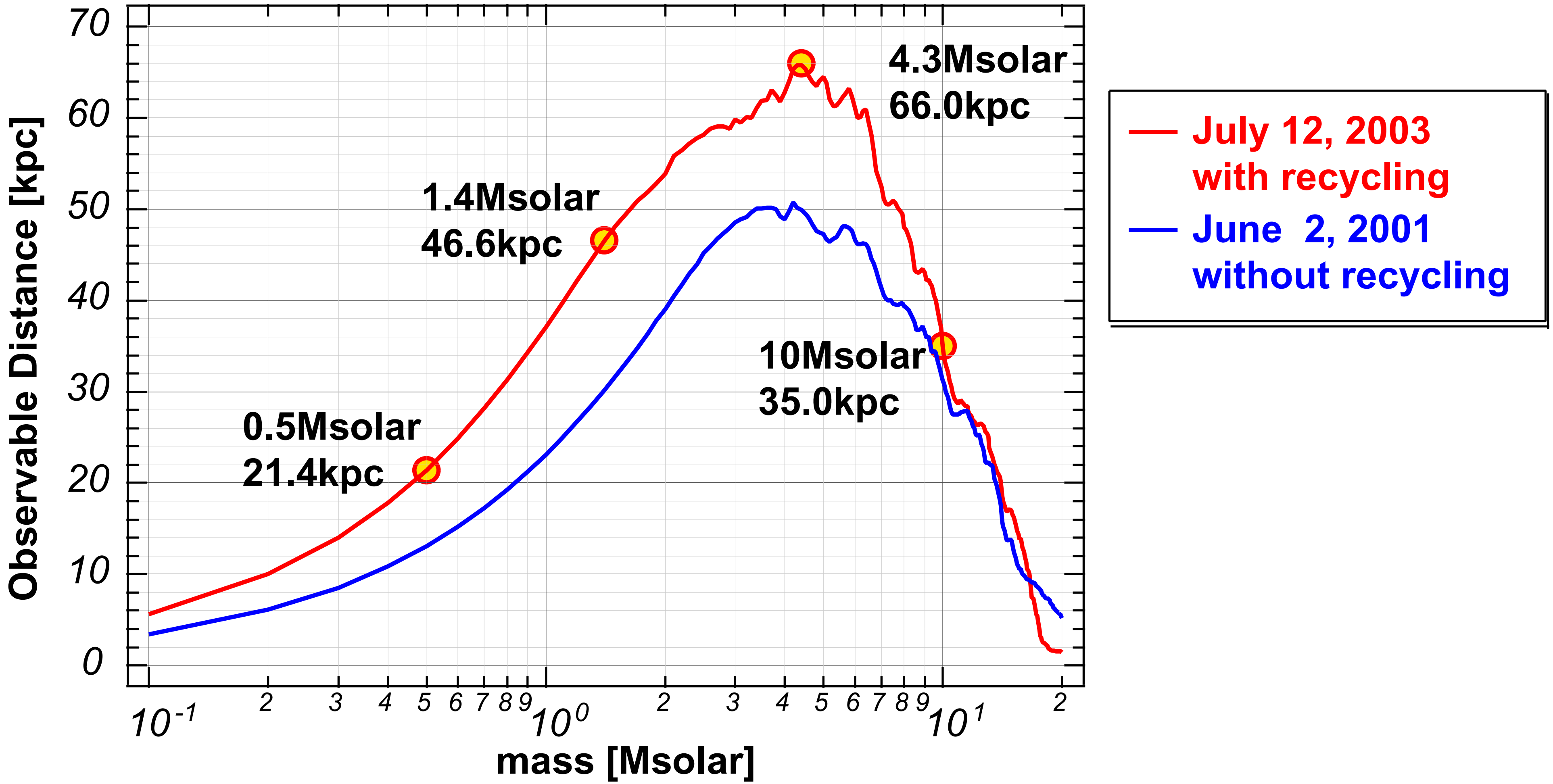
- **Improvement by a factor of 10^3 ~ 10^4**
  ~ operation since 1999



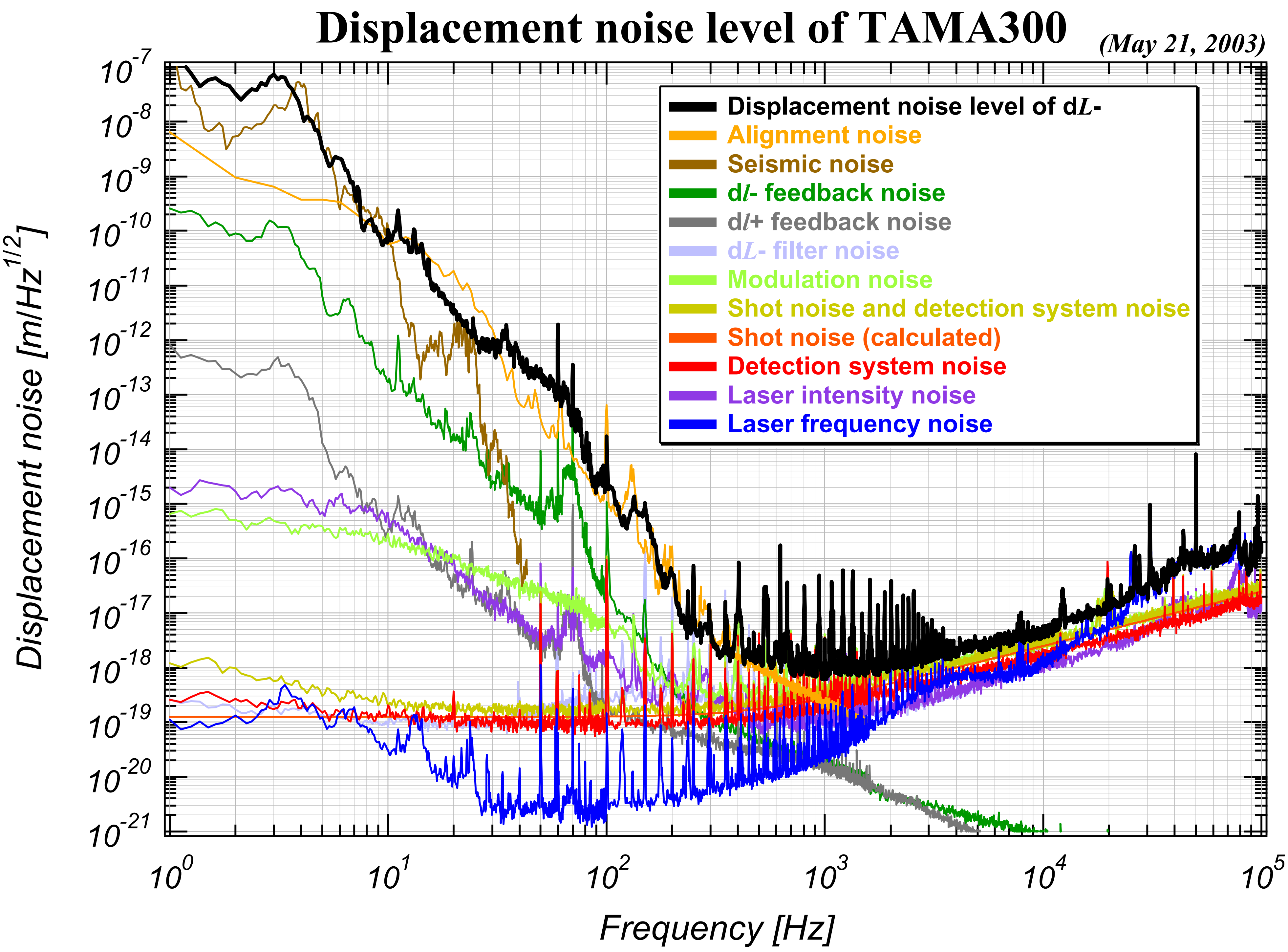
Observable distance

- ## Distance of binary inspirals

  ~ expecting SNR=10, optimal incident angle assumed



Sufficiently sensitive to galactic inspiral events



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

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	**Coincidence**
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**

Data Taking 8 (LIGO S2)

- **DT8 ~ 2 months run (2003/2/14~4/15)**

First full-time joint observation with LIGO

(c.f. DT7: partial participation of TAMA to S1)

First long-term observation with power recycling

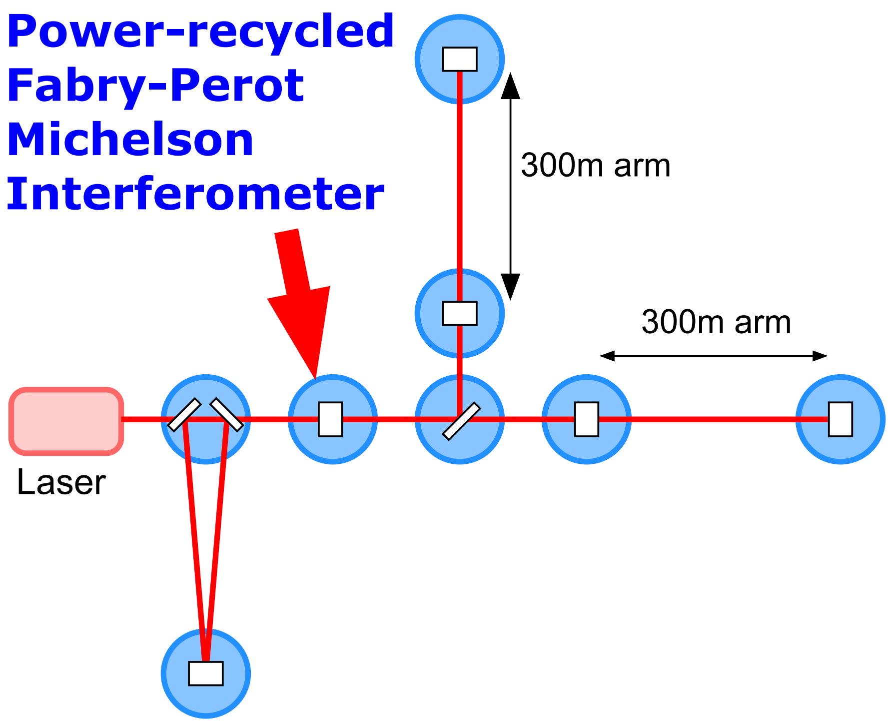
Power recycling of TAMA300 (2001/10~Present)

Power recycling gain of 4.5

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

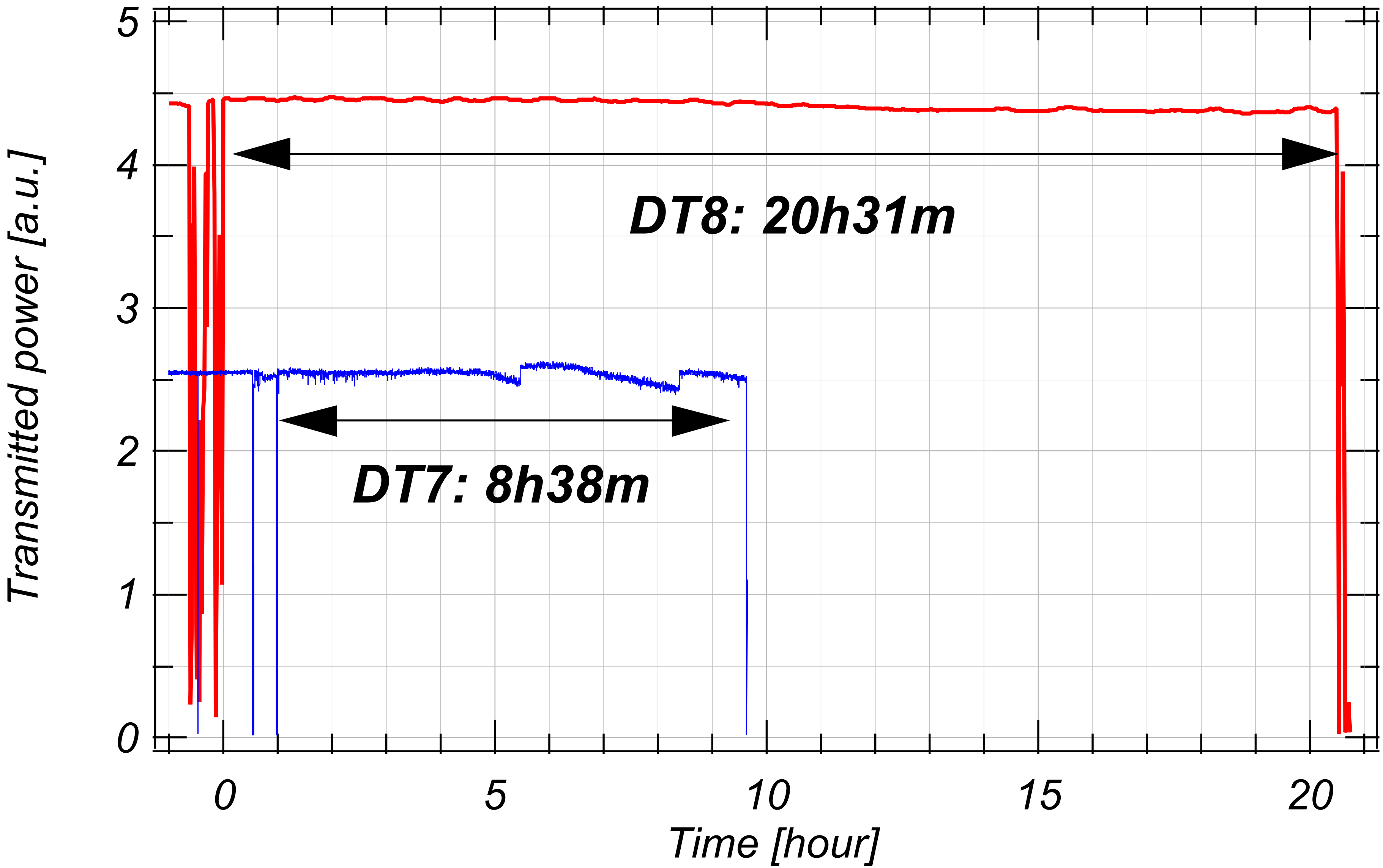
IFO operation

Accumulated data:	1158 hours
Duty cycle:	81.3 %
Longest lock:	20.5 hours



Improved long-term stability

Longest lock stretch in the observations



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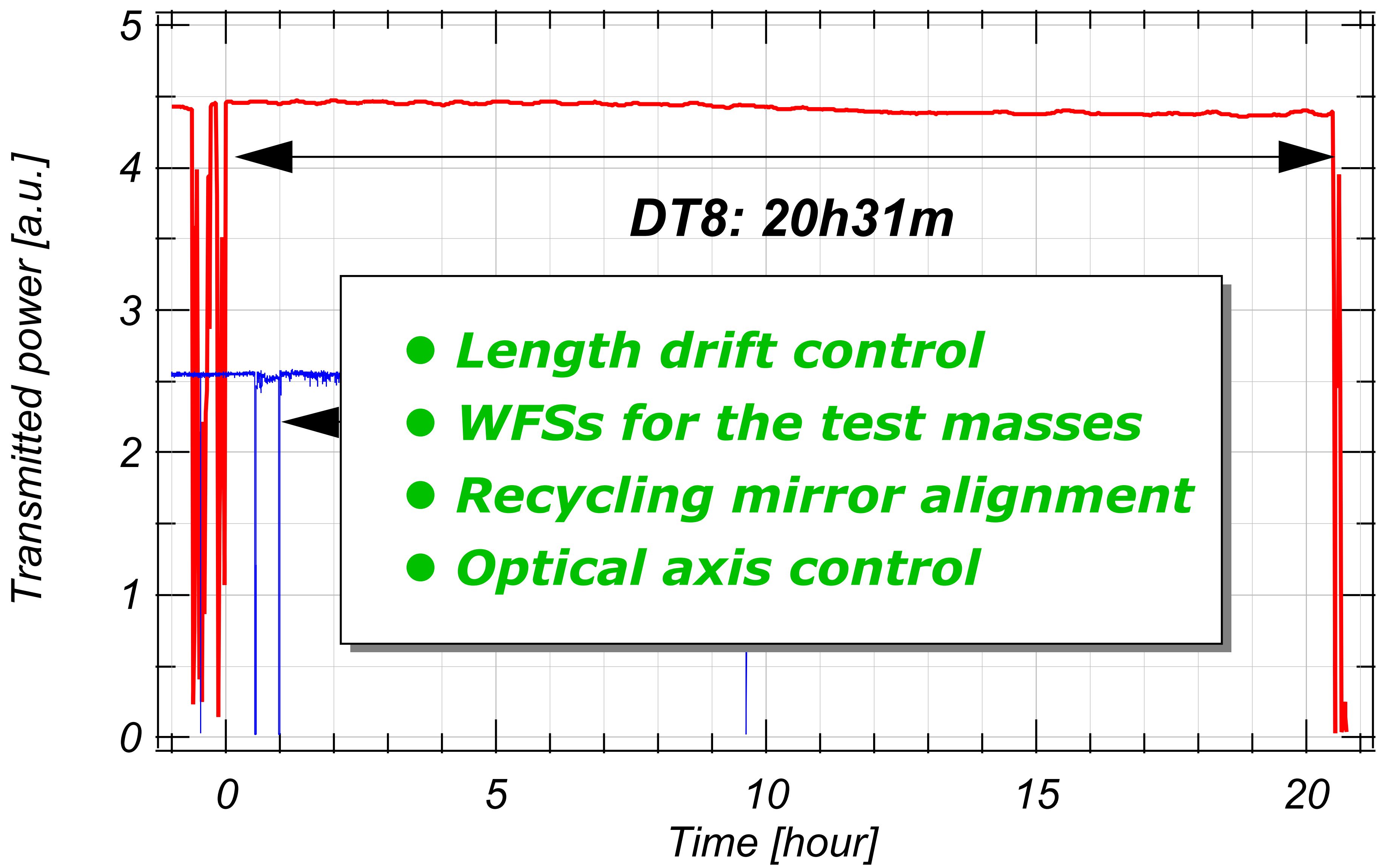
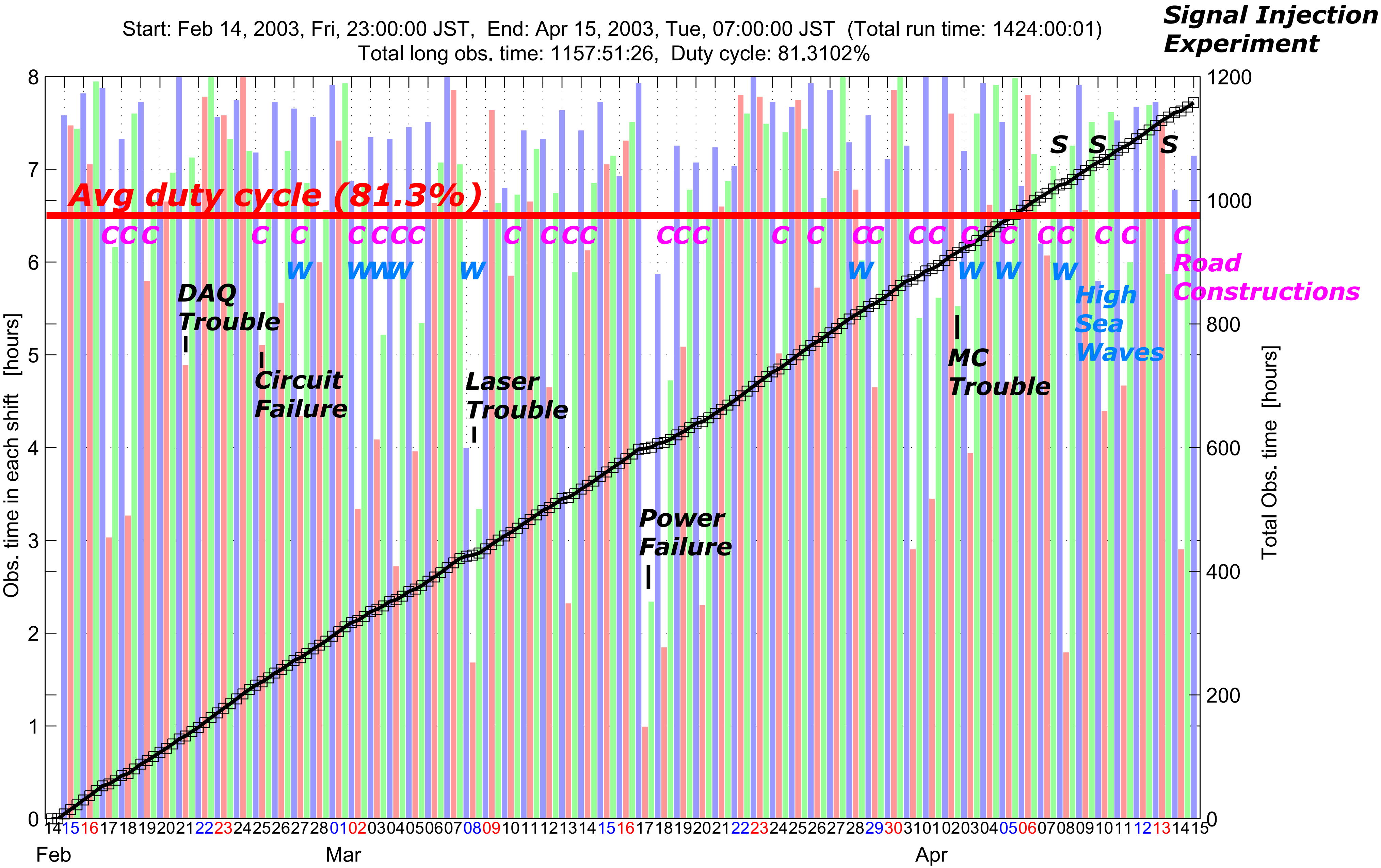


Duty cycle

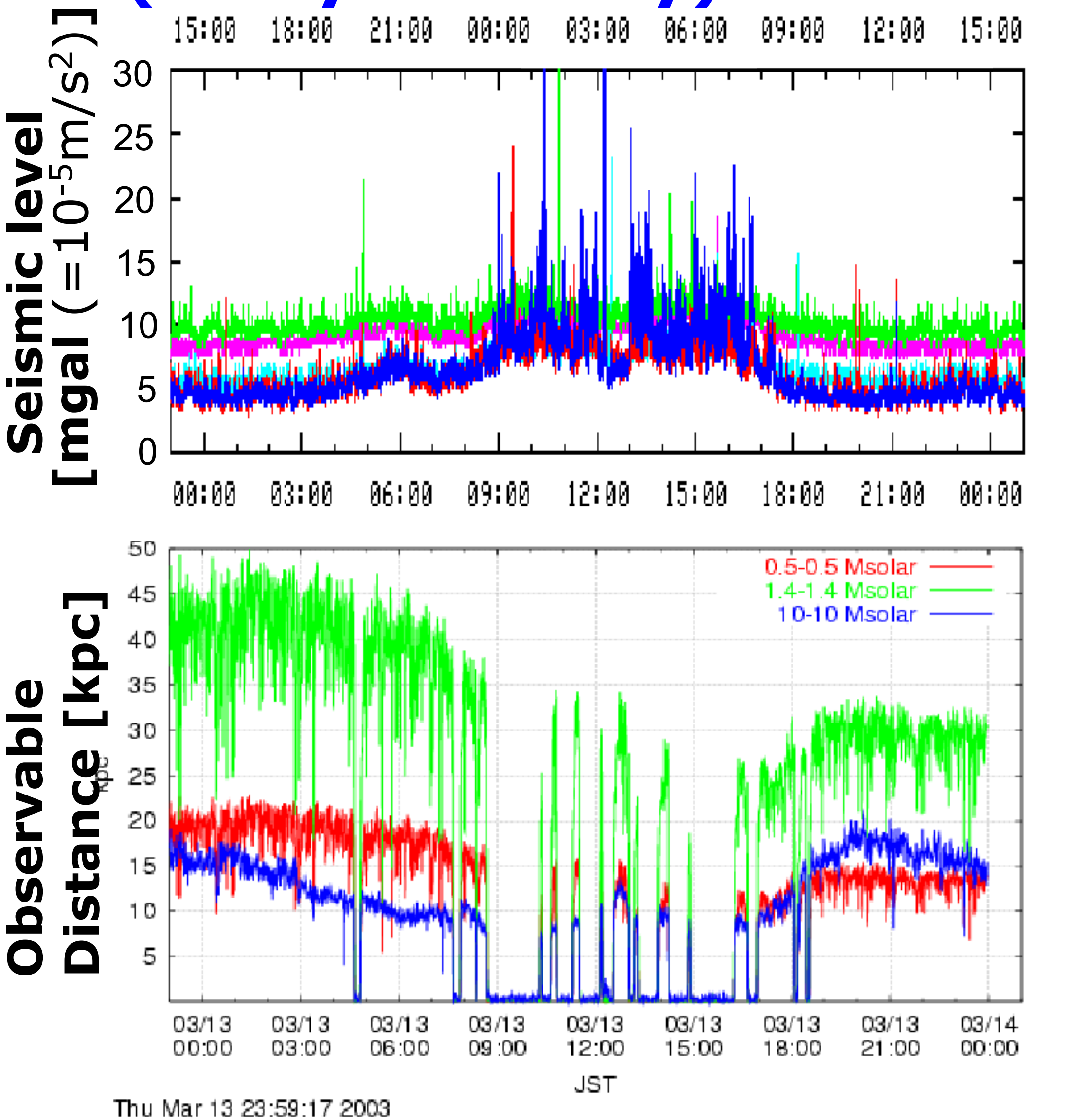
- **1157h51m (out of 1424 hours, duty cycle 81.3%)**



DT8 ~ Disturbance by construction

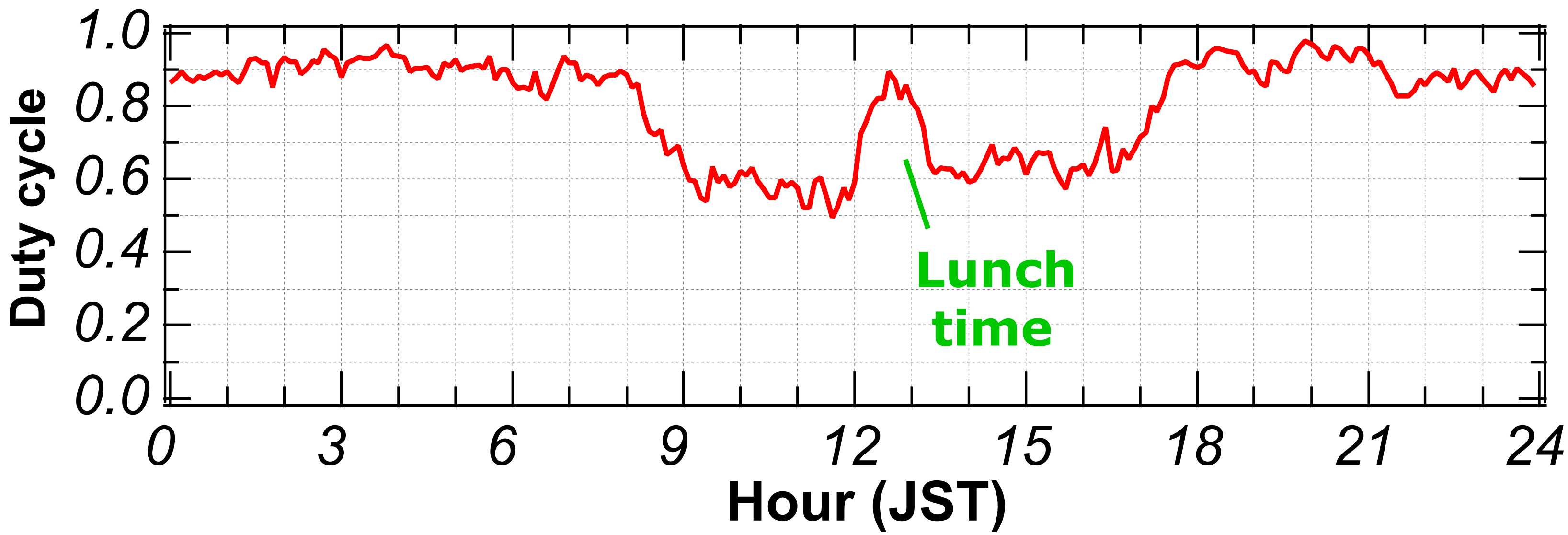
13rd May, 2003 (Thu)

(Noisy weekday)

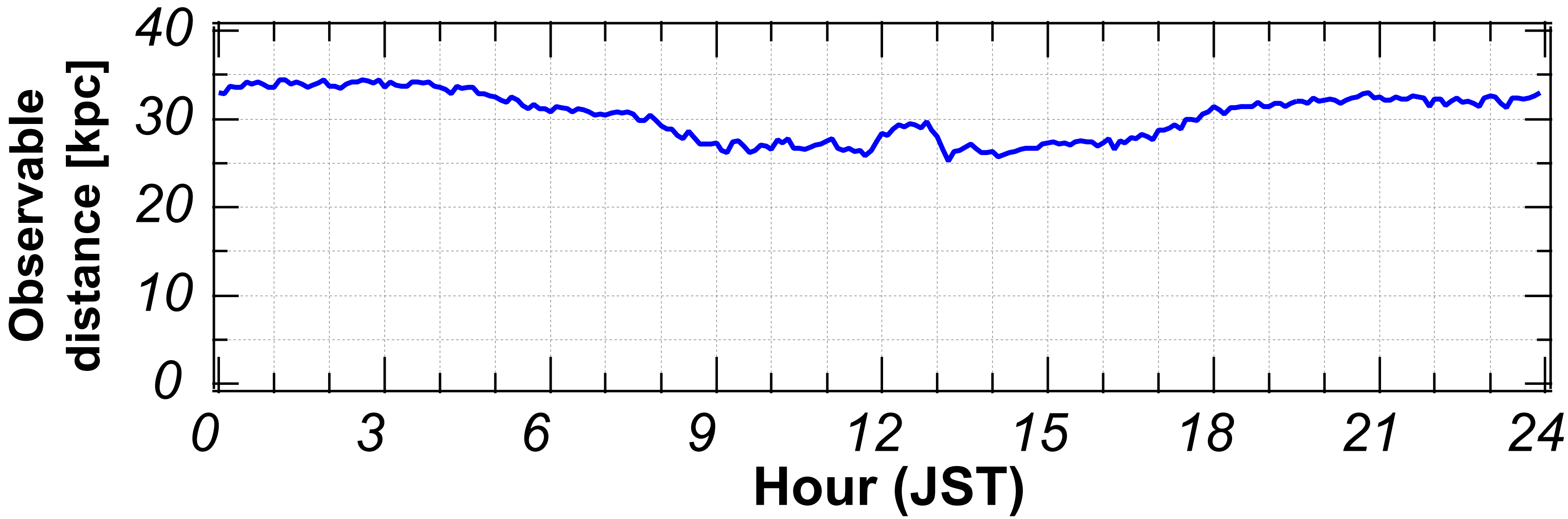


Construction works near the site

Daily trend of duty cycle/sensitivity

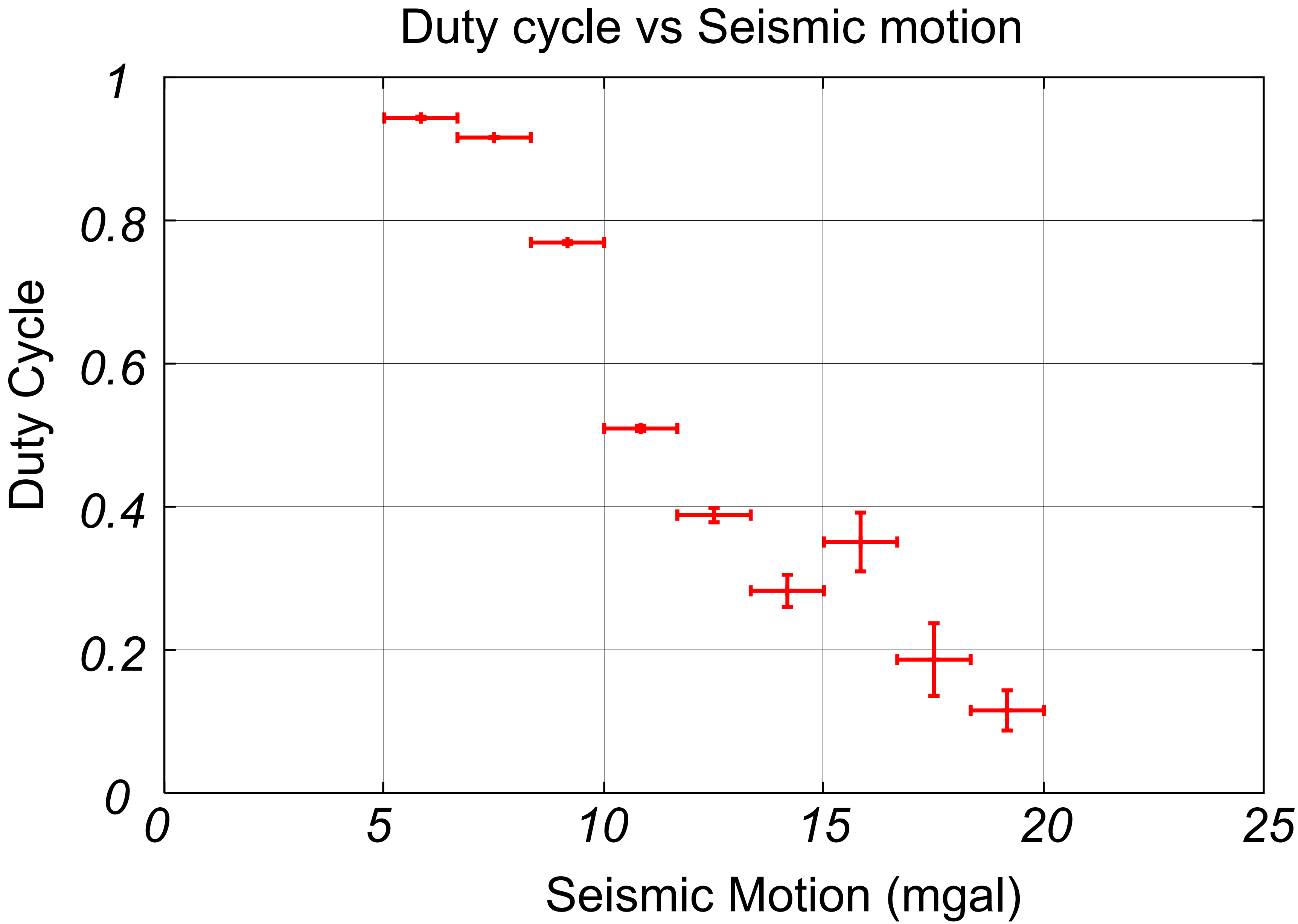


With construction ~ IFO didn't work => Duty cycle about 60%



Even without construction ~ sensitivity reduction of about 20%

Seismic level vs Duty cycle



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 GW from possible SN1987a remnant

Matched Filtering analysis

- Detector outputs: $s(t) = Ah(t) + n(t)$

  $h(t)$: known gravitational waveform (2.5PN template)

  $n(t)$: noise.

- Correlation of the detector output and the template in the frequency domain:

$$\rho(m_1, m_2, t_c, \ldots) = 2\int \frac{\tilde{s}(f)\,\tilde{h}^*(f)}{S_n(f)}\,df$$

- Weighted by $S_n(f)$ noise spectrum density

- Signal to noise ratio $\mathrm{SNR} = \rho / \sqrt{2}$

- Find the optimal parameters

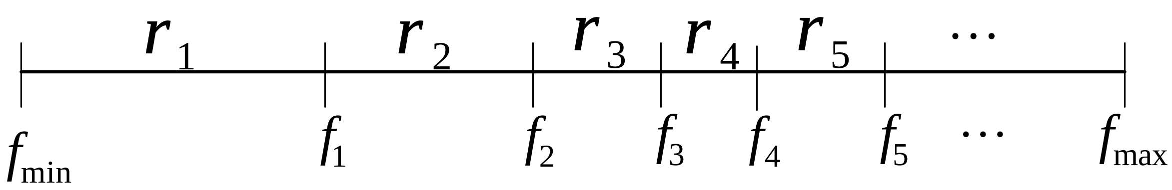
$$m_1, m_2, t_c, \ldots$$

  in a data chunk which maximizes ρ

c^2 test

Divide frequency region into bins.
Test whether the contribution to r from each bins agree with that expected from chirp signal

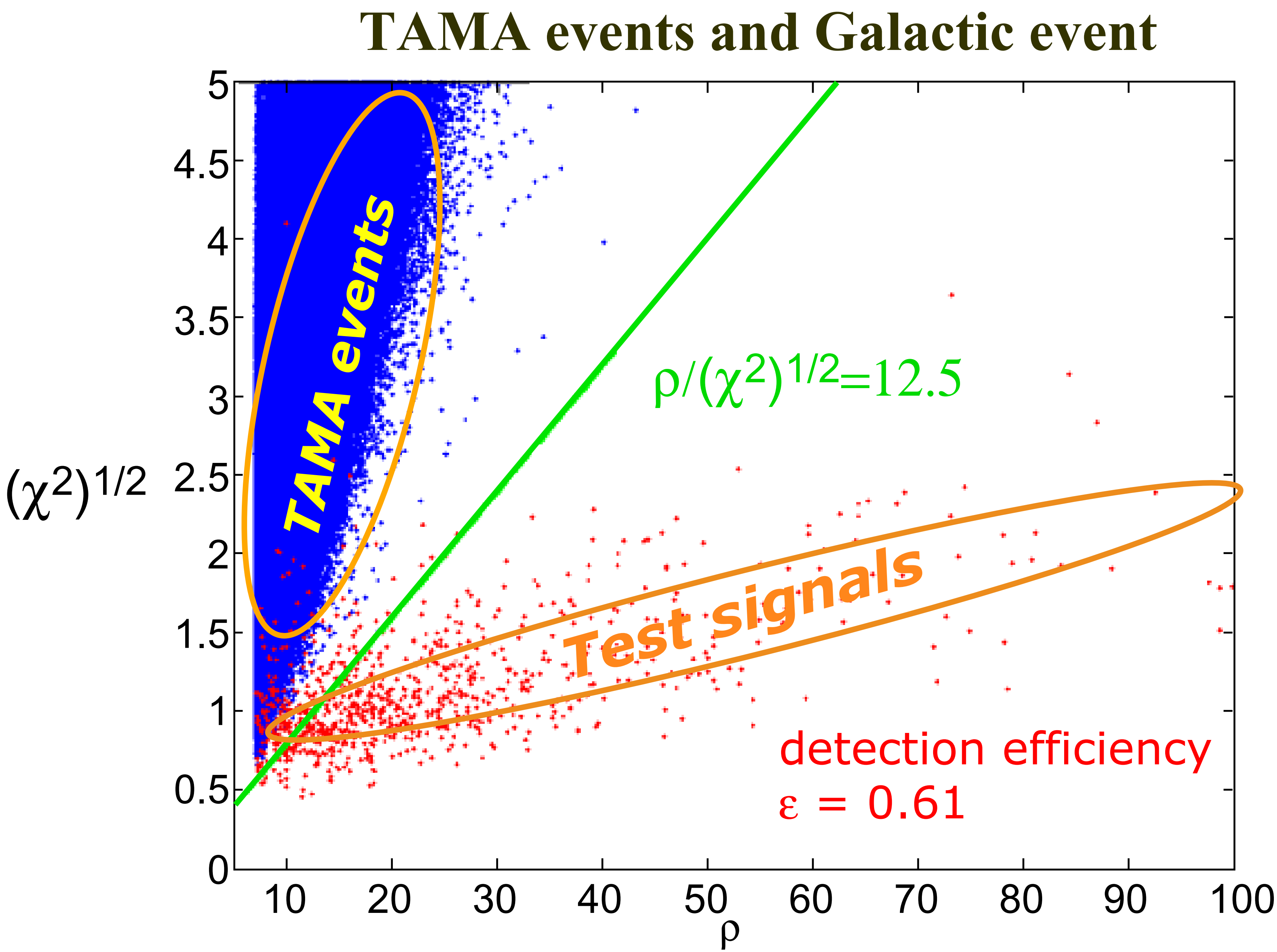
$$r \equiv (s, h) \quad \left(= 2\int \frac{\tilde{s}(f)\tilde{h}^*(f)}{S_n(f)}\, df \right)$$



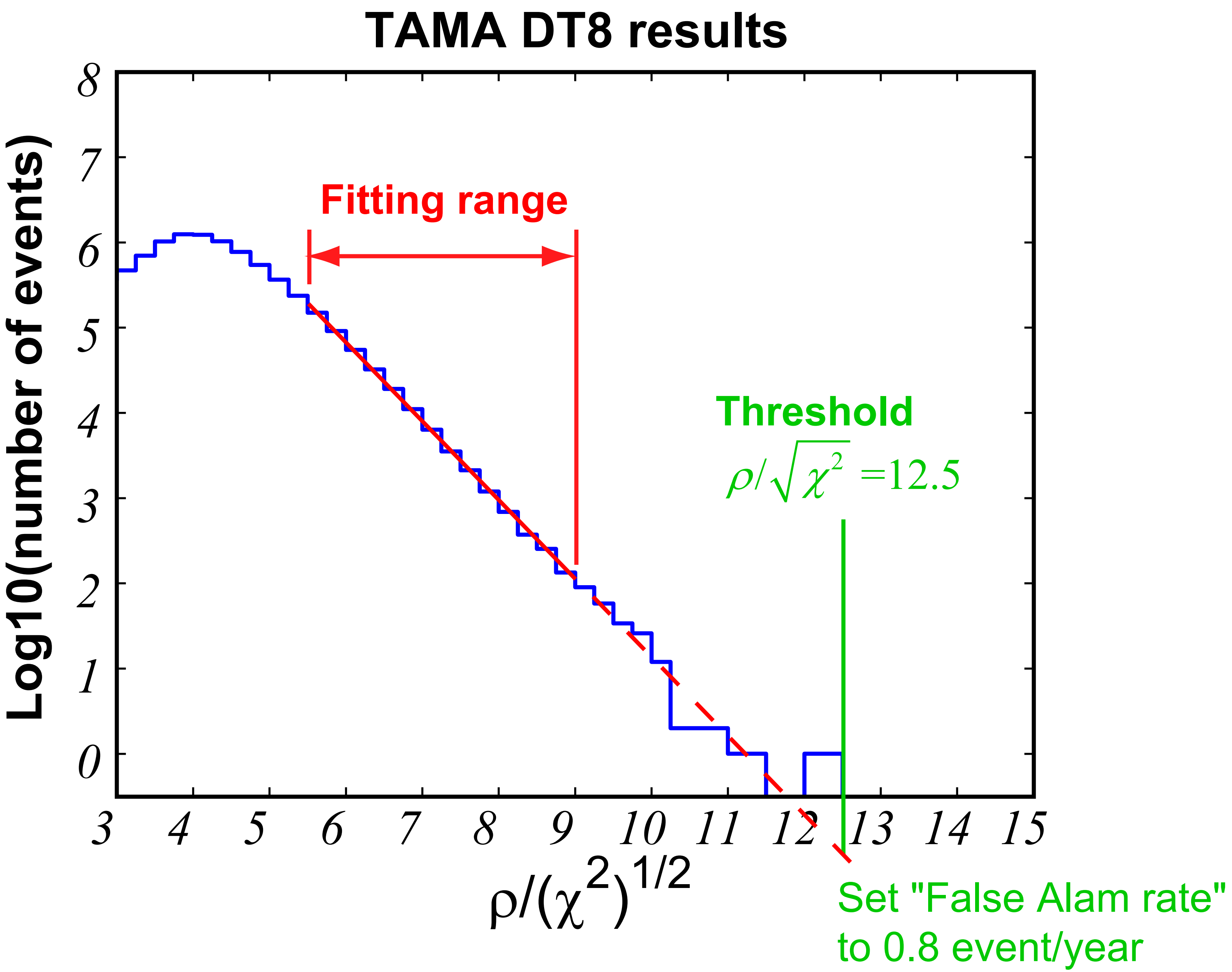
$$c^2 \equiv \sum \frac{1}{s_i^2}(r_i - \bar{r}_i)^2$$

$$s_i^2 \equiv \left\langle (r_i - \bar{r}_i)^2 \right\rangle, \quad \bar{r}_i = \left\langle r_i \right\rangle$$

Event distrib. / detection efficiency



Event distribution / threshold



Upper limit to the Galactic NS merger

- ***Observation time***

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

  1039 hours for DT6

- ***Event threshold***

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

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

- ***Detection efficiency***

  $\varepsilon = 0.61$ (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]

= **$2.9\text{x}10^1$** [event/yr]

for 1.0 Msolar < m_1, m_2 < 3.0Msolar

For DT6

=**0.0095** [1/hr]

=**$8.3\text{x}10^1$** [1/yr]

1 < m < 2Msolar

Future Plan

- ***Data Analysis of the DT8 data other than NS inspirals***
  In progress
- ***Investigation on the noise issues***
  In particular, noises between 100Hz and 1kHz.
- ***Further automation of the observation***
  To operate the interferometer with less operators
- ***Upgrade of the vibration isolation system***
  Seismic attenuation system (SAS)
    Isolation from low frequency (~0.1Hz)
    R&D with Caltech and Univ. of Pisa
    Installation in early 2005
- ***More power in the arms***
  High gain (G=10) recycling

Summary

- ***Interferometric GW detector TAMA300***
- ***Data Taking 8***

  Full-time joint observation with LIGO

  First long-term operation with power recycling

  With improved sensitivity by power recycling

  $h = 2.7 \times 10^{-21}$ /sqrtHz @1.5kHz

  1158 hours of 1424 hours => duty cycle 81.3%

- ***Data Analysis using DT8 data***

  NS ispirals: Galactic event rate

  R < 0.0033 event/hr (C.L.90%)

  for 1.0 Msolar < m_1, m_2 < 3.0Msolar