KEKセミナー　　2004.5.7
「高エネルギー物理学と宇宙像」

重力波実験と精密重力実験
その一

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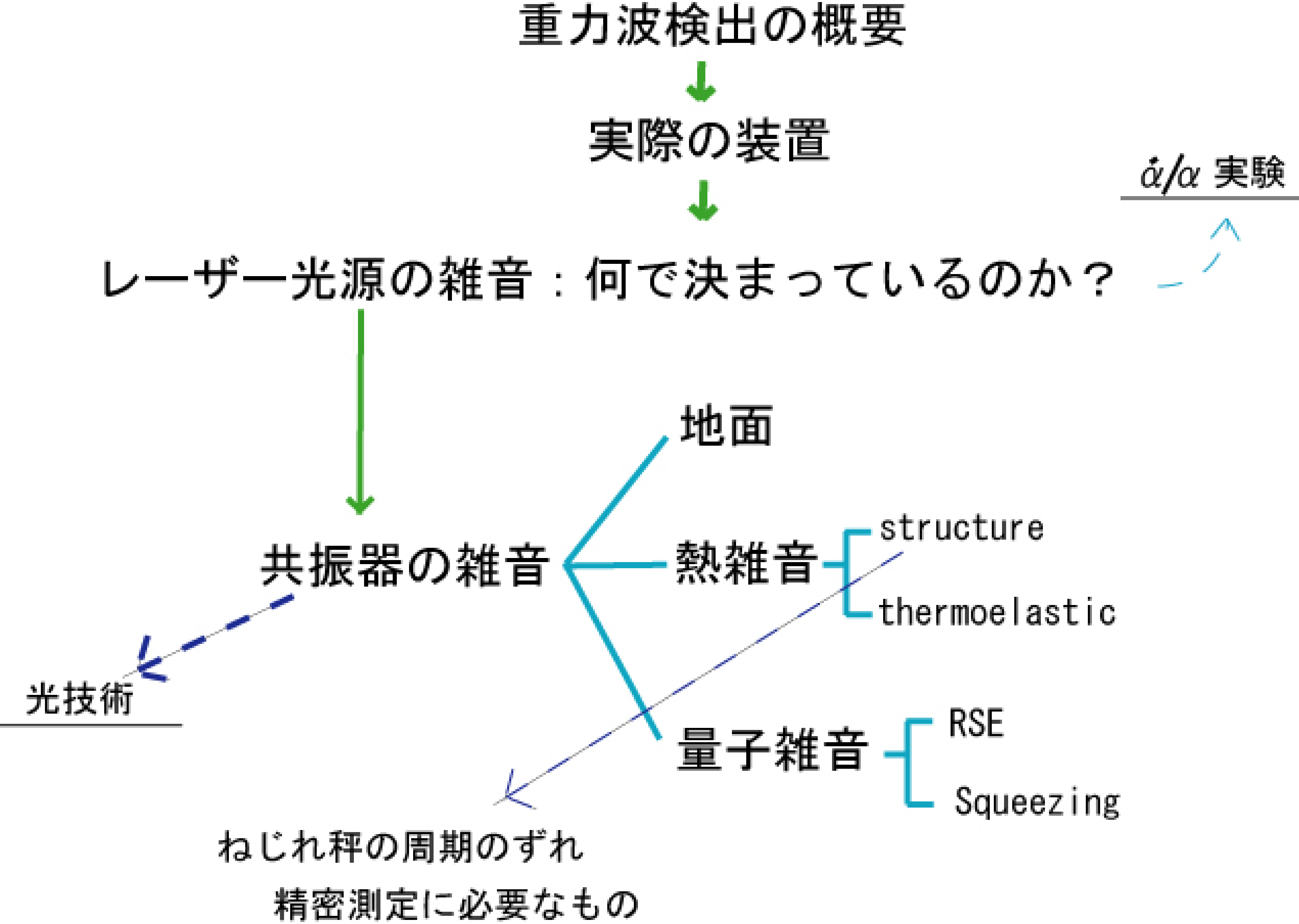
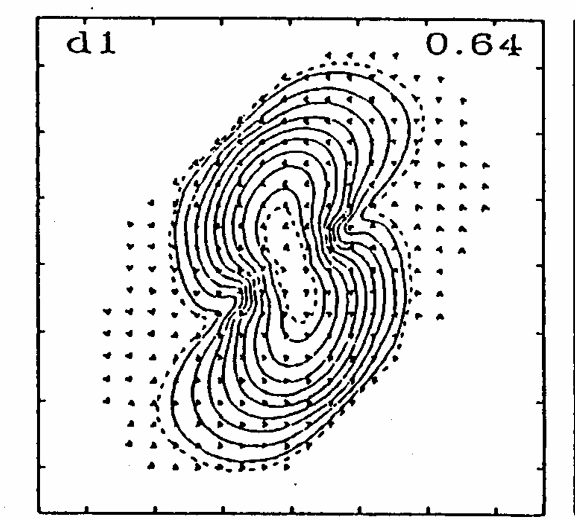
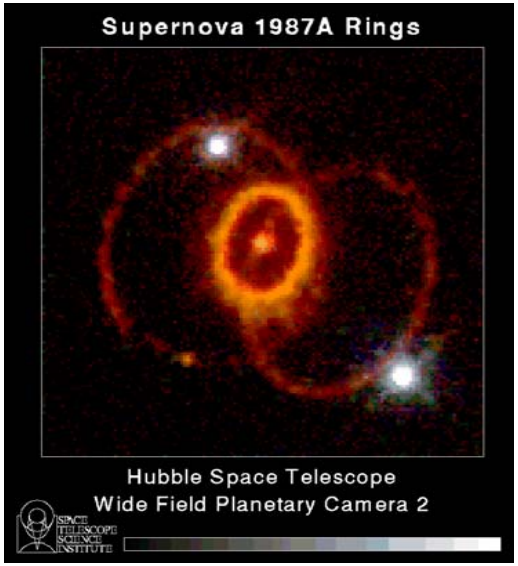

重力波検出の概要
実際の装置
α̇/α 実験
レーザー光源の雑音：何で決まっているのか？
地面
共振器の雑音
熱雑音
structure
thermoelastic
光技術
量子雑音
RSE
Squeezing
ねじれ秤の周期のずれ
精密測定に必要なもの

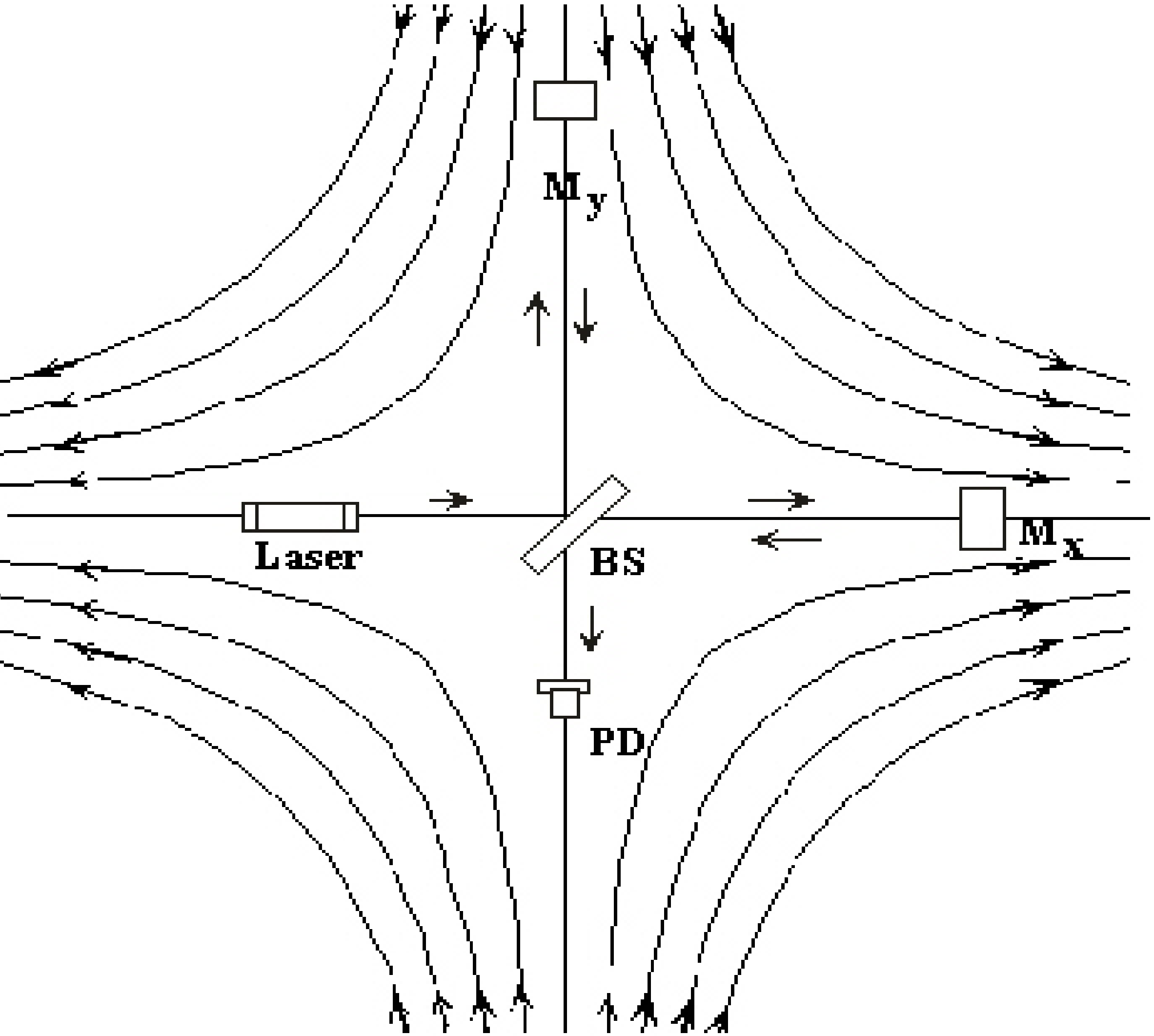
Sources of Gravitational Wave (GW)

- Coalescence of binary neutron stars
- Supernova explosion
- Coalescence of binary black holes
- Falling stars into black holes
- Spinning neutron star
- Orbiting binary stars
- Cosmological background
- Vibration of a cosmic string





When GW passes through space where two masses are placed, a distance between them changes.

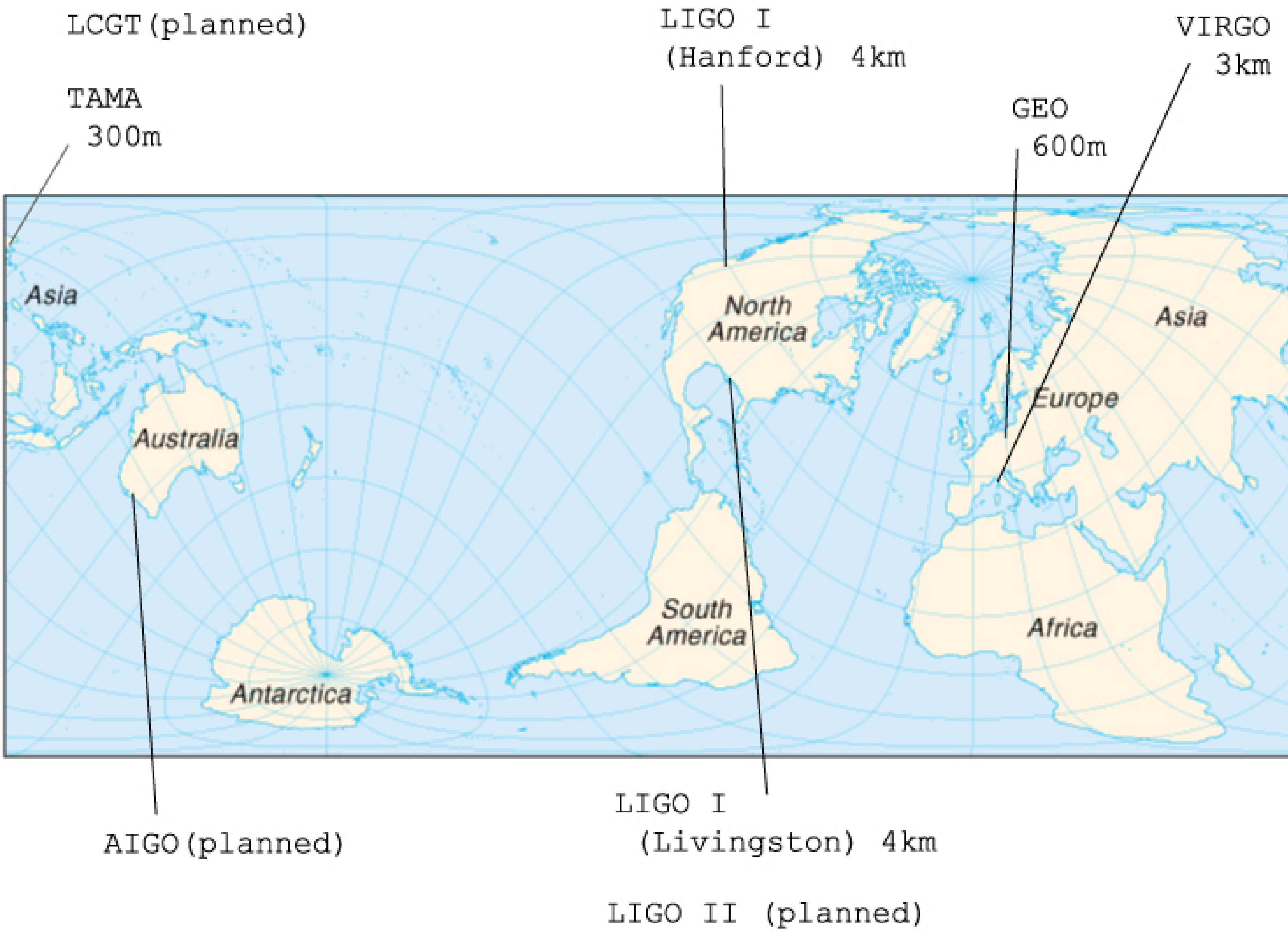


- Suspended mirror (Mx) and suspended beam splitter (BS) behave as test masses for GW
- Michelson Interferometer measures differential displacement between two arms in optical phase
- Typical magnitude of the event at Virgo cluster is 10^{-14} rad, 10^{-18} m for 1km baseline
- To increase phase sensitivity, optical path is folded many times using Delay-Line, Fabry-Perot, and so on

Definition of Sensitivity

- change of each arm δL_1、δL_2 $\quad x = \delta L_1 - \delta L_2$
- distorsion $\quad h = x / L$
- noise：
  Power spectrum $S_x(f)$ $\quad \langle x^2 \rangle = \int_0^\infty S_x(f)\,df$
- Displacement noise $\quad x_n(f) = \sqrt{S_x(f)} \quad [\mathrm{m}/\sqrt{\mathrm{Hz}}]$
- Distorsion noise $\quad h_n(f) = x_n(f)/L \quad [1/\sqrt{\mathrm{Hz}}]$
- Integral sensitivity $\quad h_{rms}(f) = h_n(f)\sqrt{f}$

Several projects on the Earth are ongoing



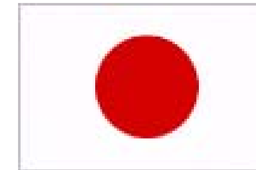
海外の状況

LIGO
(Washington, Louisiana, 4km 2基)
LIGO(I)は2002年に装置完成後、2003－2004年で感度調整の後、観測，2005年－2007年にLIGO(II)への改造予定.

VIRGO （Pisa，3km）
2002年9月完成予定が2004年夏完成見込み．完成後感度調整.
EGOへ拡張

GEO（Hannover，600m）
2001年完成後、2002-2003年感度調整後、観測開始.

TAMA



The Objective of TAMA is to develop advanced technologies for km scale interferometer and to observe possible GW events in our Galaxy.

The funding originally covered five years. We began its construction in April of 1995. It ended in March, 2002 after two years extension. Four year research money was approved from April, 2002.

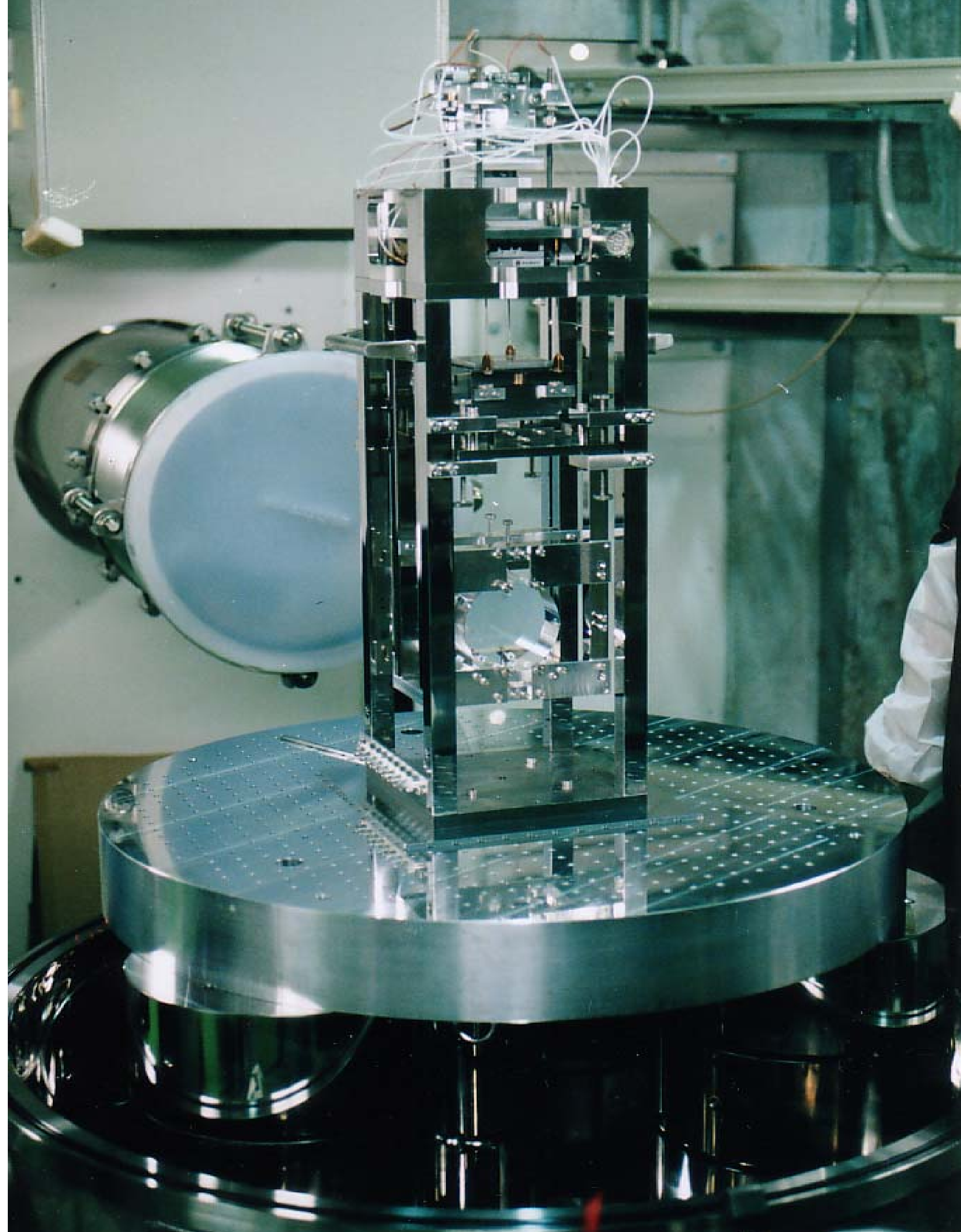
Parameters of TAMA

- Fabry-Perot-Michelson (power recycling)
  - Finesse 516, Power Recycling Gain 10
  - Arm length 300m
- Light source LD-pumped Nd:YAG laser
  - Output power 10W, Wavelength 1064nm
- Mode cleaner
  - Ring type, 9.75m, Finesse 1700
- Vibration Isolation
  - Active isolation system, Stack, Double suspension sys.
- Data acquisition
  - 16bit, 20kHz, 8chs.
- Vaccum system
  - $<10^{-6}$Pa

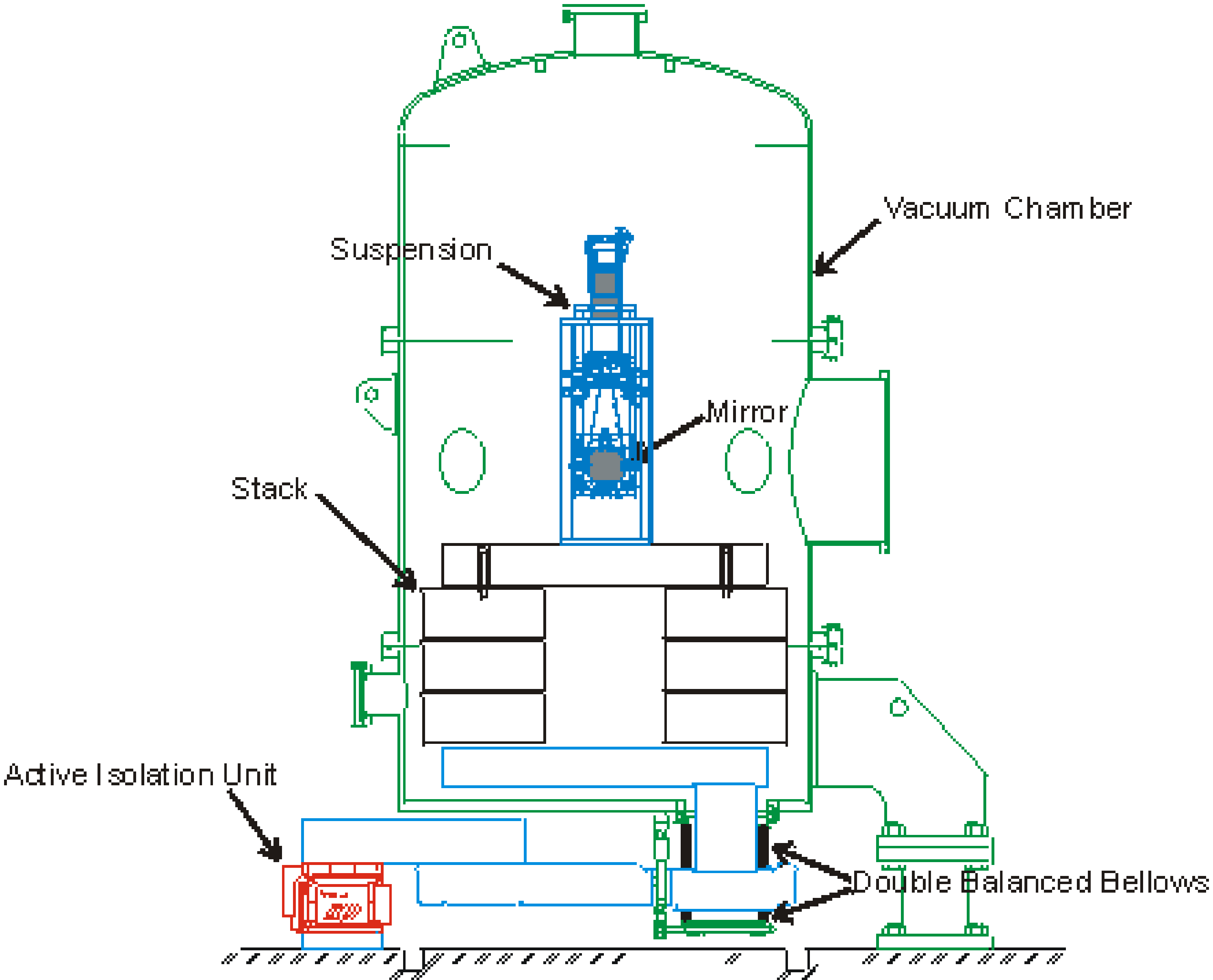
300m Vacuum Duct

Double suspension with magnet damping

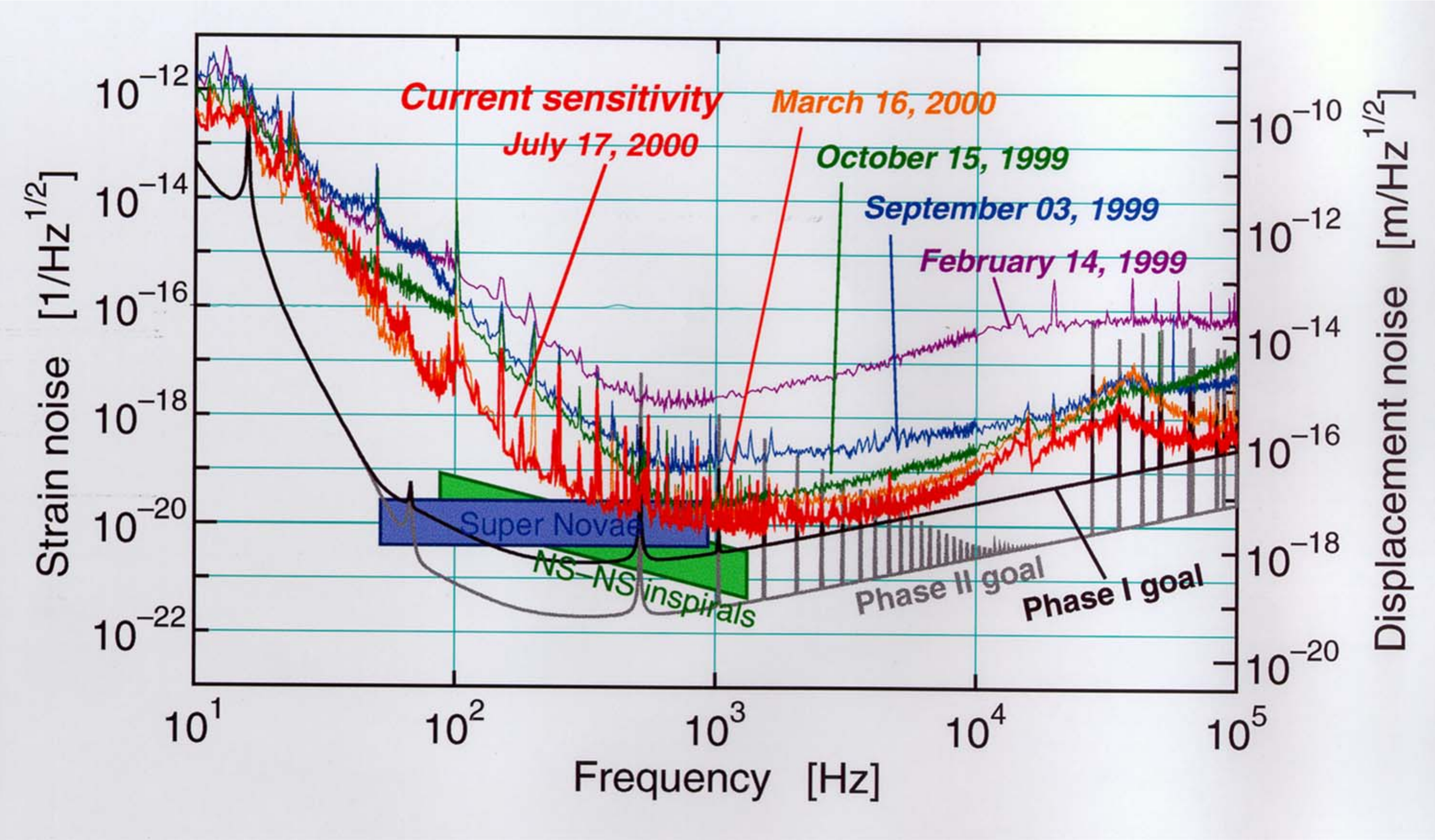
- All suspension system adopts the identical structure
- Low contamination vacuum material



Active isolation system was introduced in 1998

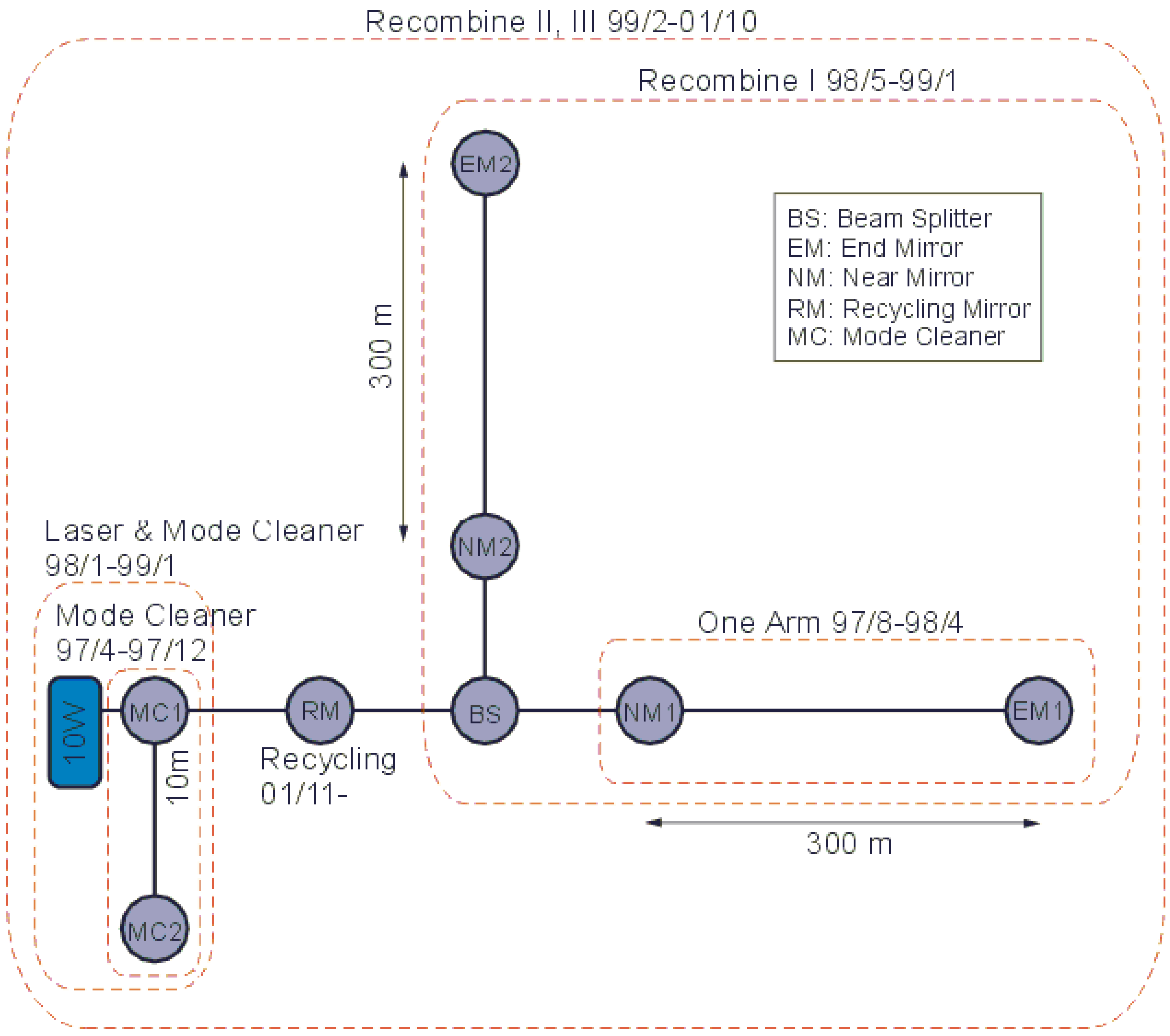


Sensitivity improvement before RM installation (DT1 → DT6)

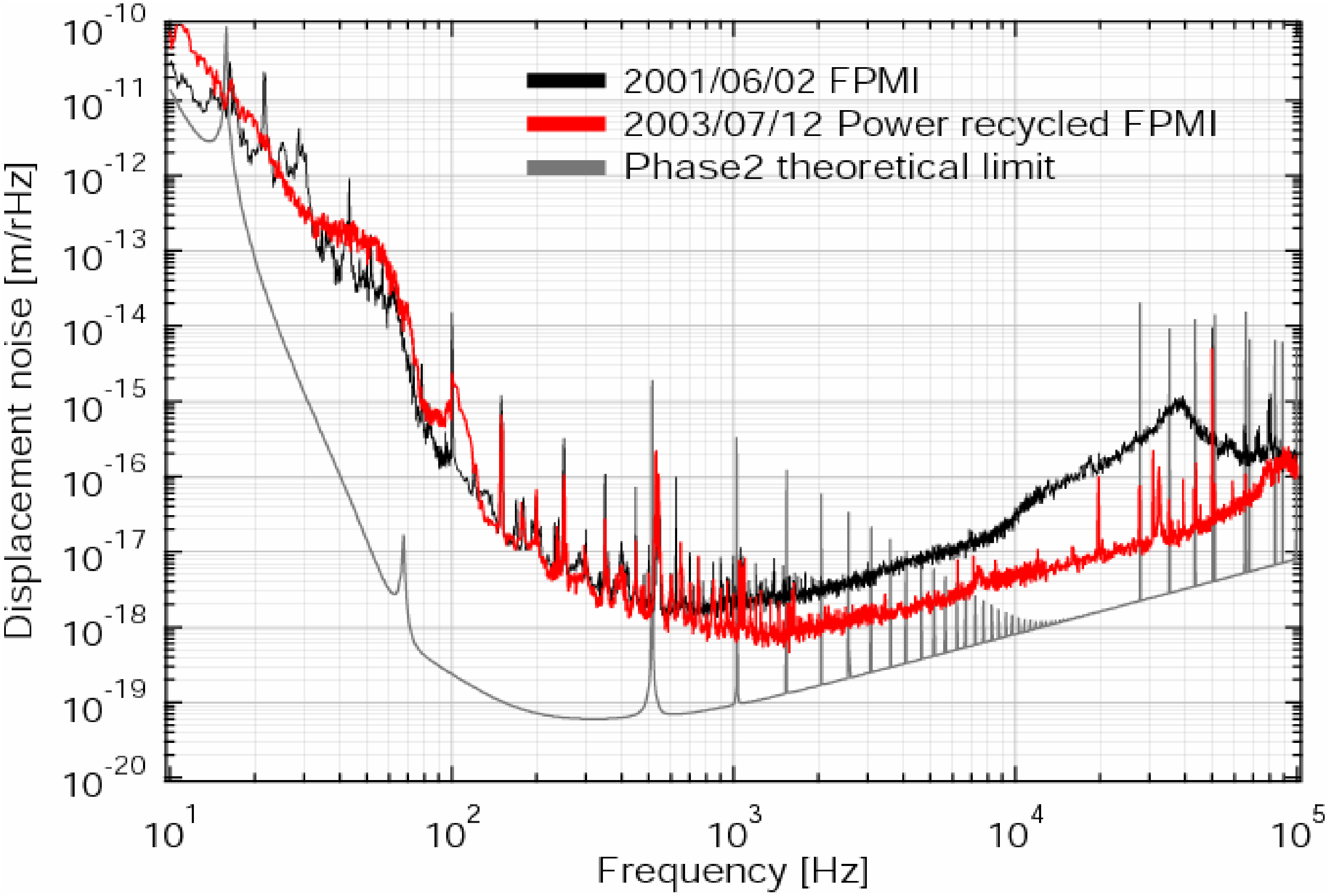


Test & Observation runs with data taking

- DT1 6-Aug --- 7-Aug 1999 7 hr
- DT2 17-Sept --- 20=Sept 1999 31
- DT3 20-Apr --- 23-Apr 2000 13
- DT4 21-Aug --- 4-Sept 2000 160
- DT5 2-Mar --- 8-Mar 2001 111
- DT6 15-Aug --- 20-Sept 2001 1038


Recombine II, III 99/2-01/10
Recombine I 98/5-99/1
EM2
300 m
BS: Beam Splitter
EM: End Mirror
NM: Near Mirror
RM: Recycling Mirror
MC: Mode Cleaner
Laser & Mode Cleaner
98/1-99/1
NM2
Mode Cleaner
97/4-97/12
One Arm 97/8-98/4
10W
MC1
RM
BS
NM1
EM1
10m
Recycling
01/11-
300 m
MC2

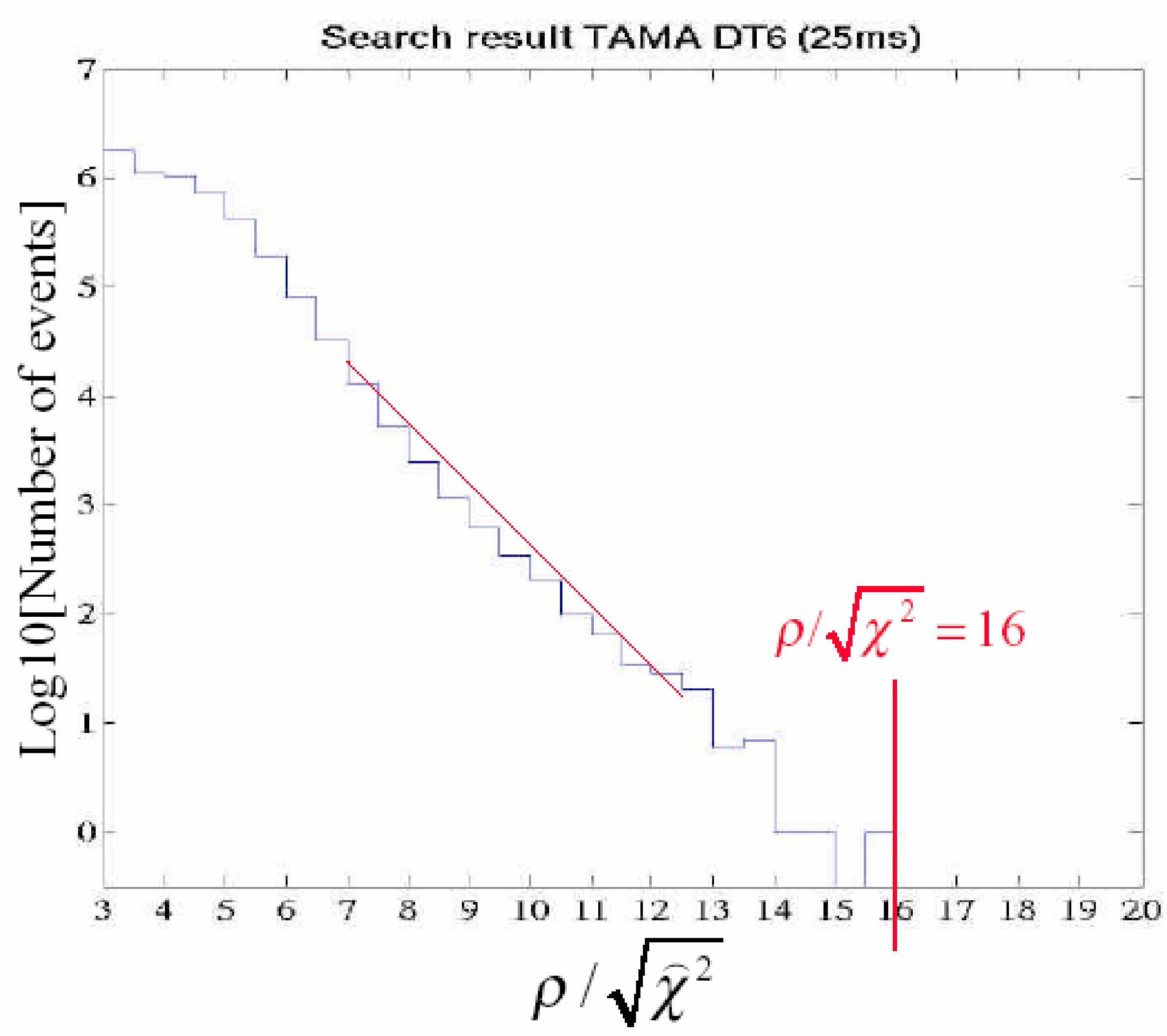
Improvement of Sensitivity



Observation after installation of RM

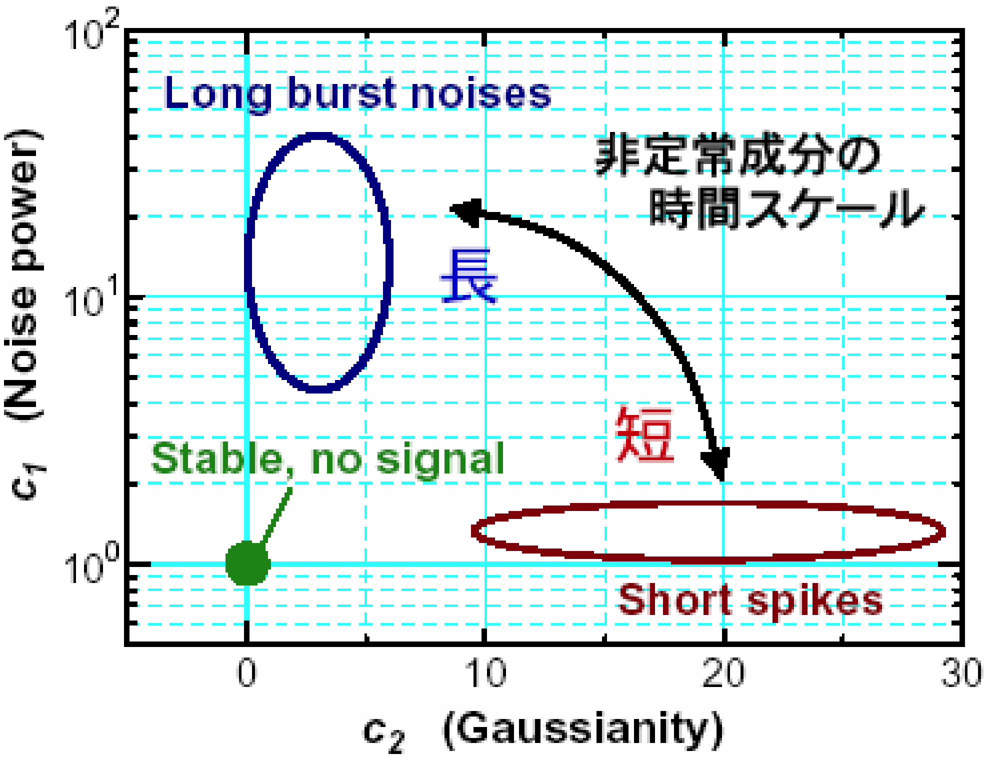
Run (hr)	Period	Year	Data
• DT7	30-Aug --- 4-Spet	2002	100
• DT8	14-Feb --- 15-Apr	2003	1158
• DT9	28-Nov --- 10-Jan	2004	557

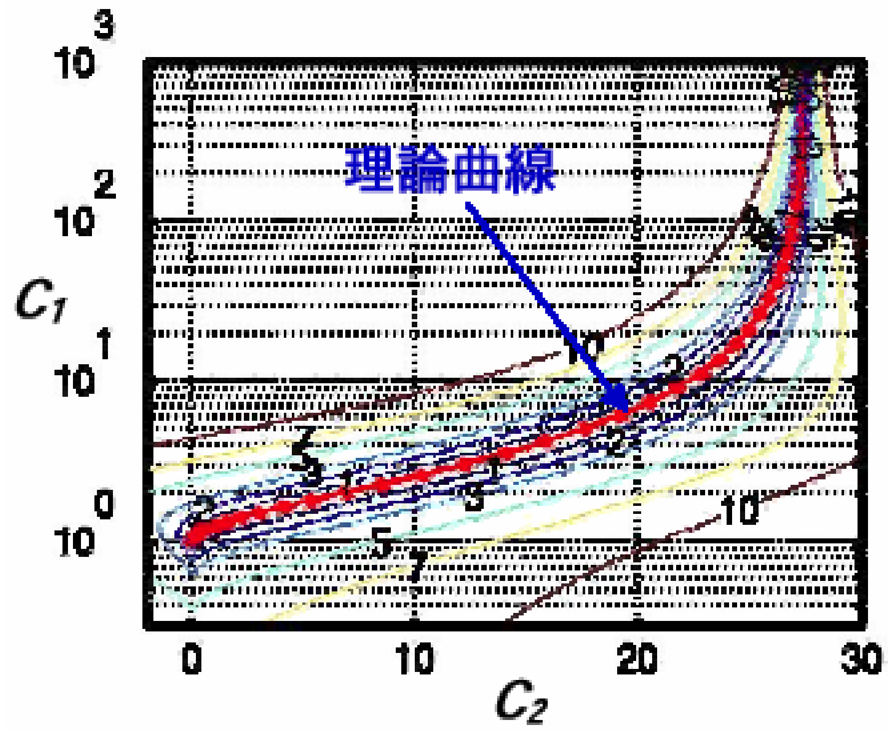
- Result of DT6 （チャープ波の解析）
  - 計数値は0.0022 event/hour (C.L.90%)
    一銀河系イベントを仮定して検出効率をシミュレーションで求めた
  - 平均検出効率 15%
  - 銀河イベントに対する上限値：0.014 event/hour (C.L.90%)



バースト波の解析

- 干渉計診断から発展
- あるtime spanでの信号のパワーとガウス性を比較
  - 超新星バーストについてのいくつかの波形予測
  - 典型的な干渉計の雑音と違うsignature





連続波の解析

- ● 周波数　$934.9080 \sim 934.9826\,Hz$　をサーチ
- ● スピンダウンは 2.5×10^{-10} Hz/s
- ● 平均パワー $P_0 = 3.6434\times10^{-40}(1/Hz)$

  ひずみ度にして $h = 9.1\times10^{-24}$

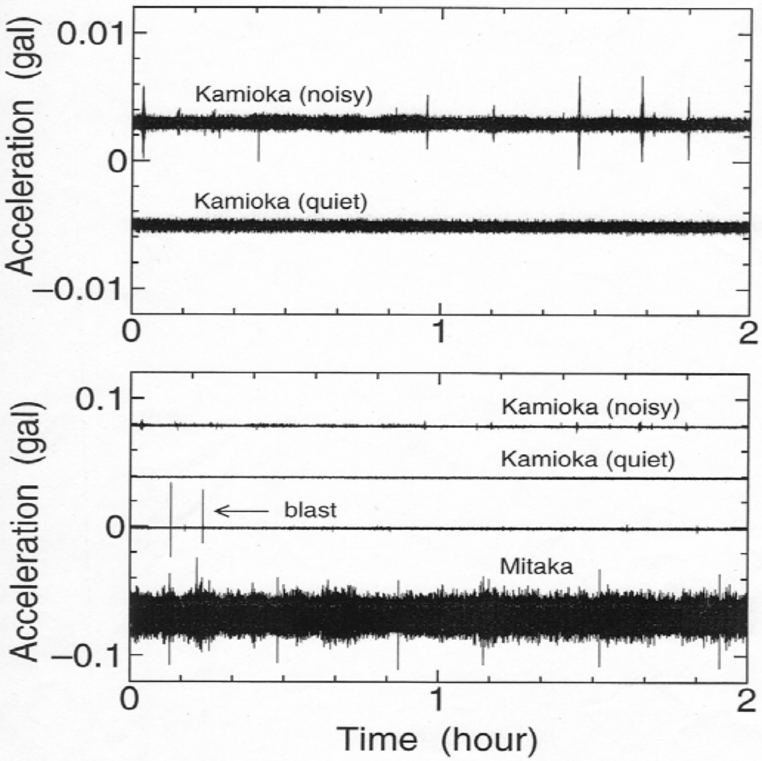
  ・・重力波なし
- ● 第一種の誤り $P_1 = 0.026 \rightarrow P_T = 14P_0$
- ● 得られた重力波のupper limitは $h_{upper} = 3.4\times10^{-23}$

  $h_{DT4} = 1.1\times10^{-22}$

LISM 実験

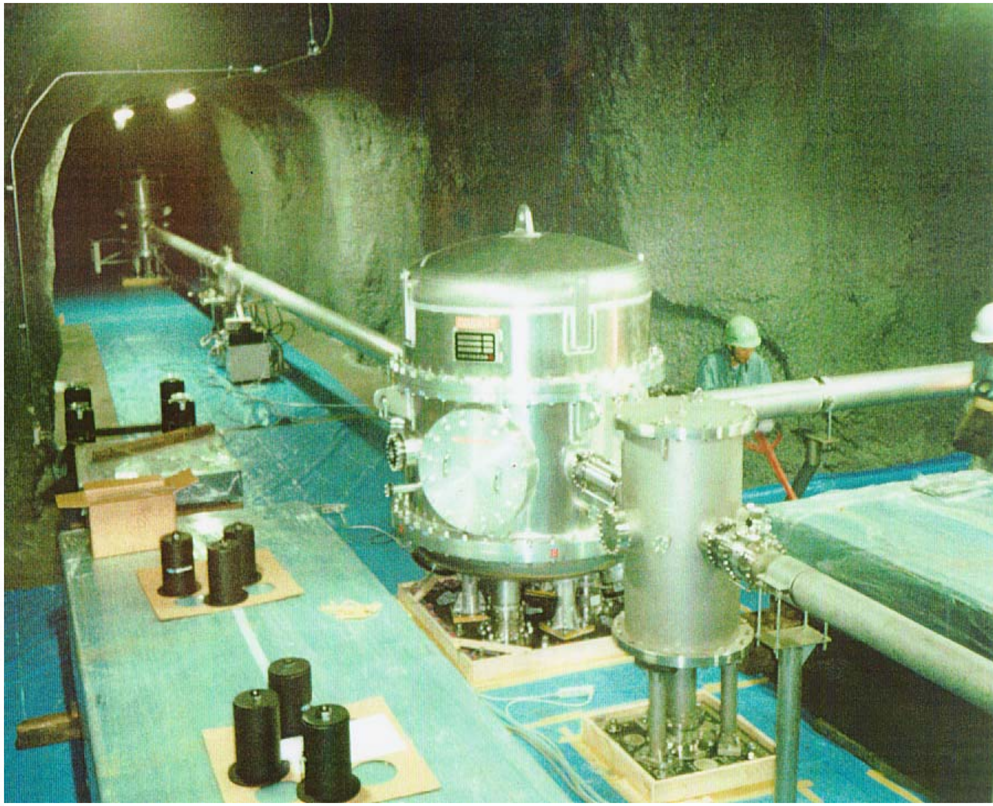
- ２０mプロトタイプ干渉計（三鷹→神岡）
- TAMAの懸架装置
- Locked Fabry-Perot へ改造
- 変位感度はTAMAと同レベル
- 低周波でTAMAを上回る
- 安定度抜群

The merit of underground is smaller seismic noise and temperature stability

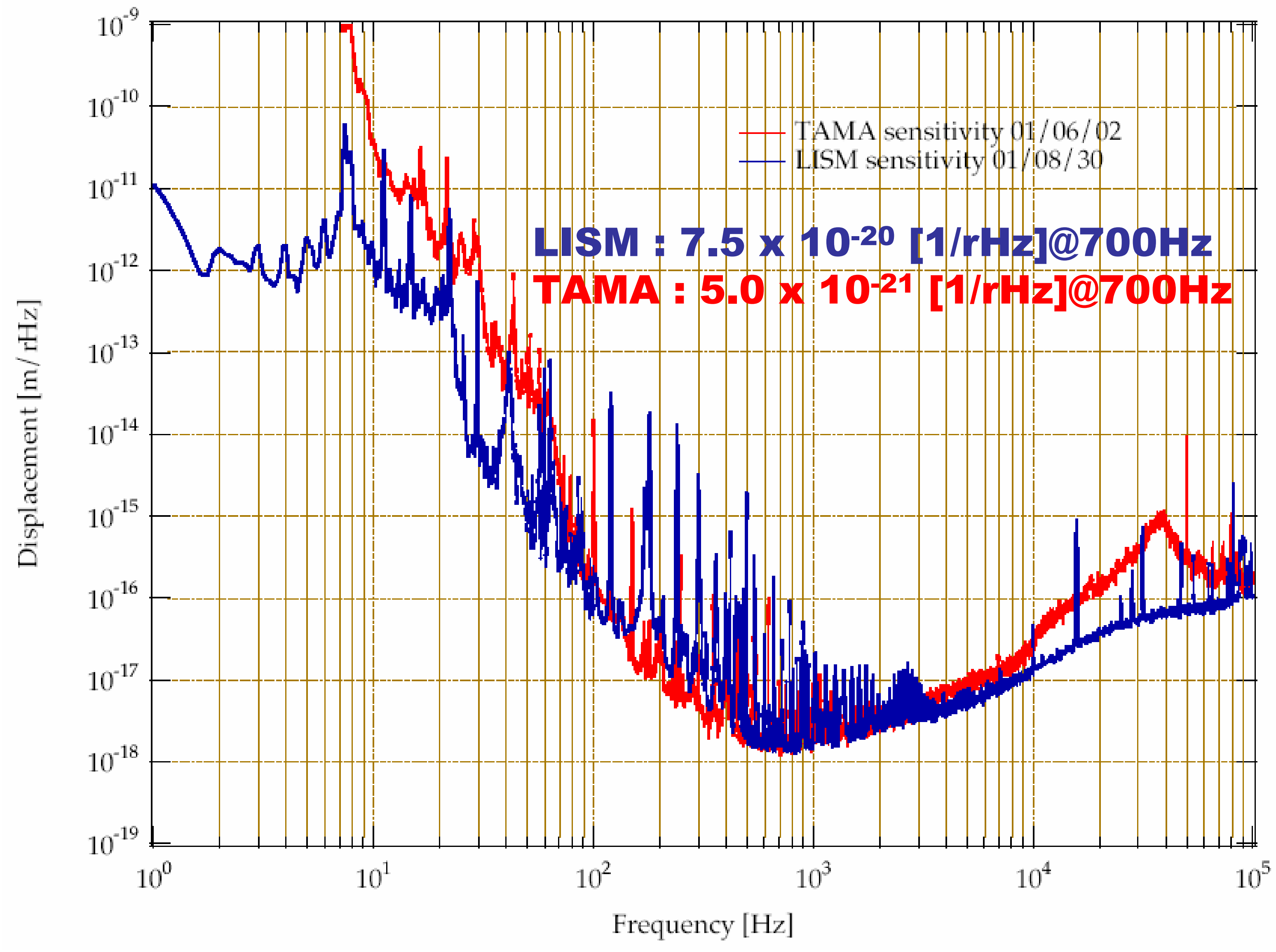


The amplitude is smaller by two orders than that of TAMA site.

20m prototype interferometer mounted

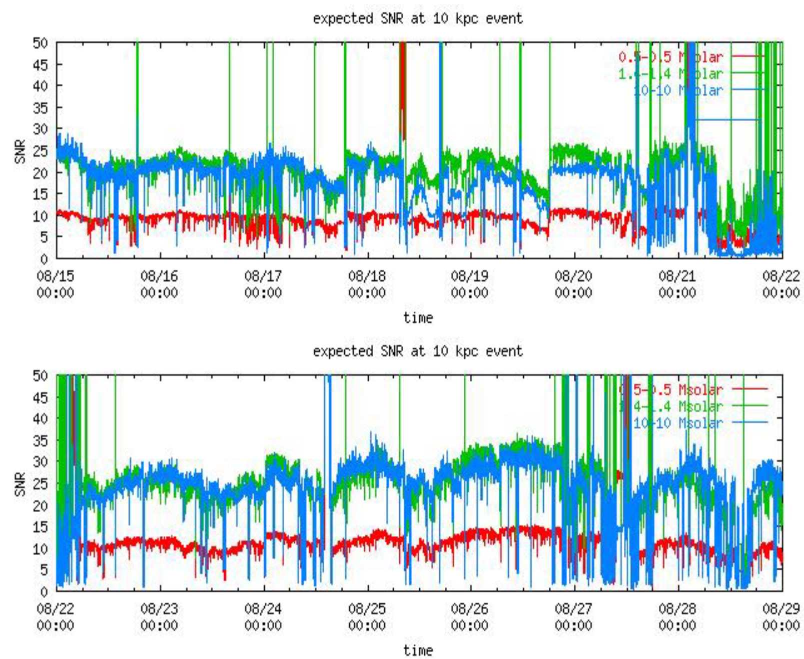


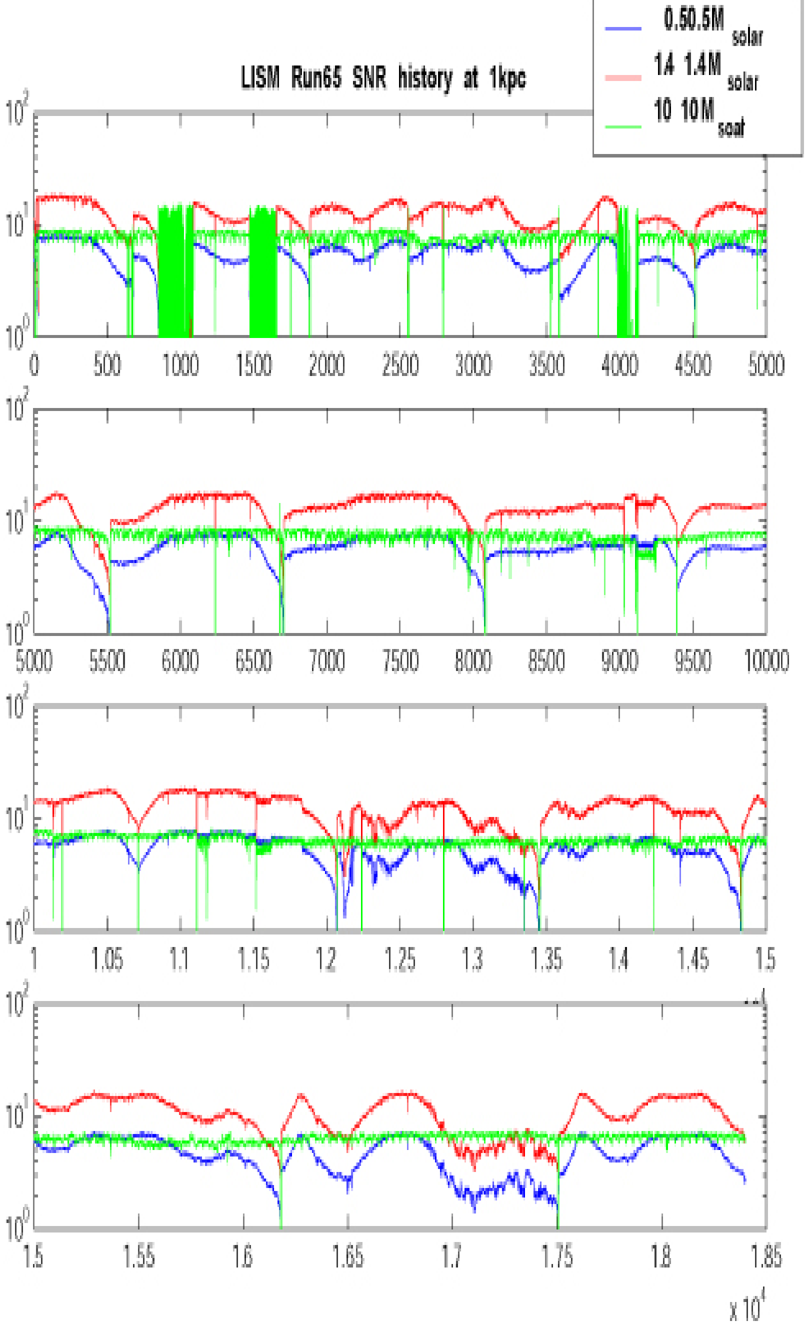
TAMA300-LISM Sensitivity



Stability of sensitivities are evaluated by smoothness of the curves.

TAMA





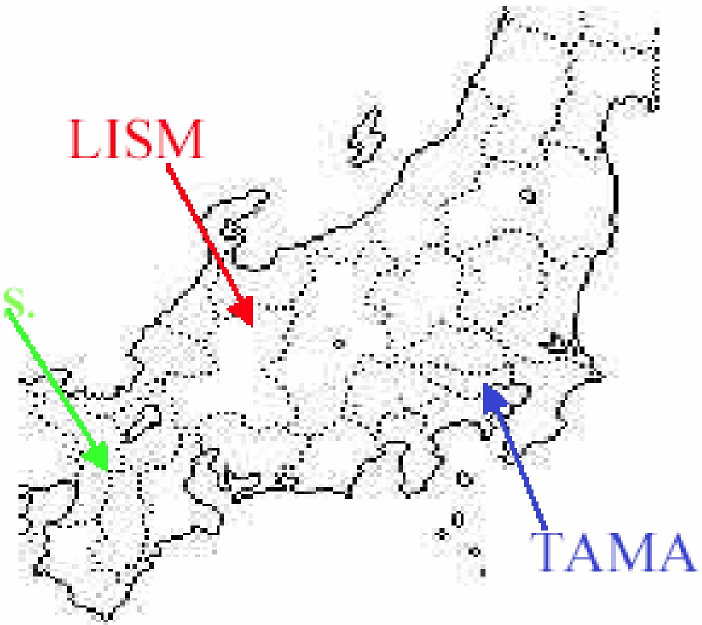
LISM

LISM - TAMA相関解析

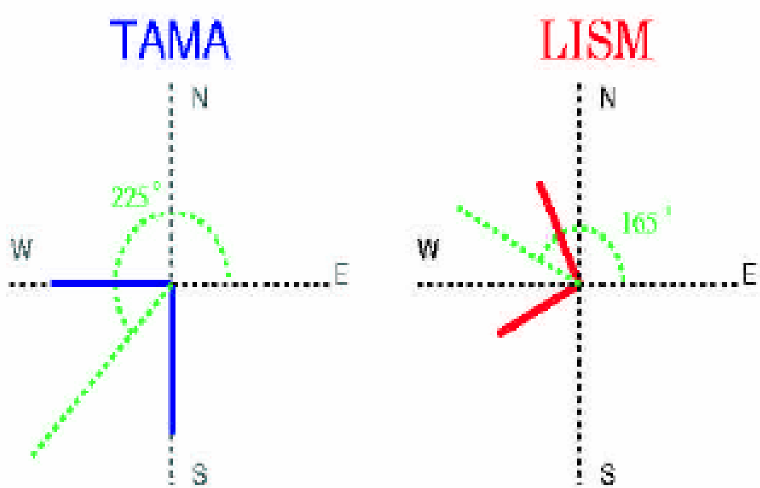
Location of TAMA and LISM

- Location of TAMA and LISM

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



Relation between TAMA and LISM arms direction



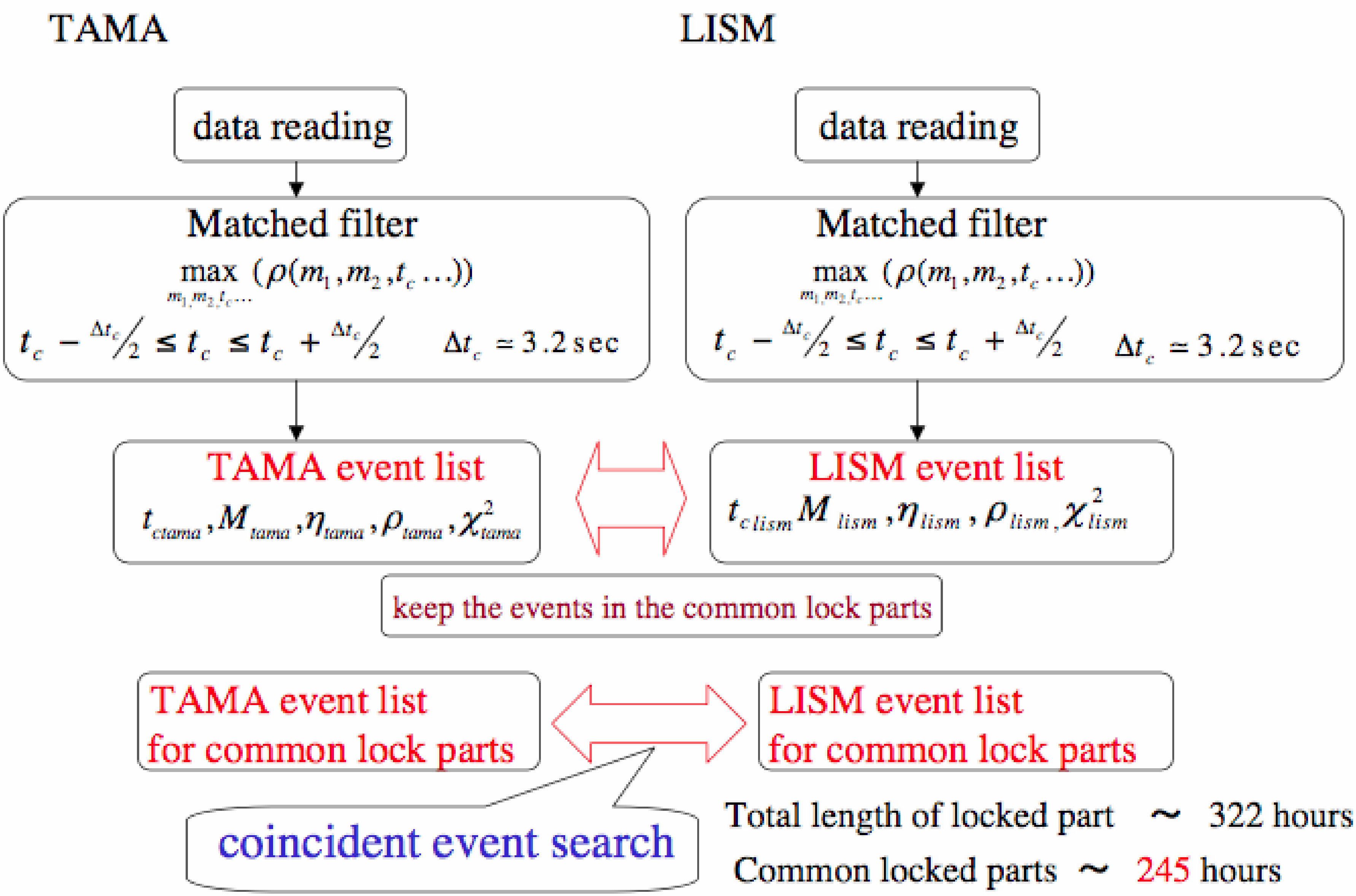
Distance between TAMA and LISM ～220km

Maximum delay of signal arrival time

～ 0.73msec

Difference of zenith direction ～ 1.97 °

TAMA－LISM Analysis Algorithm



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 $t_c, \mathcal{M}, \eta$ -coincidence — accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$

18 events — 17.55 ± 4.08

After $t_c, \mathcal{M}, \eta, \rho$ -coincidence — accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$

13 event — 12.76 ± 3.51

第一幕のまとめ

重力波検出実験の現状のおさらい