KAGRA International Workshop 4
(June 30th, 2018)

Lock Loss study of bKAGRA phase1

Yuki Miyazaki
(M1, Ando lab., Univ. of Tokyo)

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   (Classifying EQs as to its safeness)

Network of gravitational wave detectors

GEO-HF
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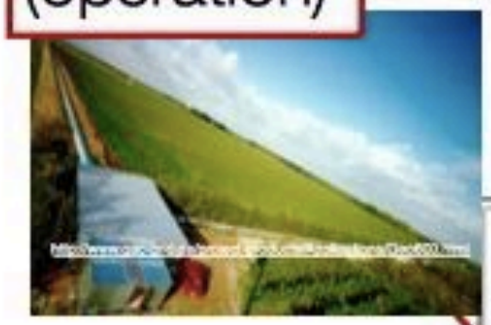


KAGRA
(construction)

Advanced LIGO Hanford
(Preparing for O3)

Advanced Virgo
(Preparing for O3)

https://wwwcascina.virgo.infn.it/

LIGO-India
(approved)

Advanced LIGO Livingston
(Preparing for O3)

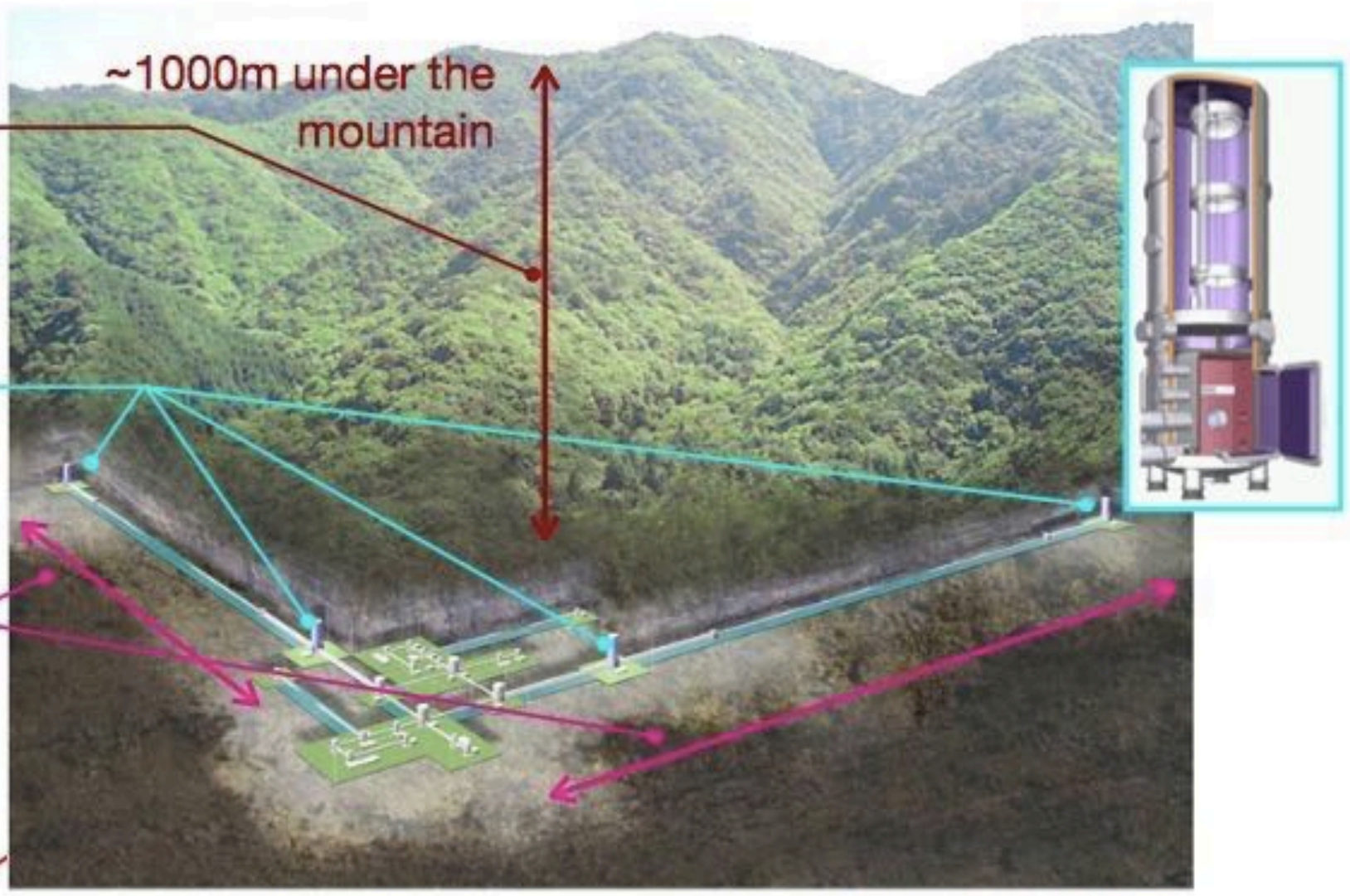
ref. H.Yuzurihara "bKAGRA phase1 operation", Area Workshop 2018 Early Summer

KAGRA detector

Underground
- in Kamioka, Japan
- Silent & Stable environment

Cryogenic Mirror
- 20K
- sapphire substrate

3km baseline



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ref. H.Yuzurihara "bKAGRA phase1 operation", Area Workshop 2018 Early Summer

Current roadmap of KAGRA

iKAGRA
Room temperature Michelson interferometer
Test run on March-April 2016

bKAGRA phase-1
Cryogenic temperature Michelson interferometer
Test run on April-May 2018

←**Today's talk**

bKAGRA phase-2
Installation and Commissioning
Improve sensitivity
May 2018 ~

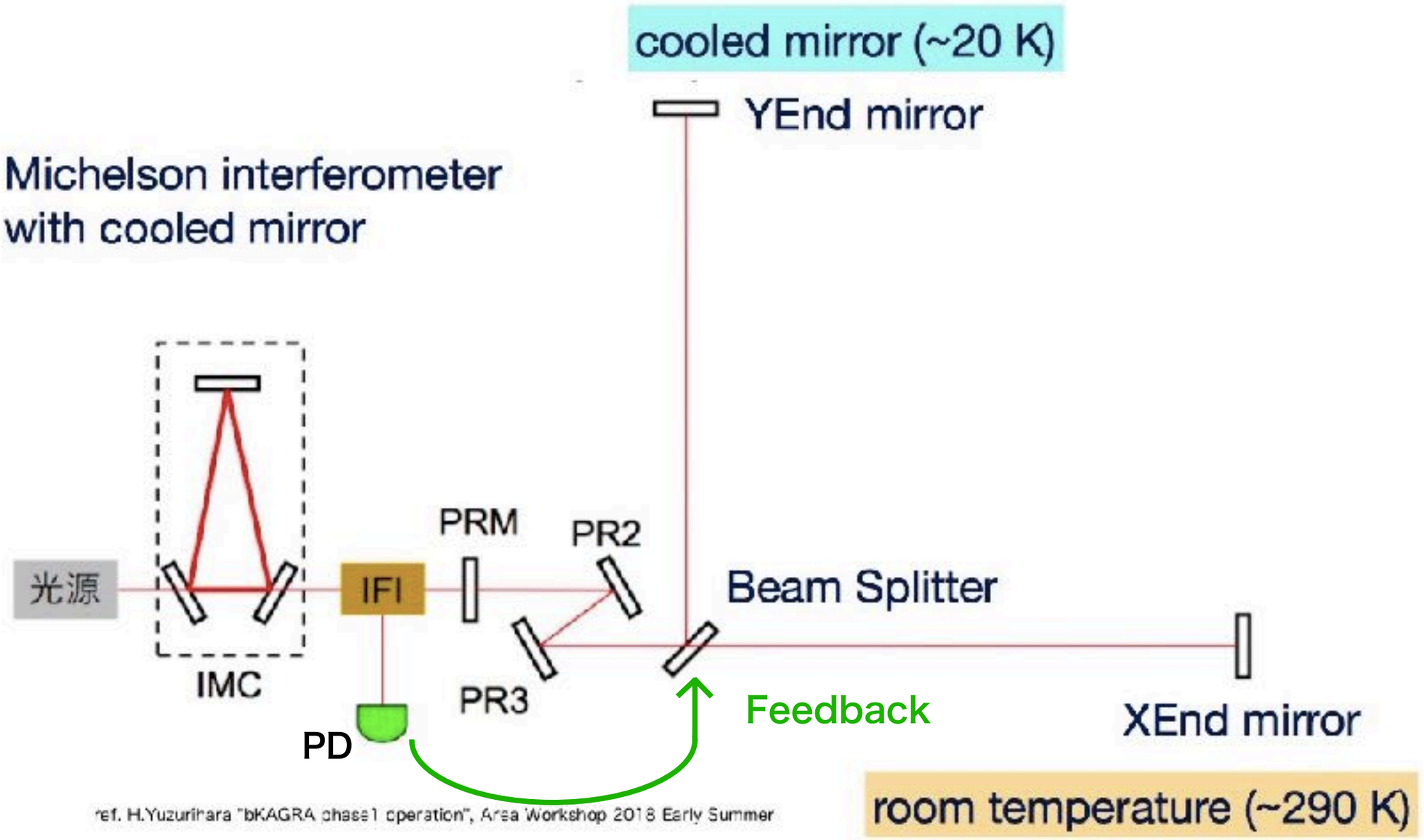
bKAGRA phase-3
Cryogenic Fabry-Perot Interferometer
Observation run and Join O3

ref. H.Yuzurihara "bKAGRA phase1 operation", Area Workshop 2018 Early Summer

About bKAGRA

Operation time:

2018/04/28 09:00:00 ~ 05/07 06:00:00 (JST)



ref. H.Yuzurihara "bKAGRA phase1 operation", Area Workshop 2018 Early Summer

Importance of this study

Lock Loss

LOCK STATE

DOWN STATE

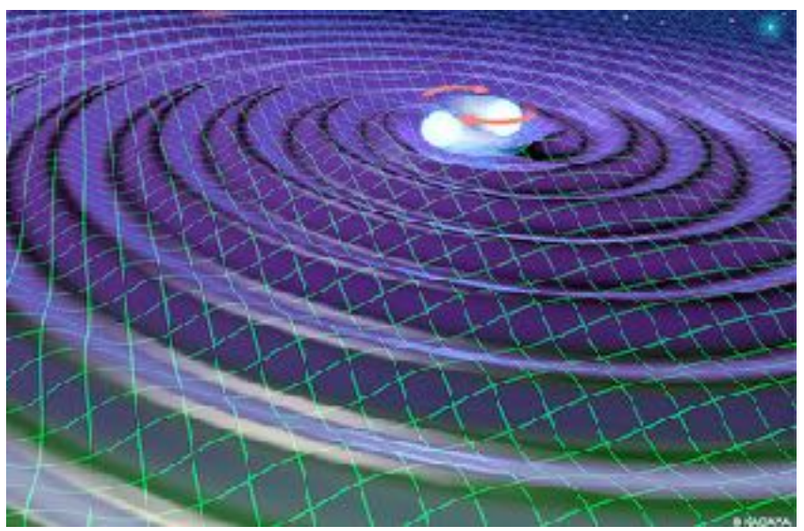
||

Lock

Observable state

detectable!

Gravitational Wave



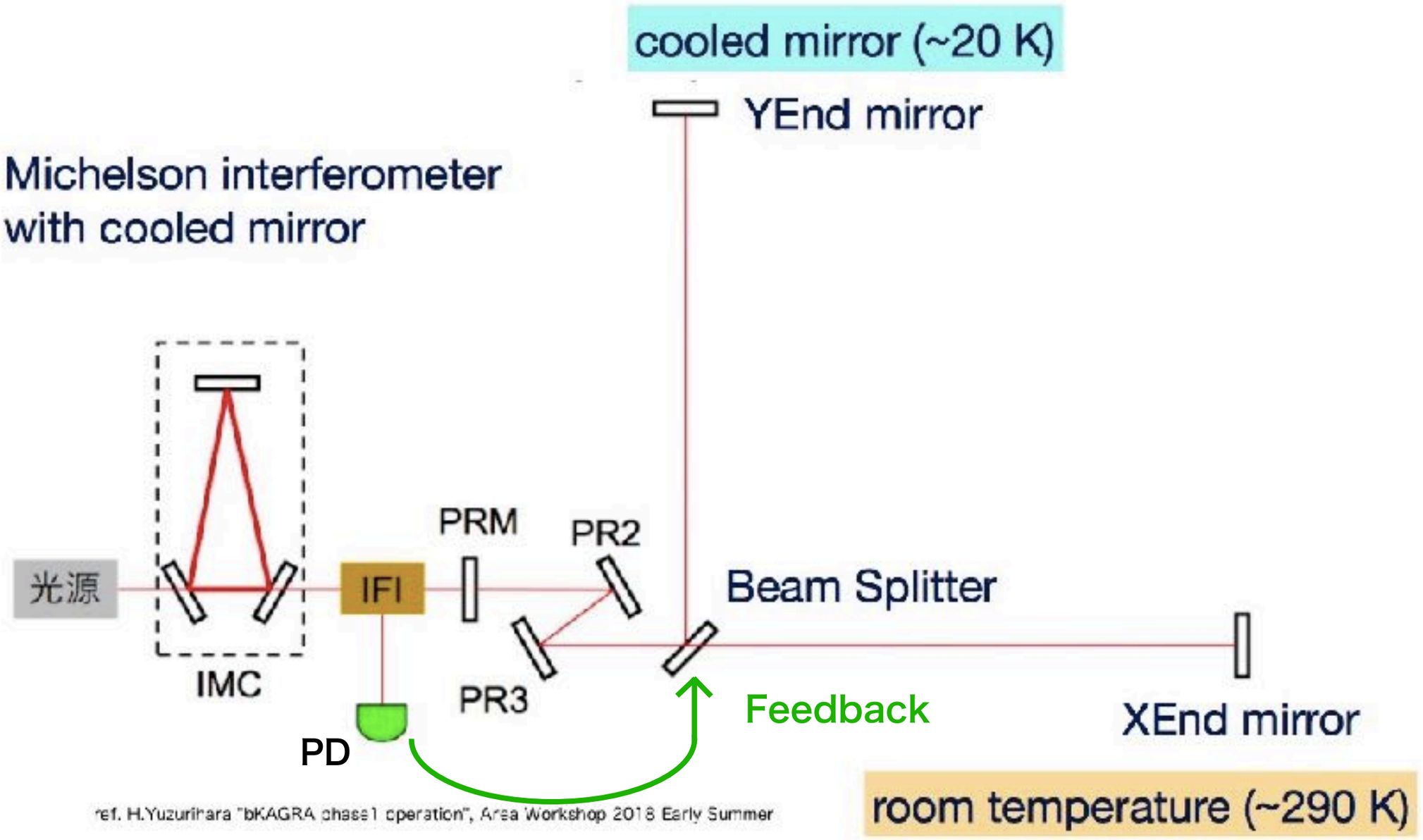
NOT detectable...

ref: NAOJ

About bKAGRA

Operation time:

2018/04/28 09:00:00 ~ 05/07 06:00:00 (JST)



ref. H.Yuzurihara "bKAGRA phase1 operation", Area Workshop 2018 Early Summer

About bKAGRA

Operation time:

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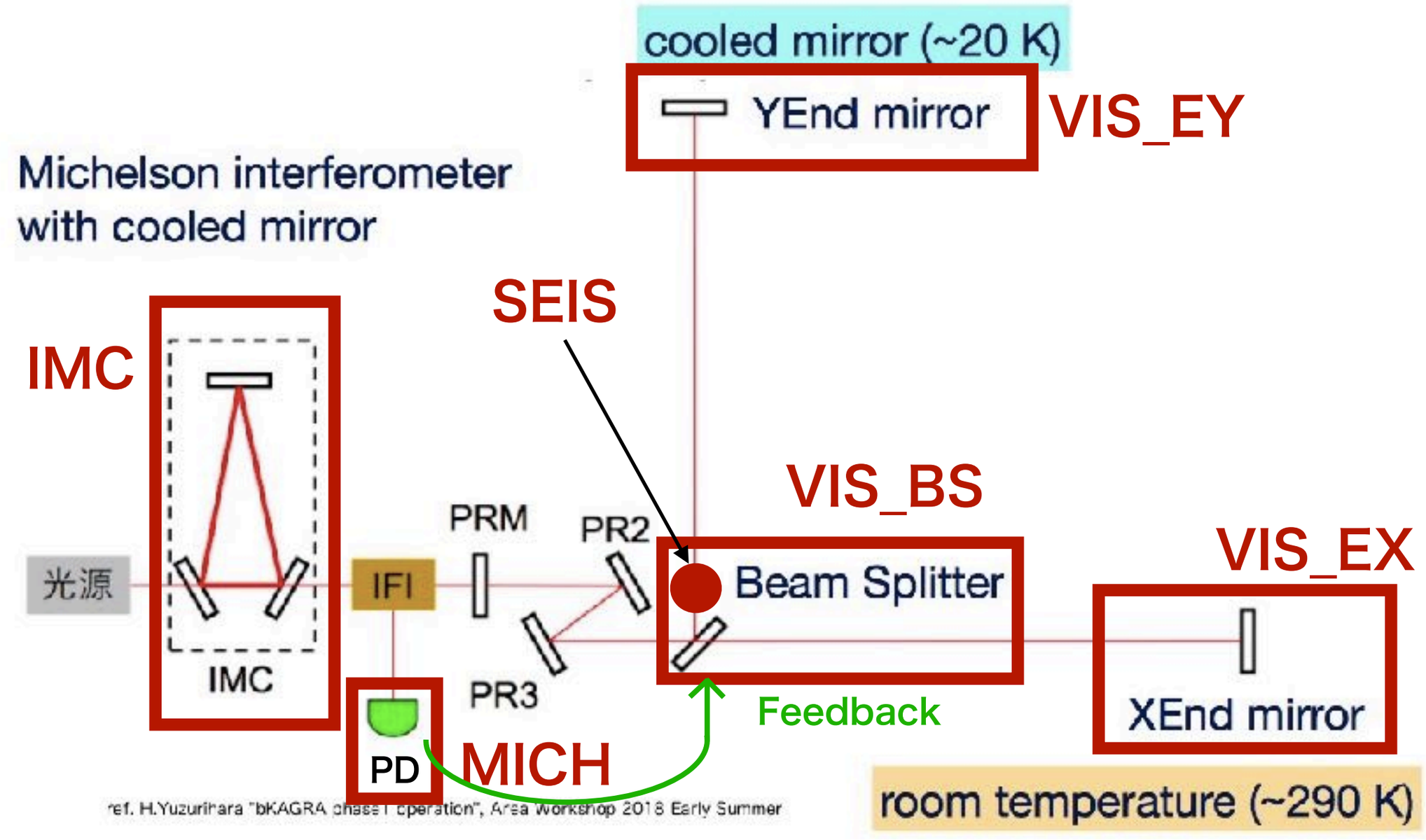
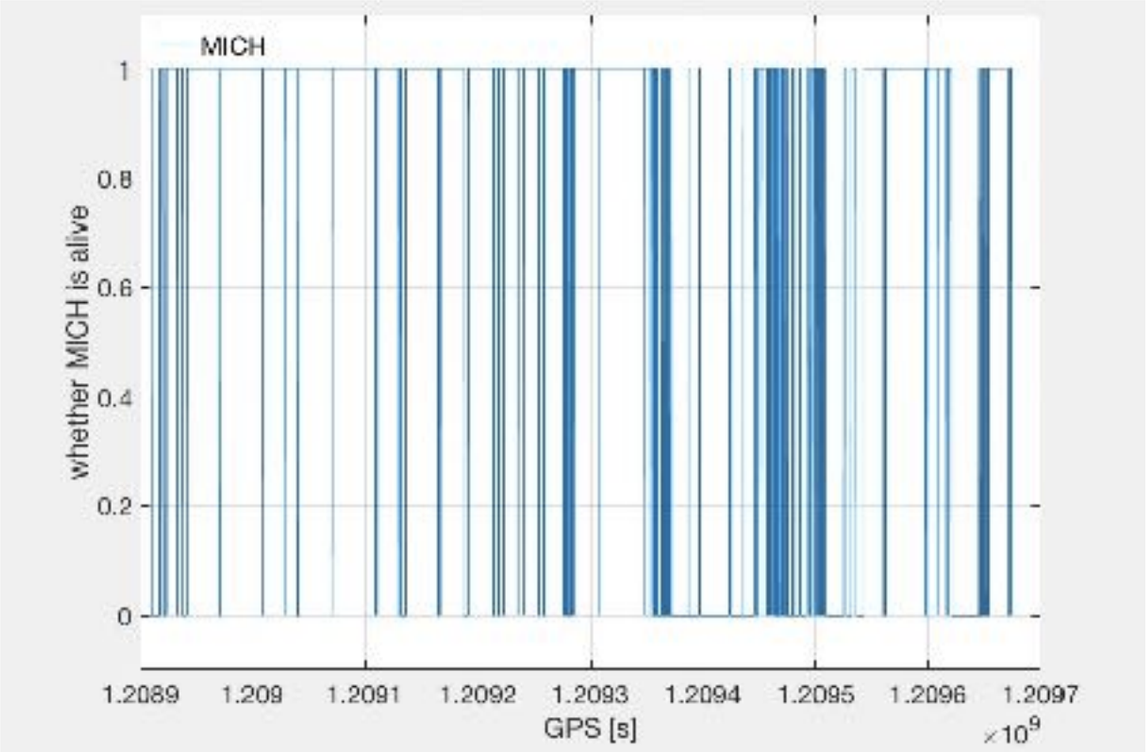


Important Channels

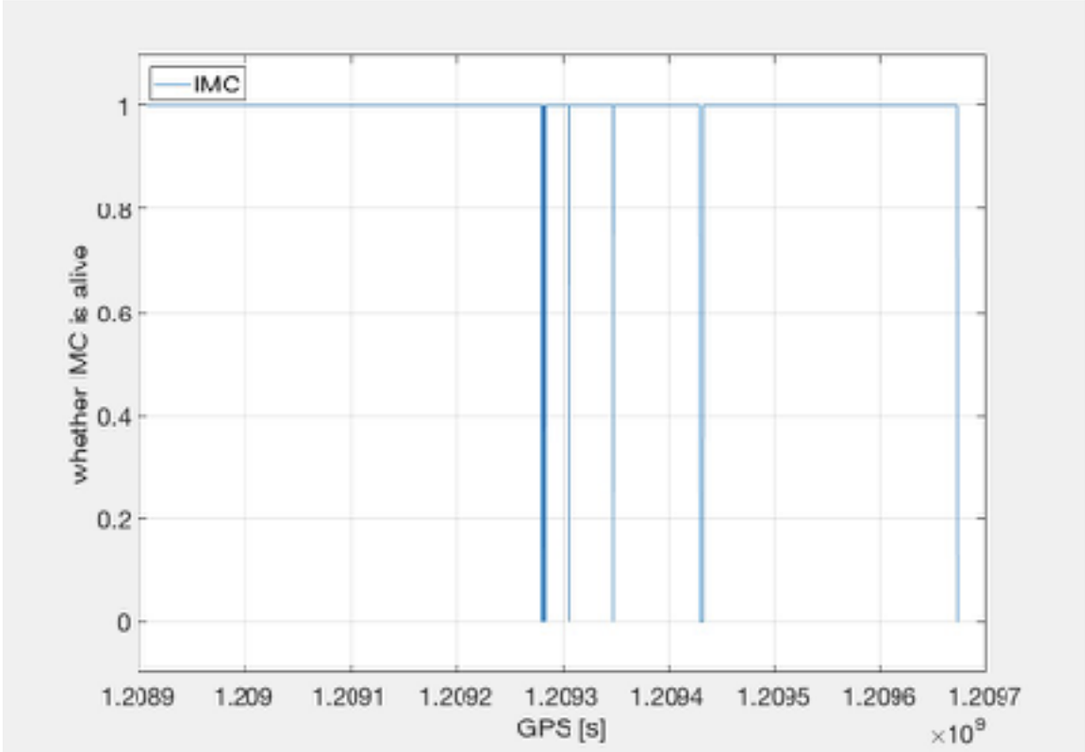
	Channel name
MICH	K1:GRD-LSC_MICH_STATE_N
IMC	K1:GRD-IMC_LOCK_STATE_N
VIS_BS	K1:GRD-VIS_BS_STATE_N
VIS_EX	K1:GRD-VIS_ETMX_STATE_N
VIS_EY	K1:GRD-VIS_ETMY_STATE_N
SEIS	K1:PEM-IY0_SEIS_{NS/WE/Z}_SENSINF_OUT

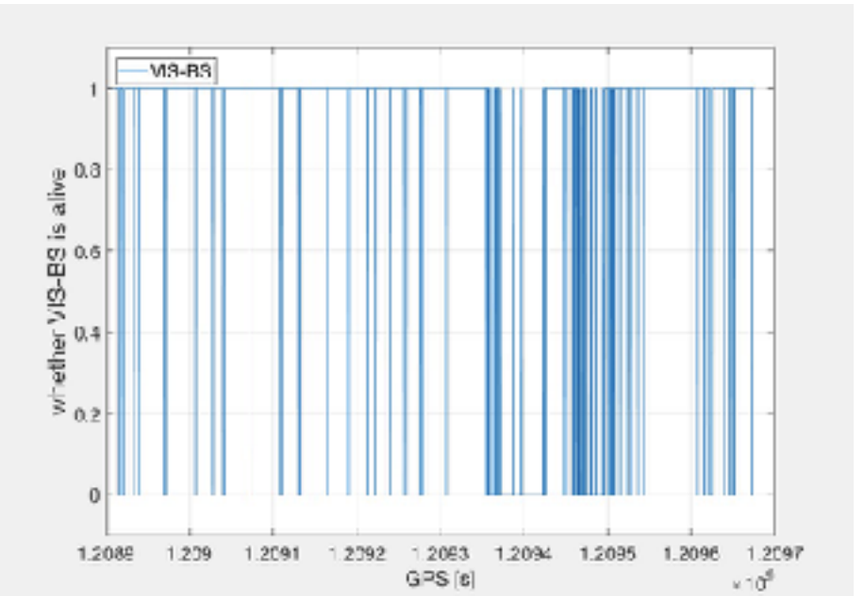
Gardian channels

MICH

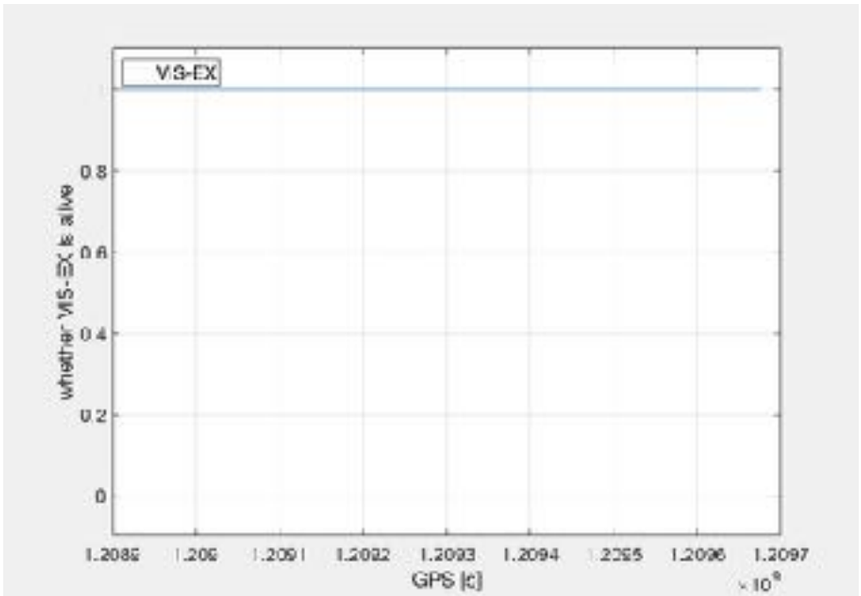


IMC

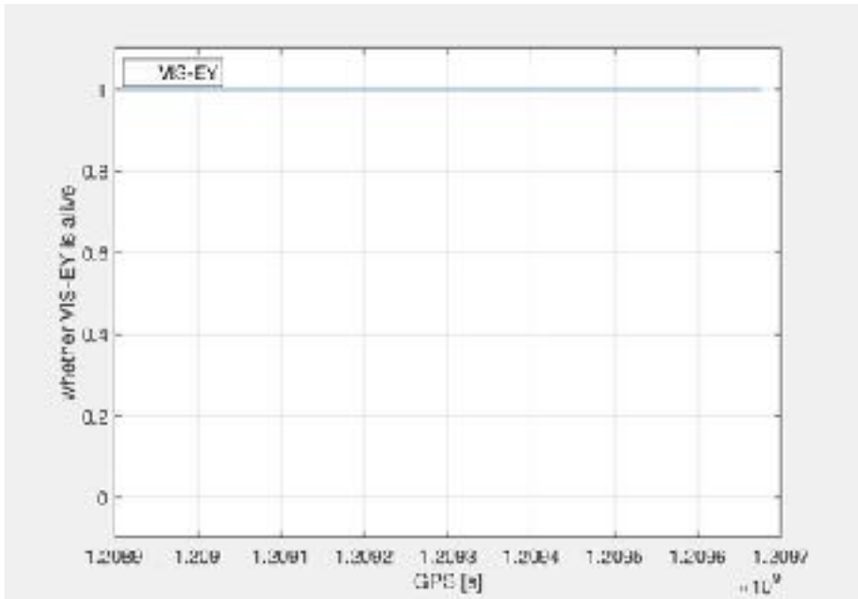




VIS_BS

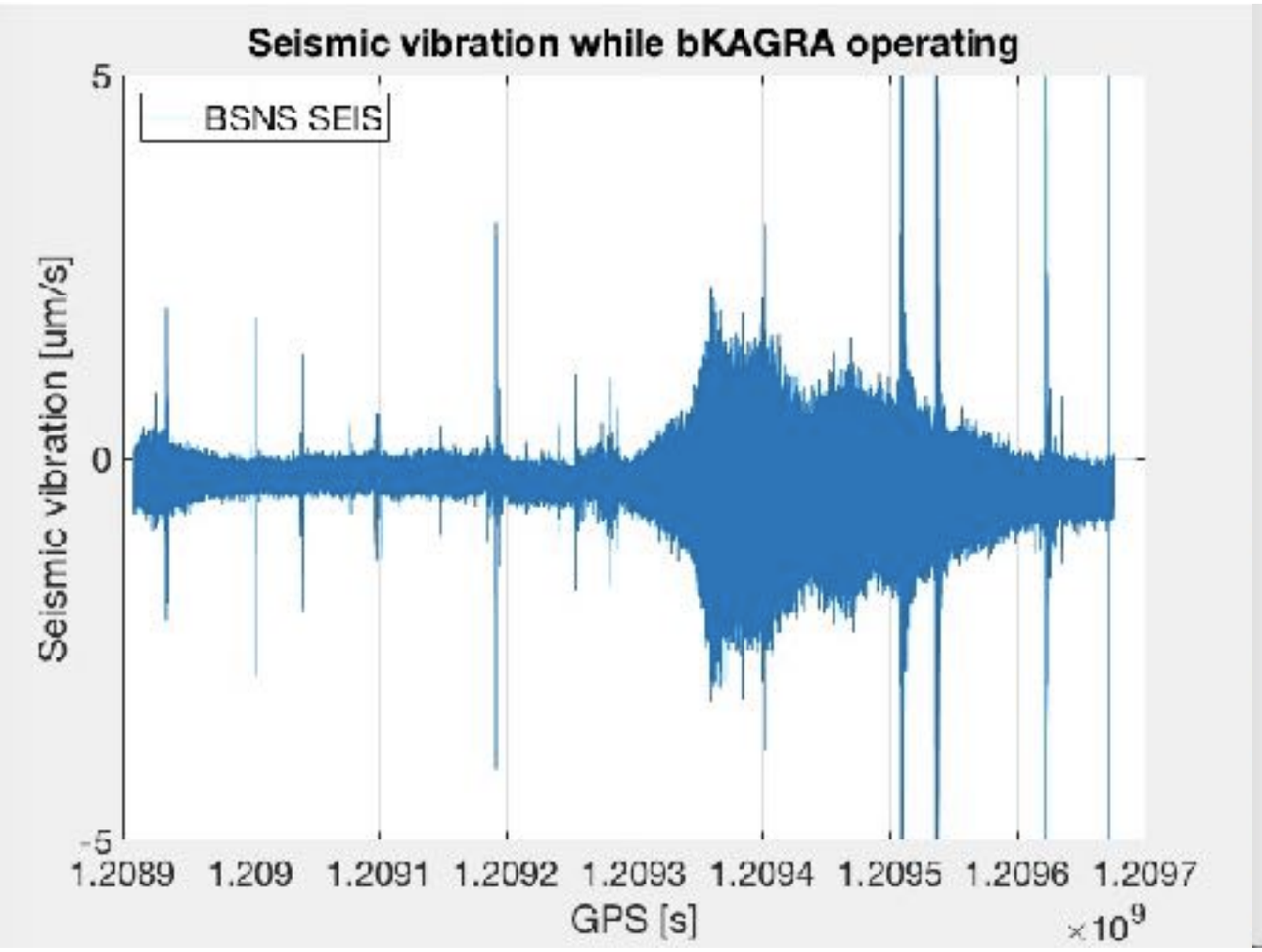


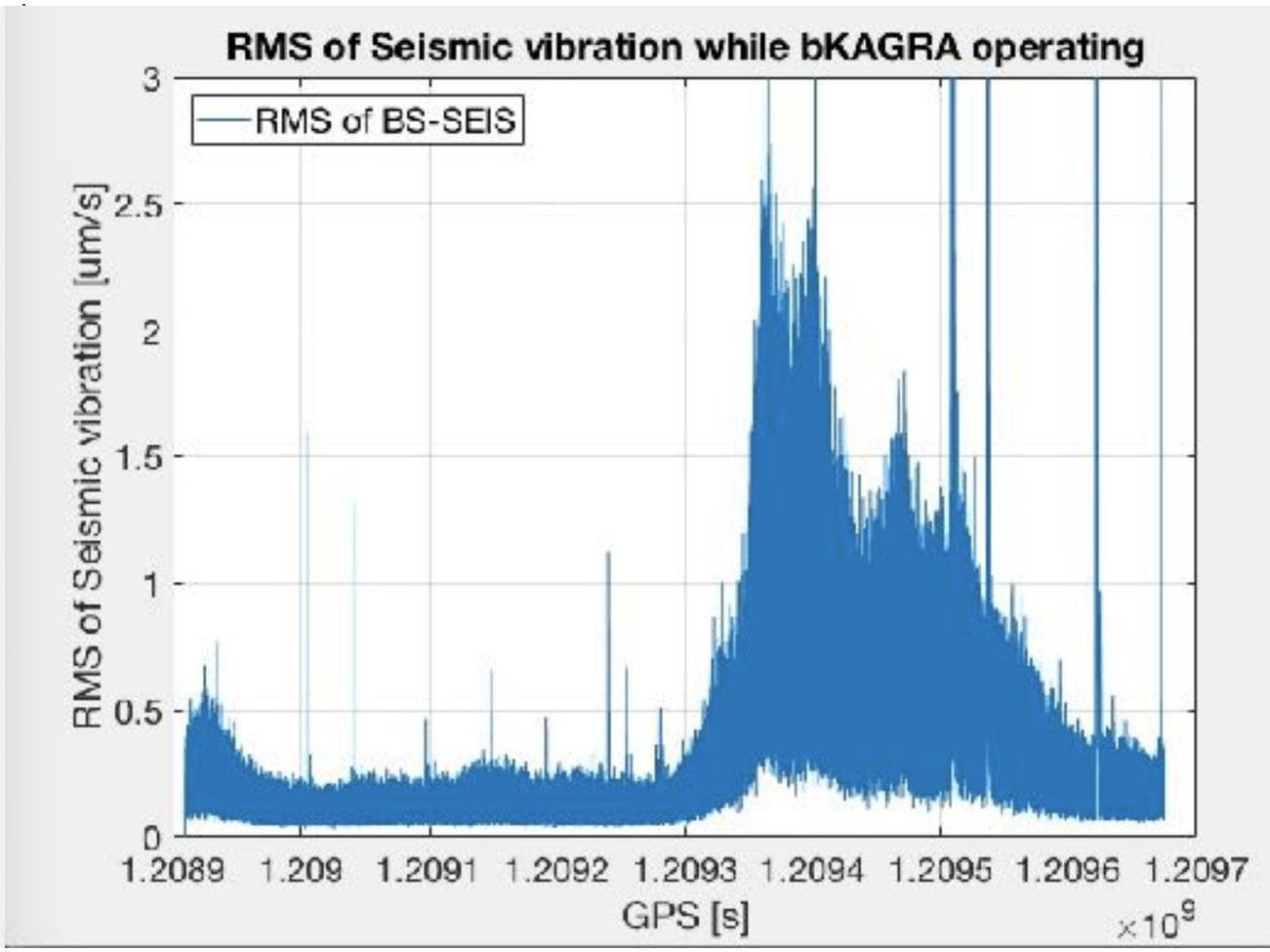
VIS_EX



VIS_EY

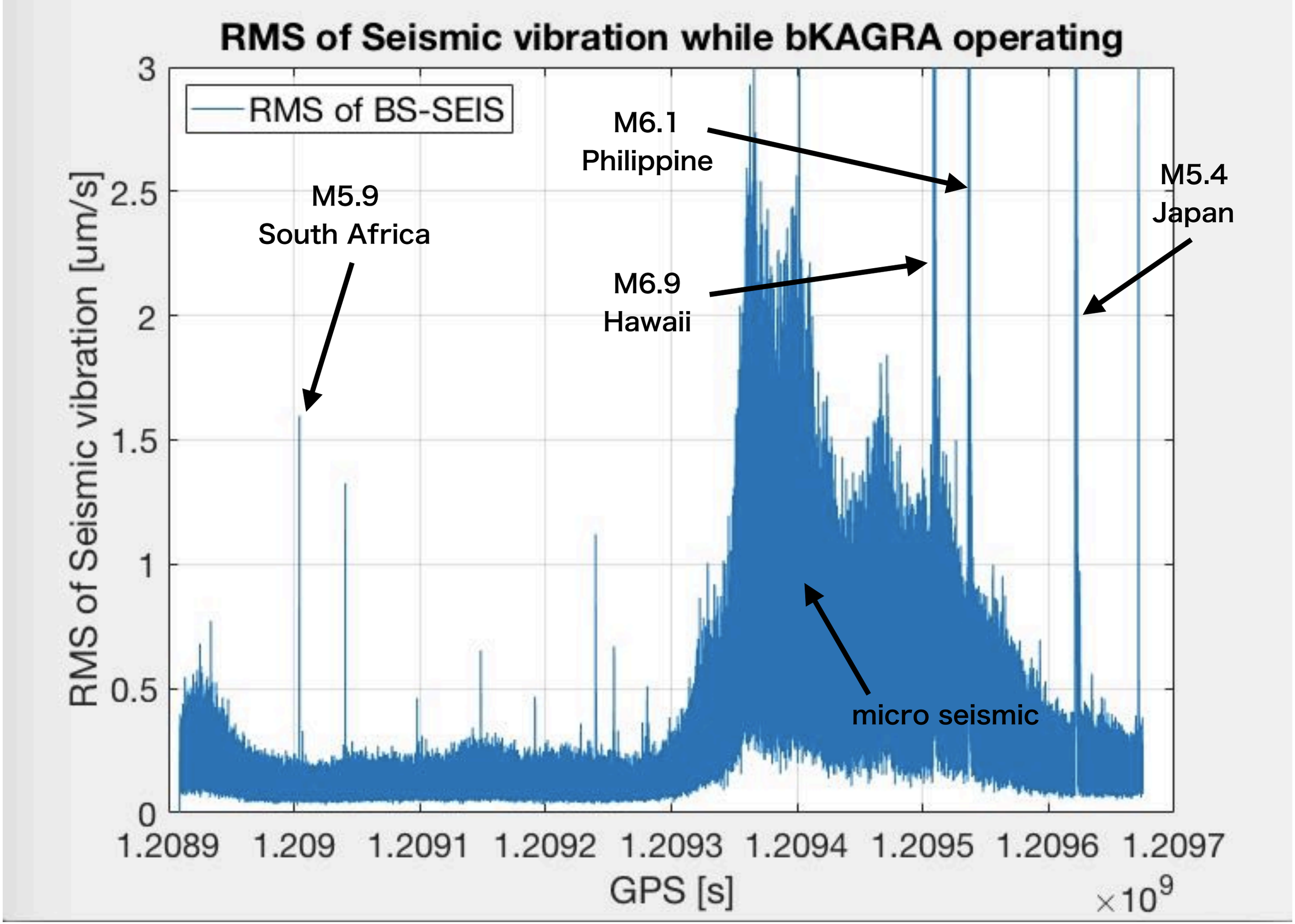
SEIS channel





bKAGRA phase1

bKAGRA phase1


RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
M6.1
Philippine
M5.9
South Africa
M6.9
Hawaii
M5.4
Japan
micro seismic
RMS of Seismic vibration [um/s]
GPS [s]
×10^9
0
0.5
1
1.5
2
2.5
3
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097

KAGRA operating

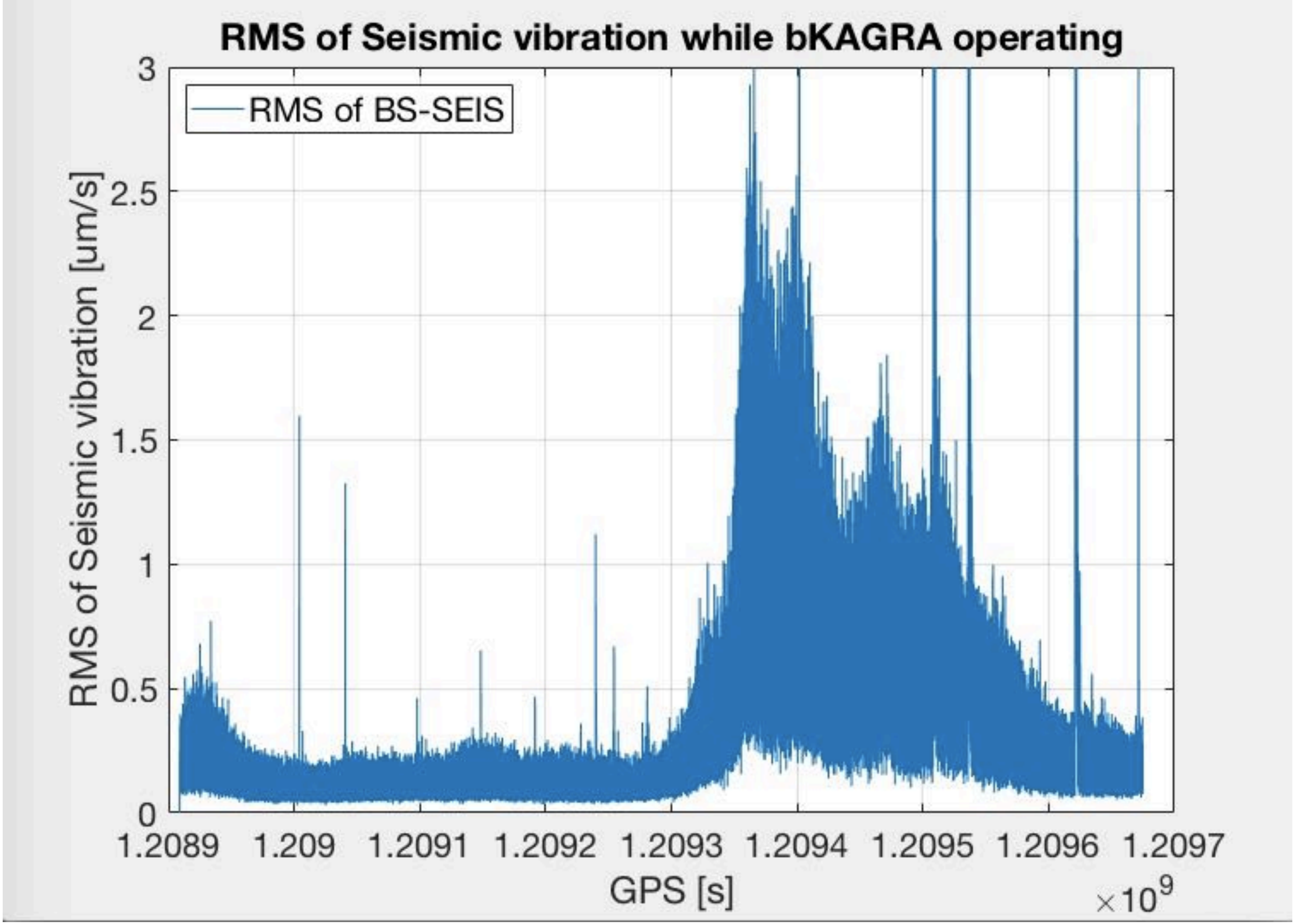
M5.4
Japan

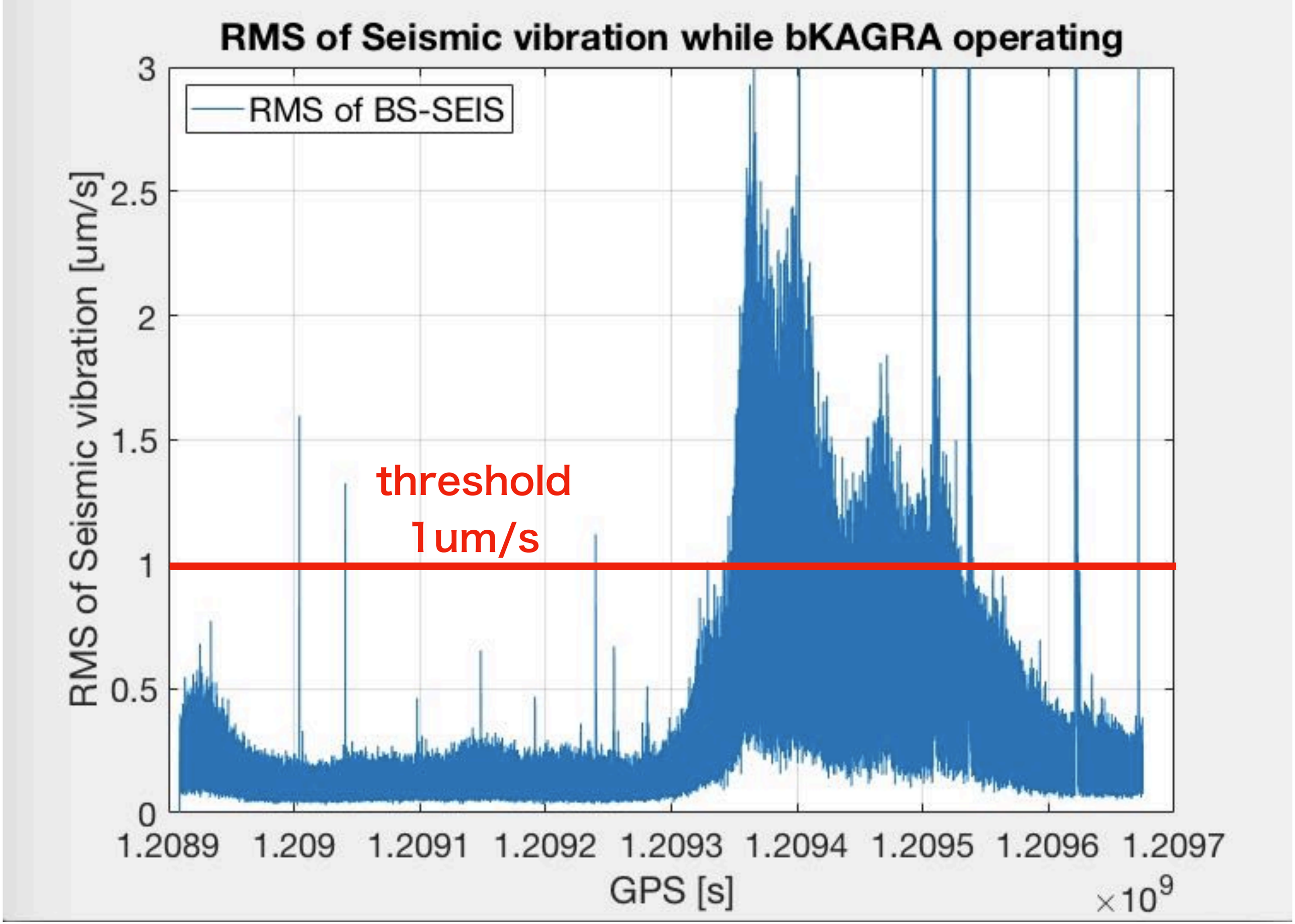
RMS of Se

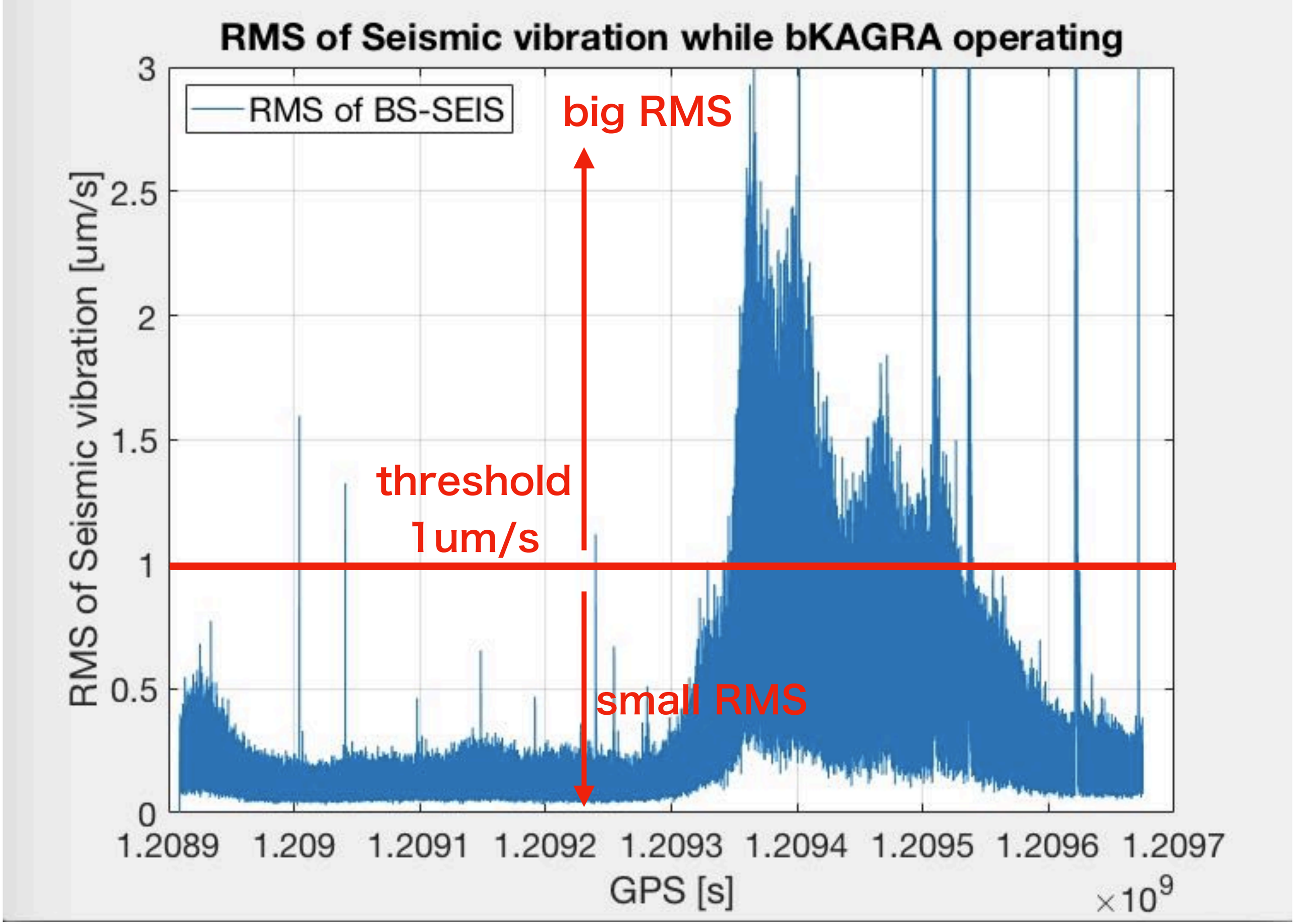
1
0.5
0
1.2089
1.209
1.2091
1.209

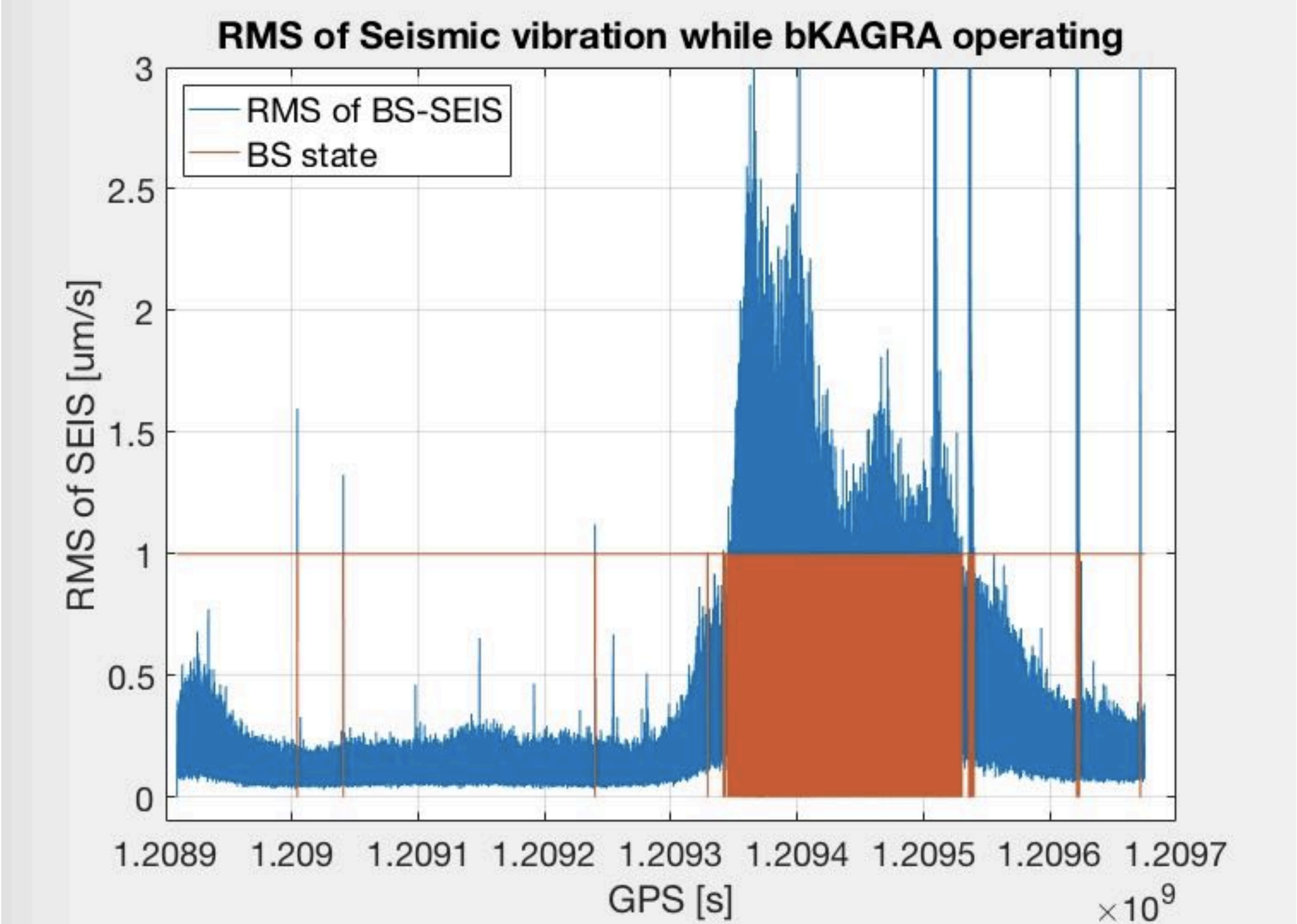
GPS [s]

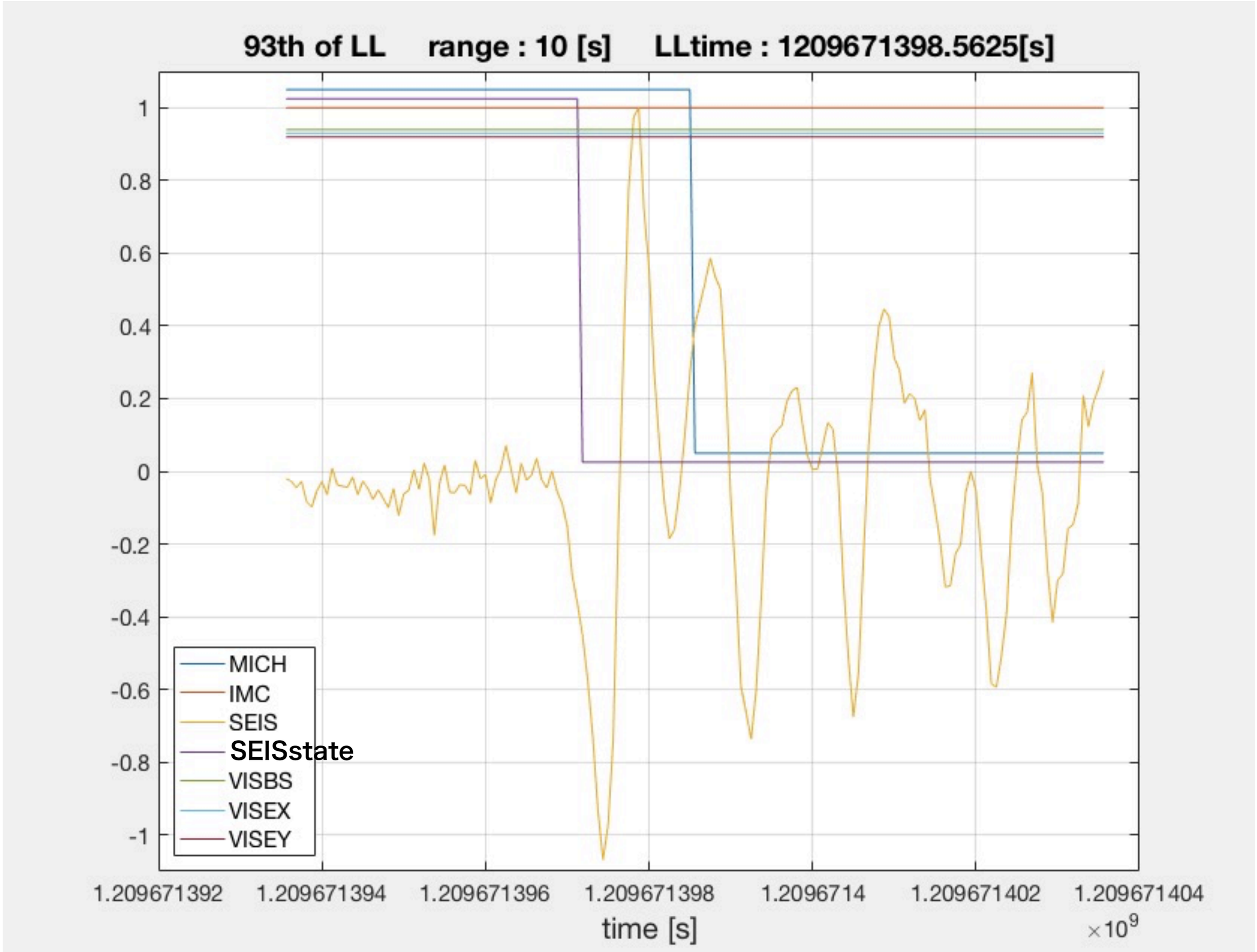
×10


RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
RMS of Seismic vibration [um/s]
3
2.5
2
1.5
1
0.5
0
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097
GPS [s]
×10^9

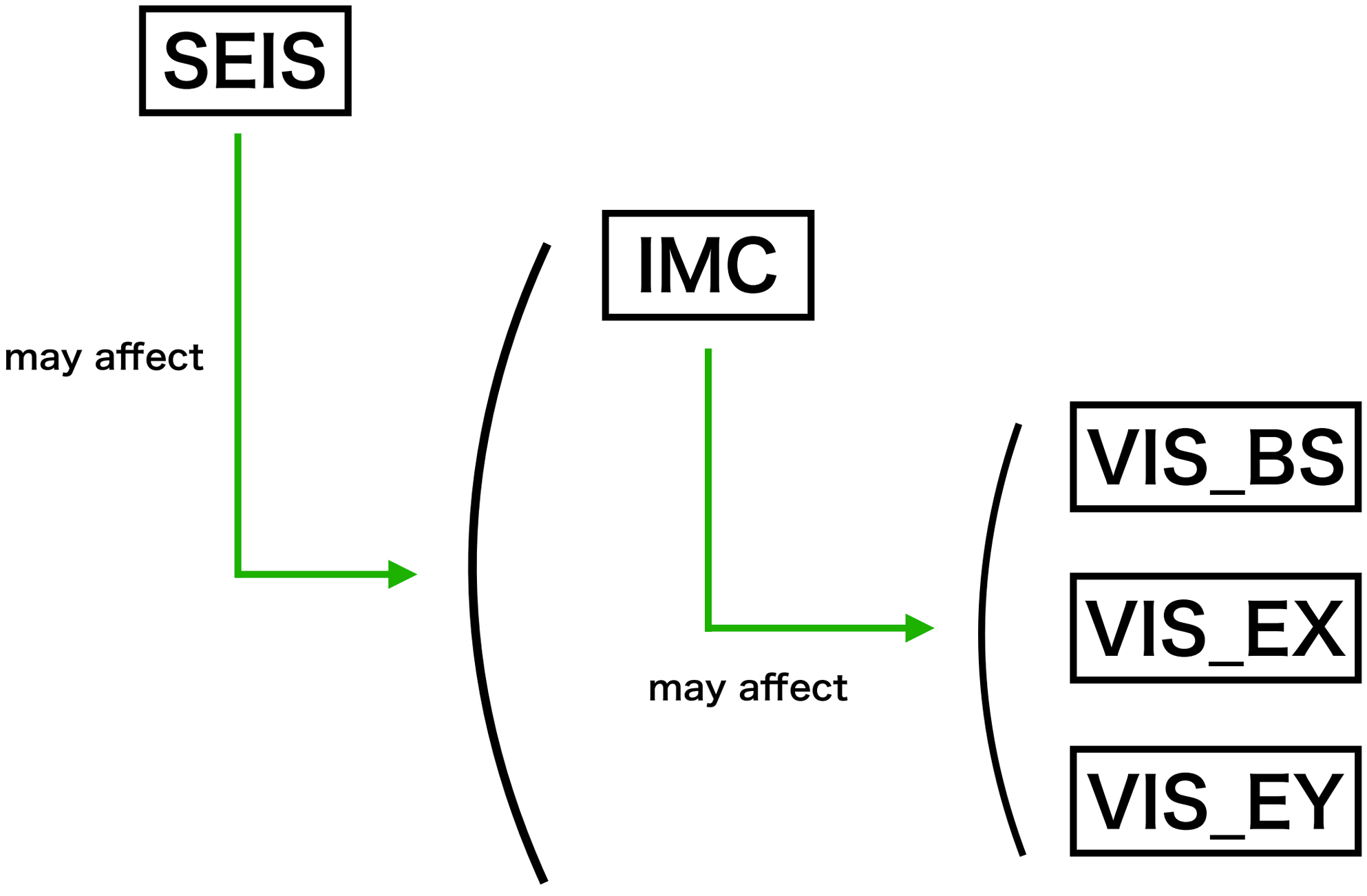

RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
threshold
1um/s
RMS of Seismic vibration [um/s]
GPS [s]
×10^9
0
0.5
1
1.5
2
2.5
3
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097


RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
big RMS
threshold
1um/s
small RMS
RMS of Seismic vibration [um/s]
3
2.5
2
1.5
1
0.5
0
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097
GPS [s]
×10^9

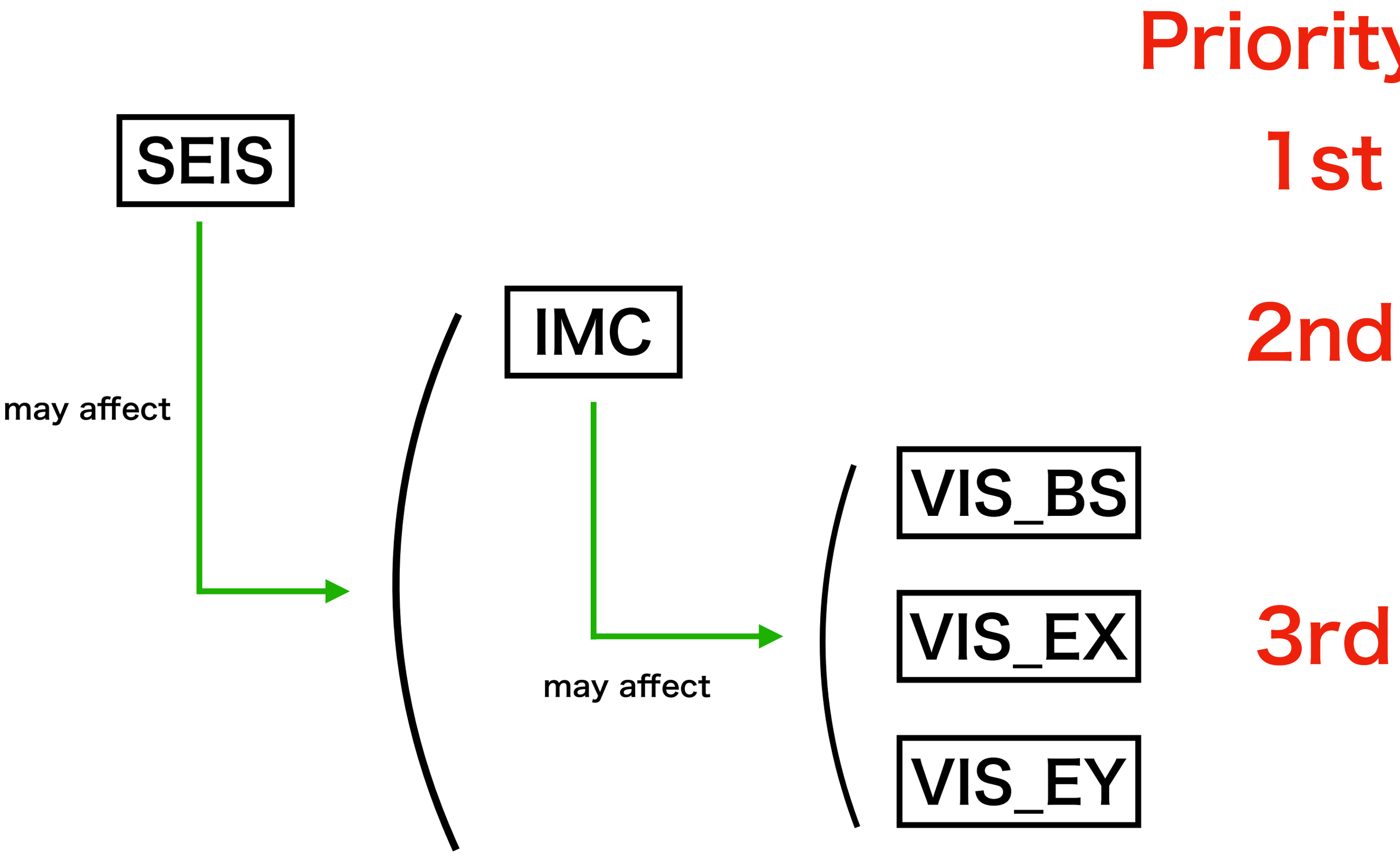

RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
BS state
RMS of SEIS [um/s]
3
2.5
2
1.5
1
0.5
0
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097
GPS [s]
×10^9


93th of LL range : 10 [s] LLtime : 1209671398.5625[s]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
MICH
IMC
SEIS
SEISstate
VISBS
VISEX
VISEY
1.209671392
1.209671394
1.209671396
1.209671398
1.2096714
1.209671402
1.209671404
time [s]
×10^9

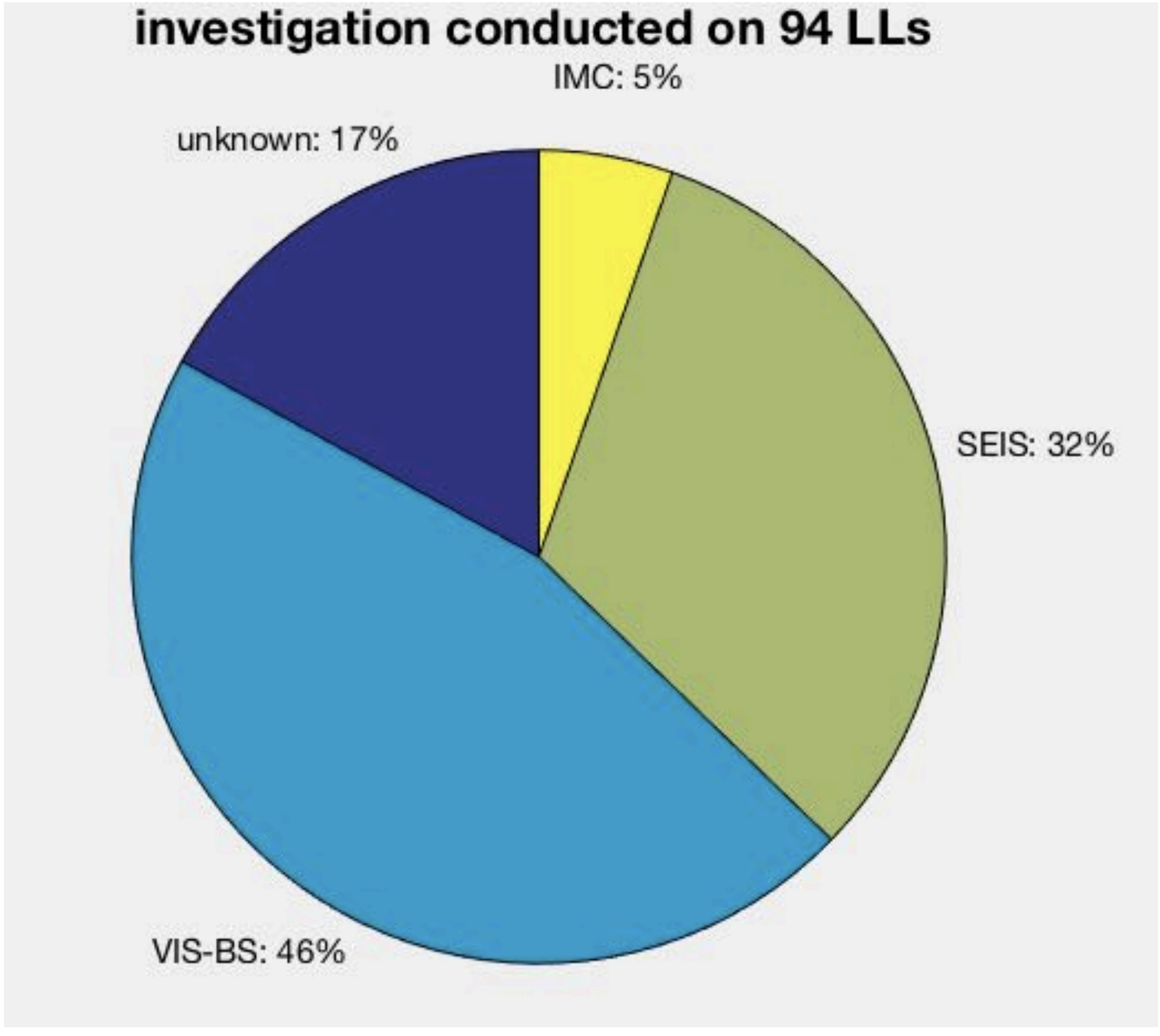
Priority of identifying the cause



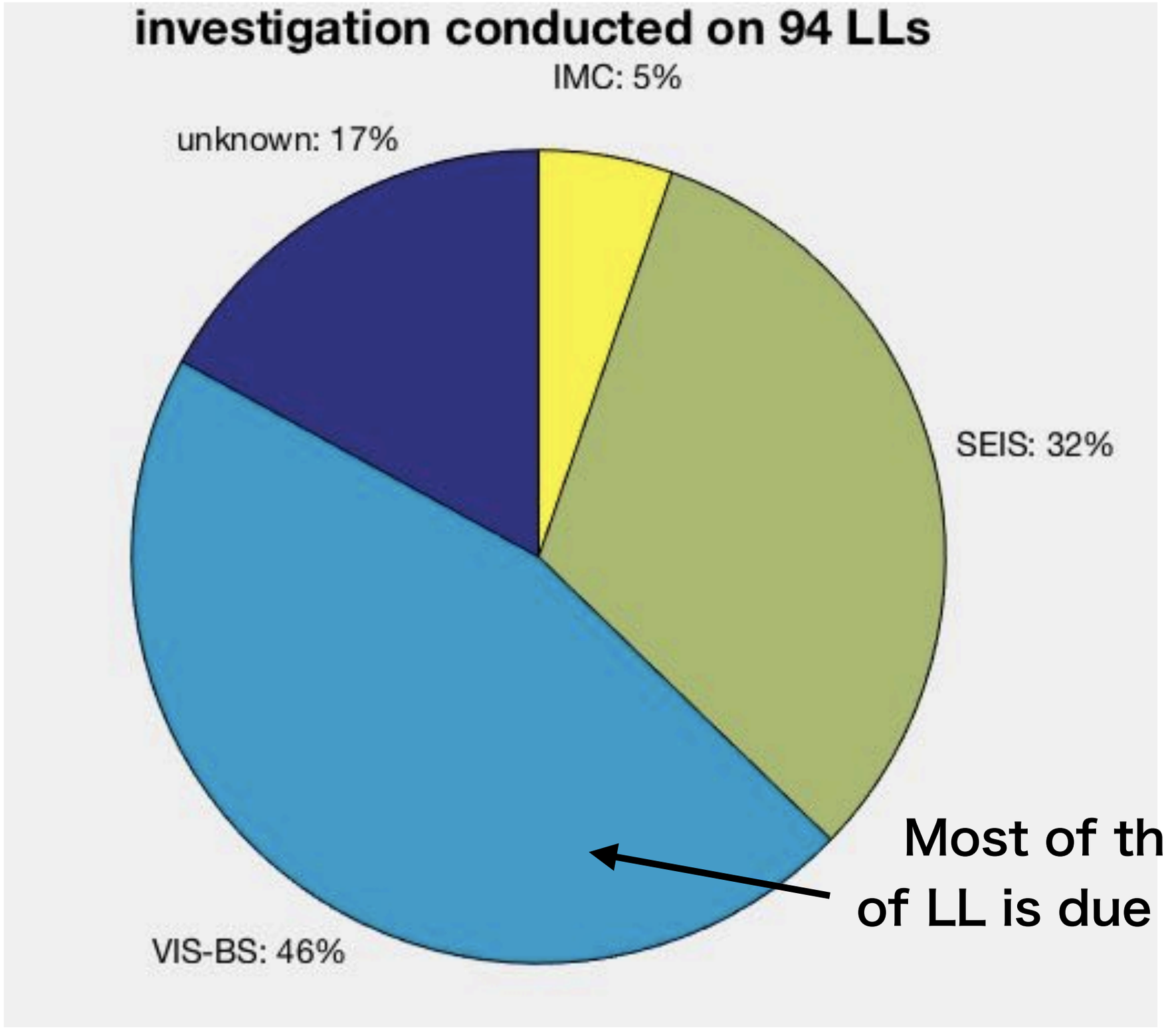
Priority of identifying the cause



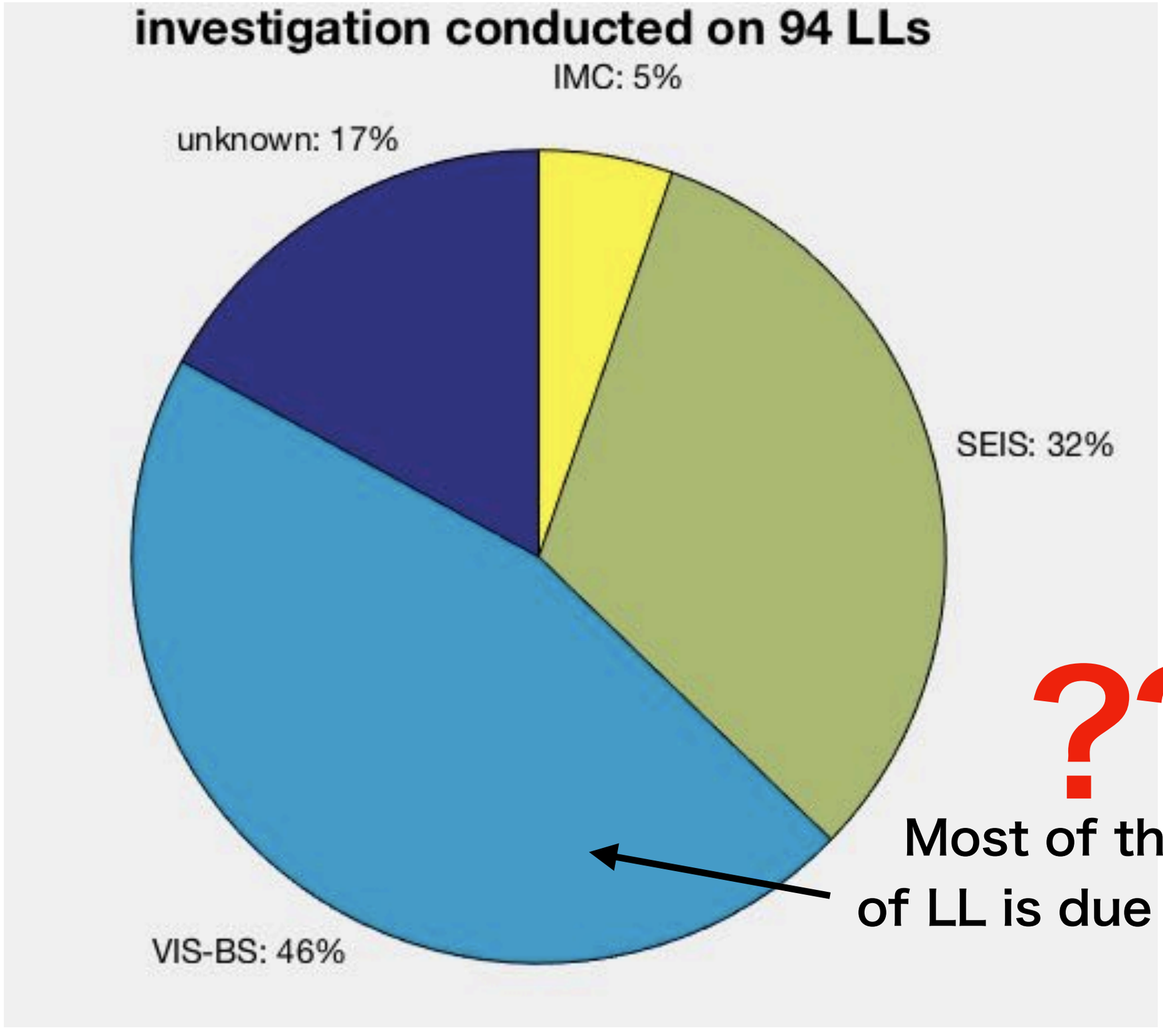
Ratio of LockLoss



Ratio of LockLoss



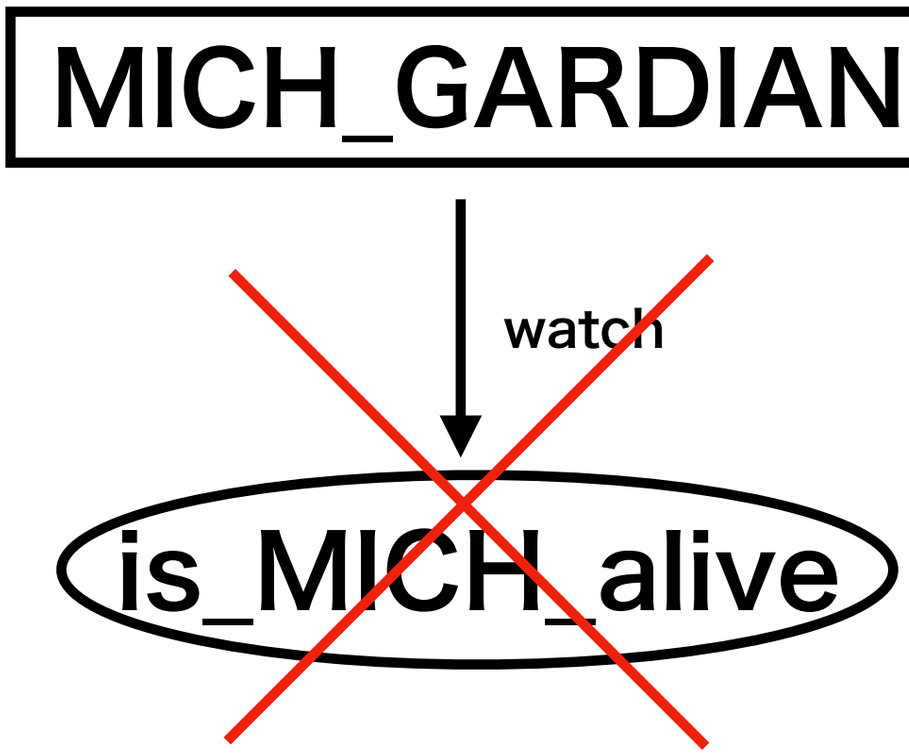
Ratio of LockLoss



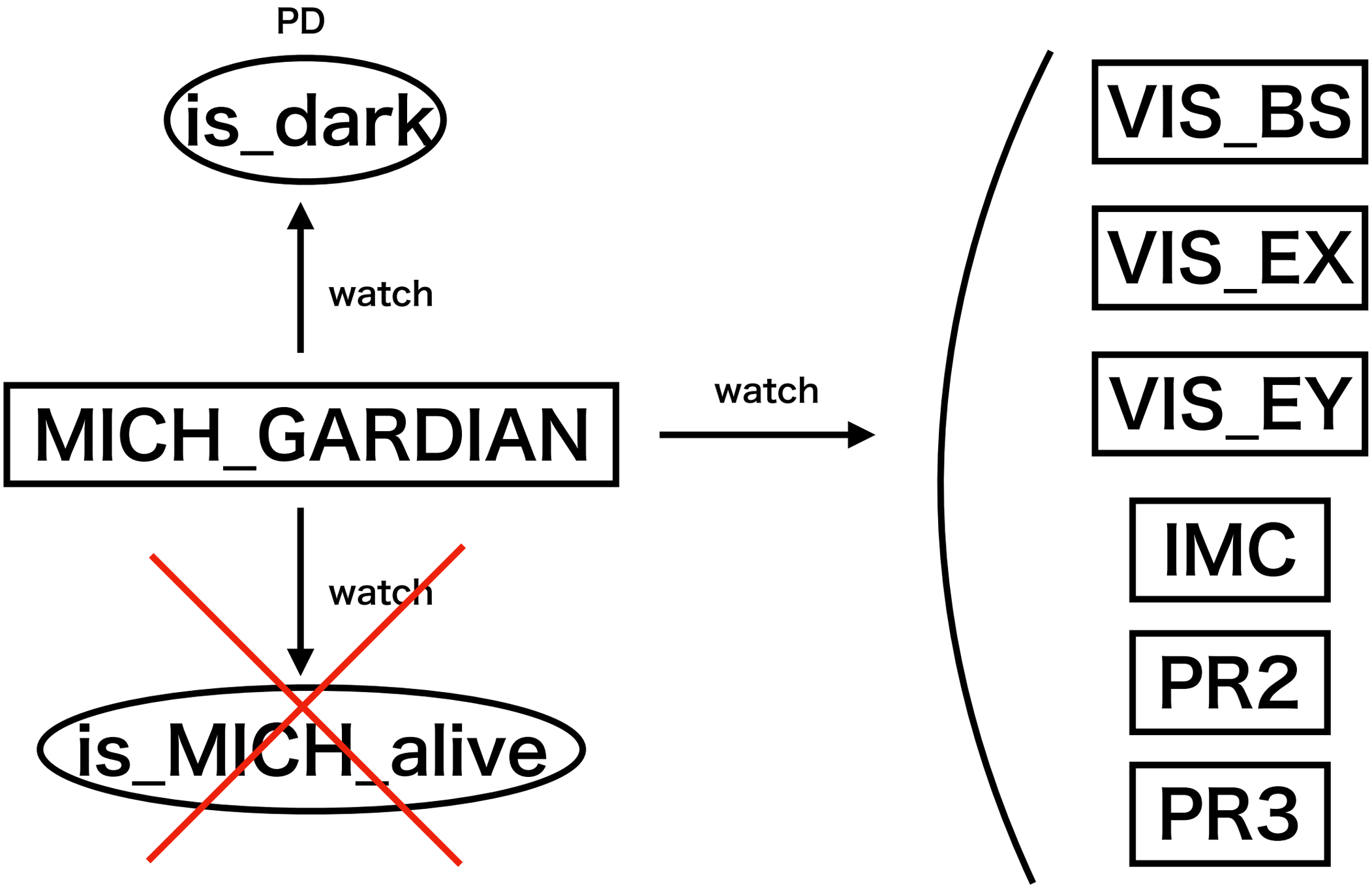
???

Most of the cause
of LL is due to VIS-BS

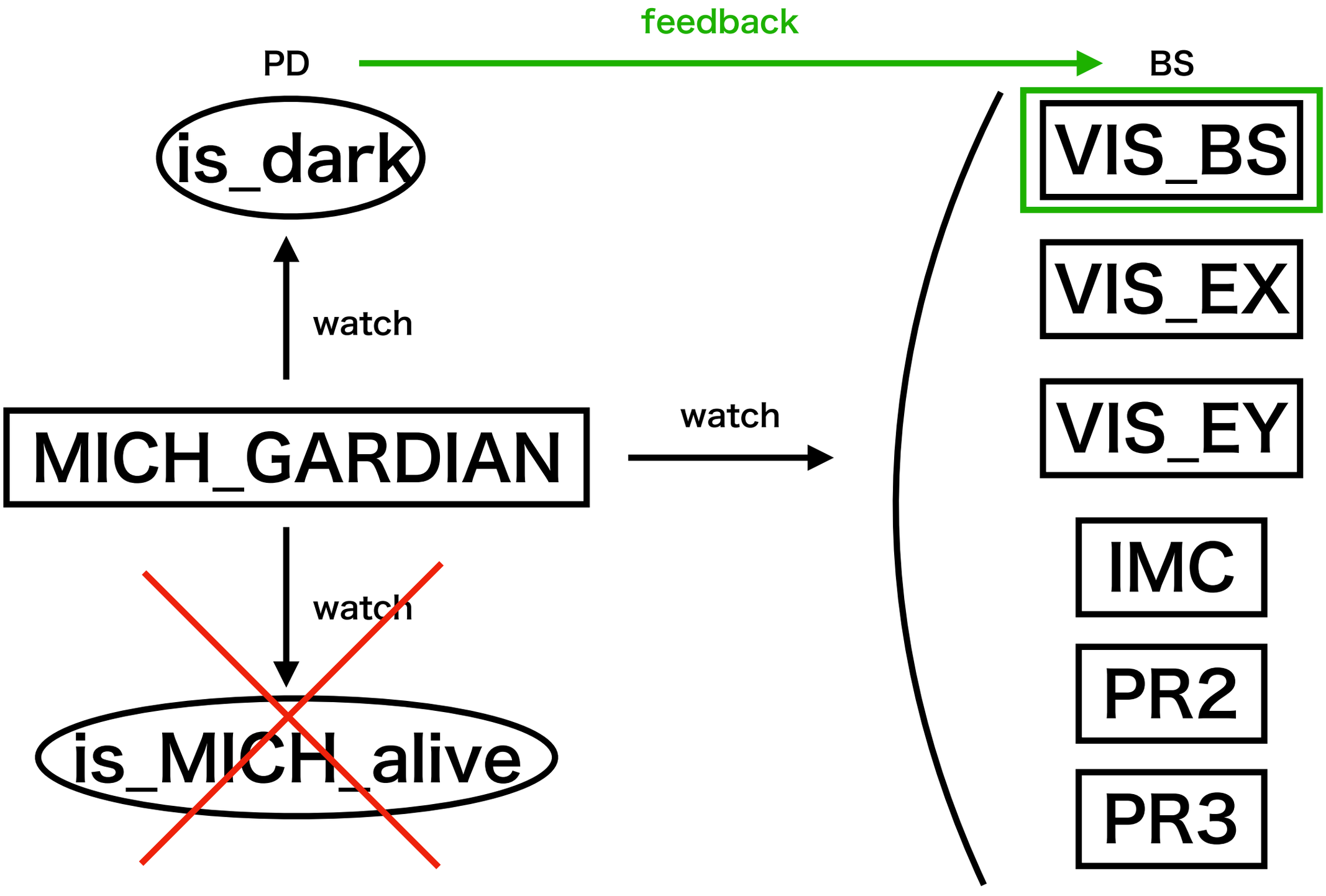
Relation between "MICH" & "VIS_BS"



Relation between "MICH" & "VIS_BS"

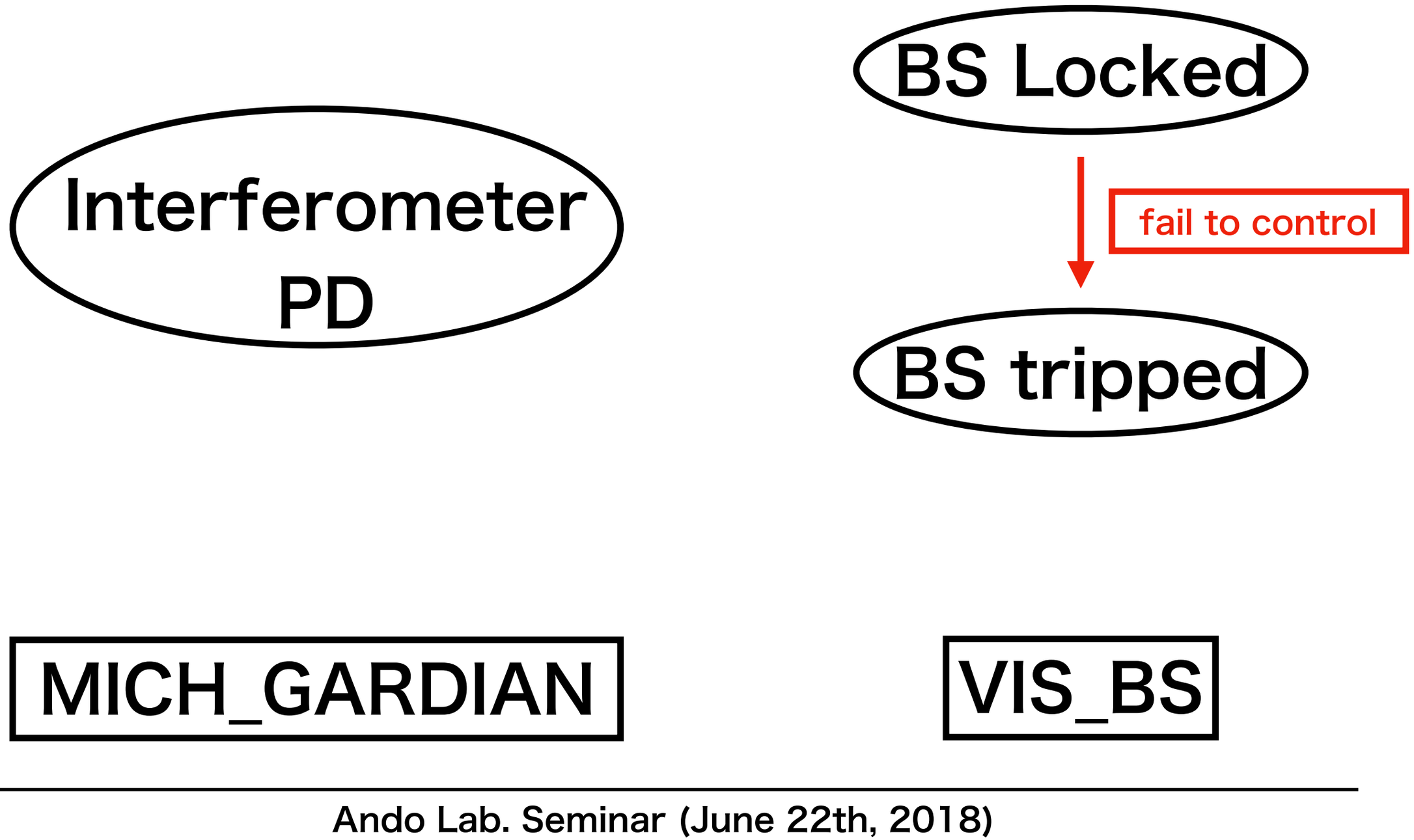


Relation between "MICH" & "VIS_BS"



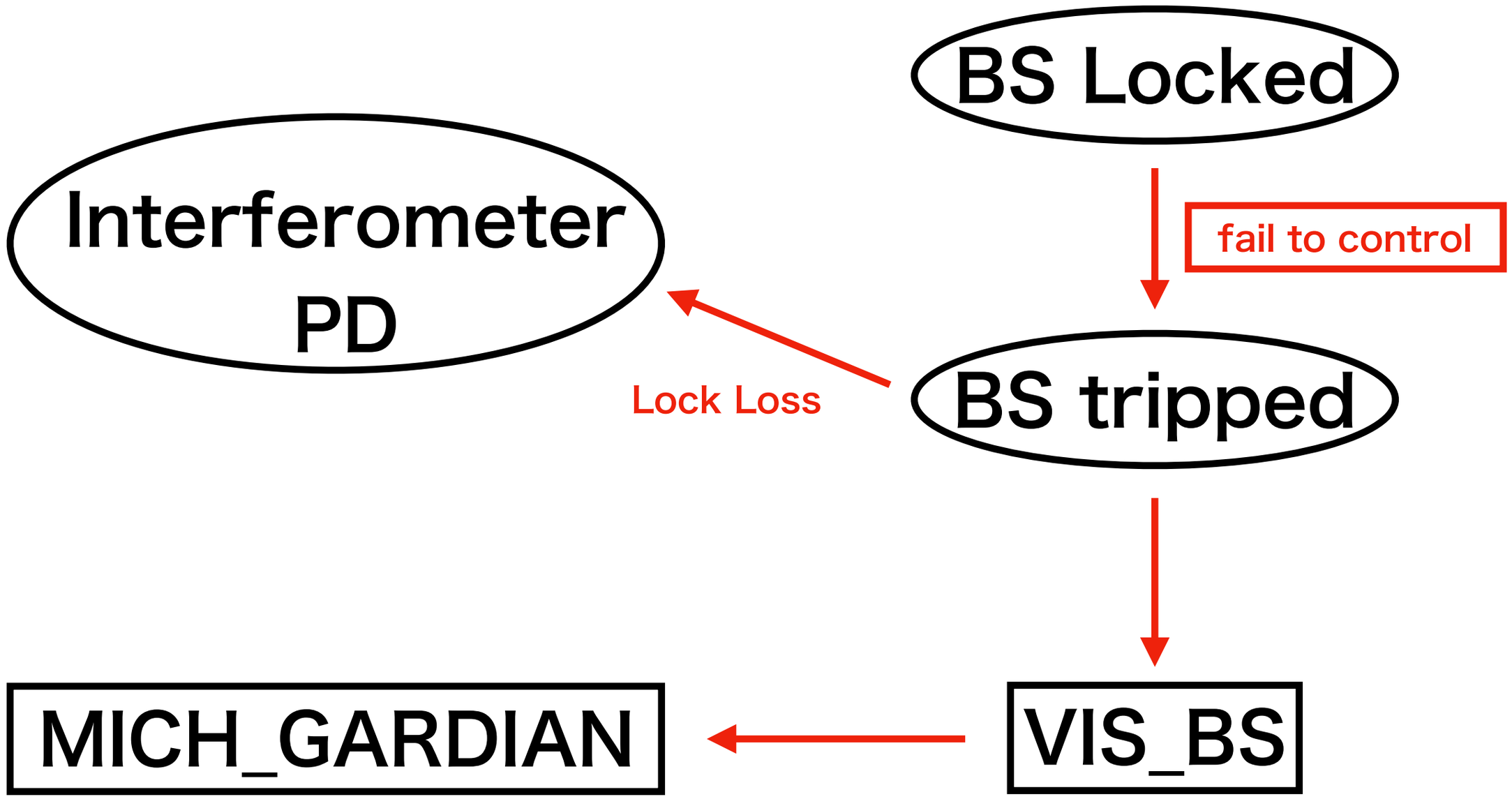
Relation between "MICH" & "VIS_BS"

① BS trip --> Lock Loss



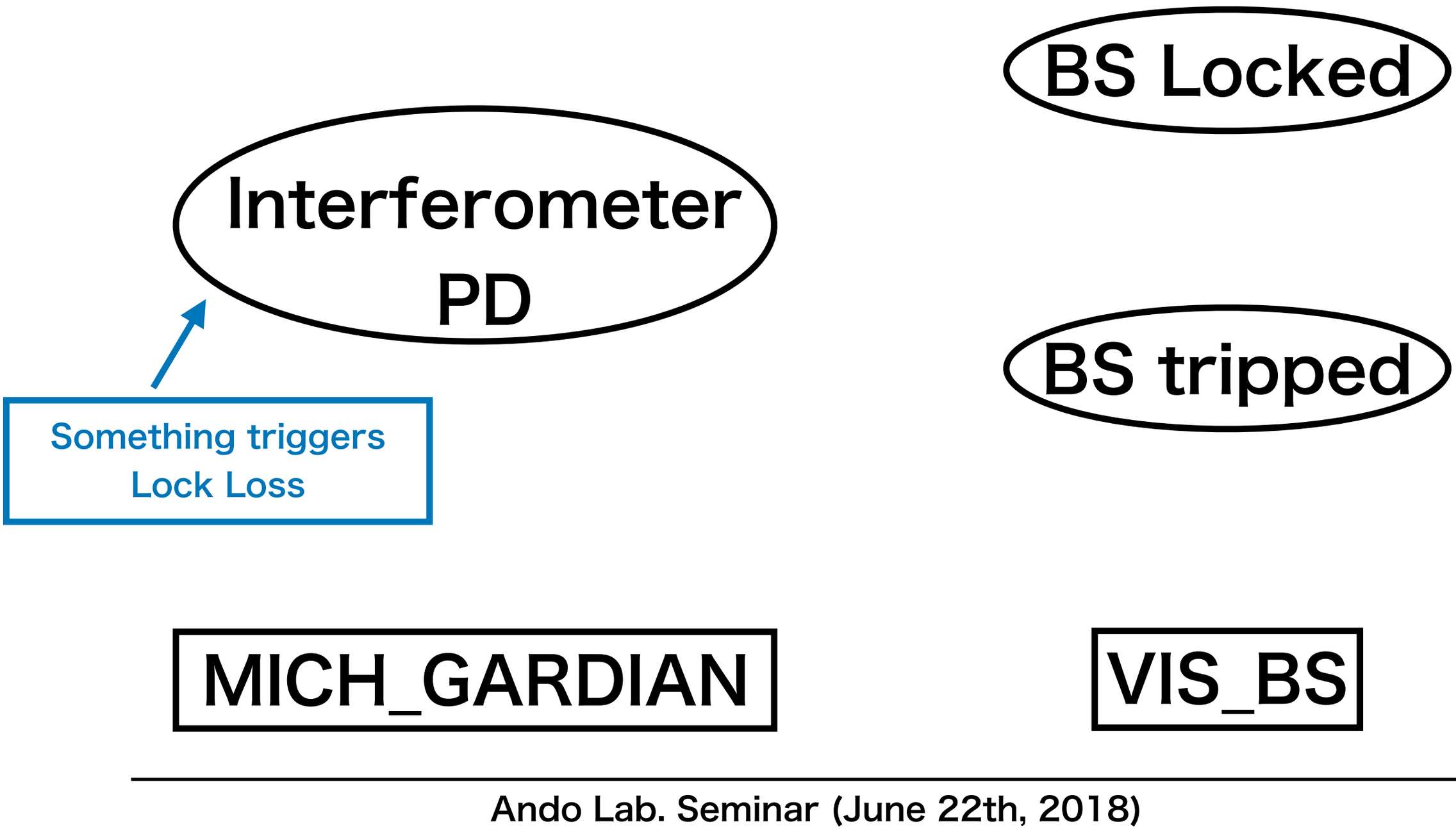
Relation between "MICH" & "VIS_BS"

① BS trip --> Lock Loss



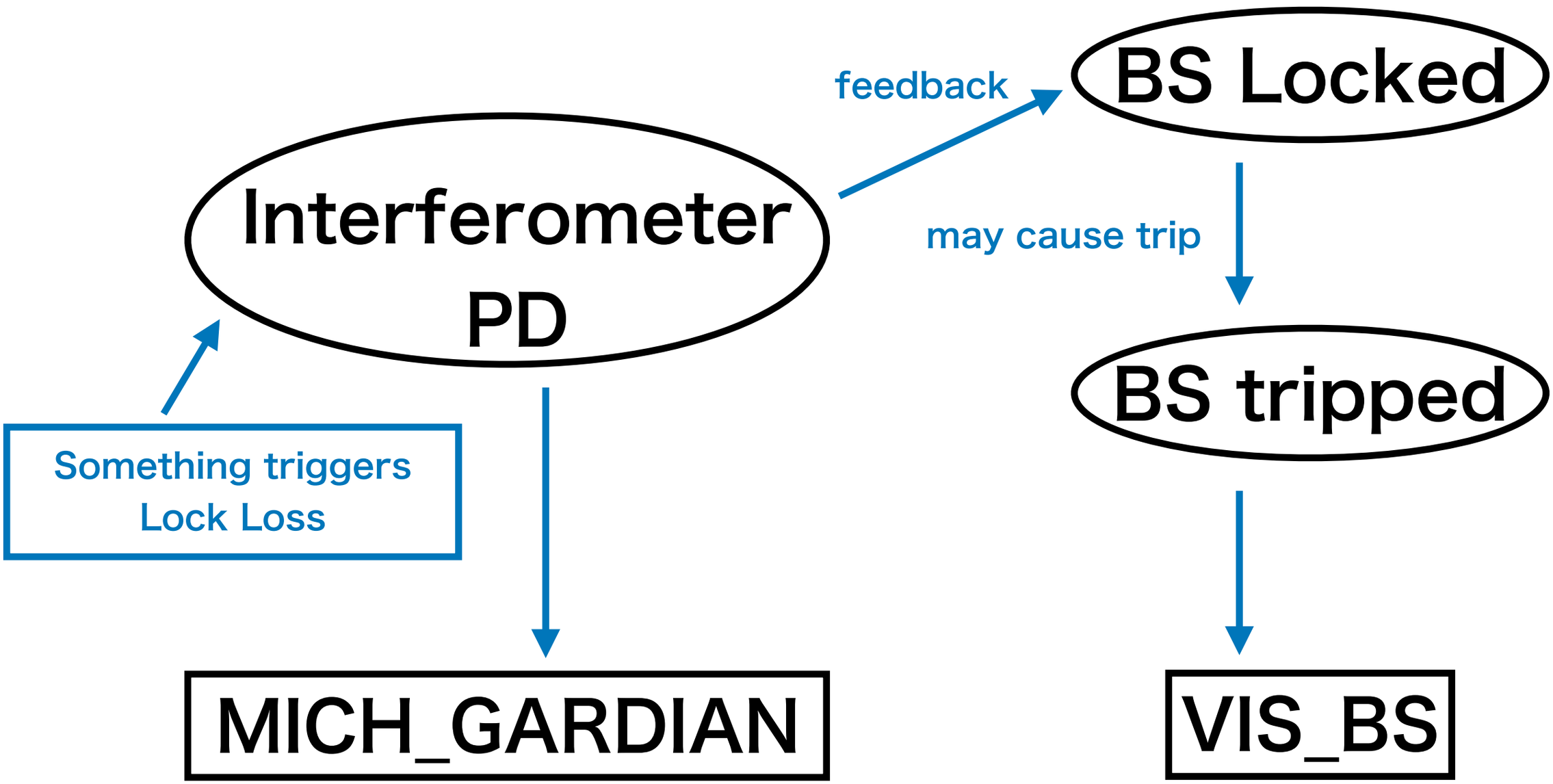
Relation between "MICH" & "VIS_BS"

② Lock Loss --> BS trip



Relation between "MICH" & "VIS_BS"

② Lock Loss --> BS trip

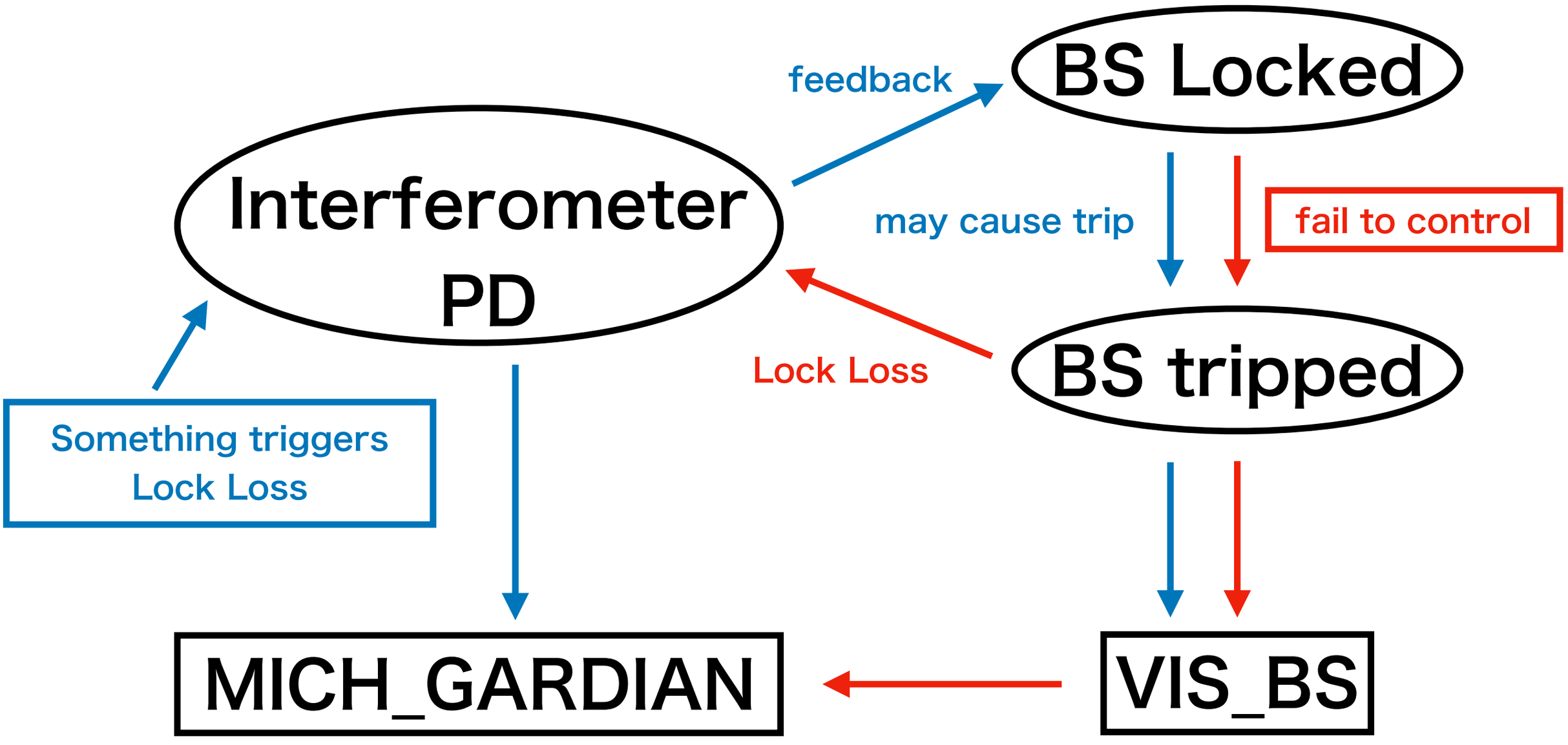


Relation between "MICH" & "VIS_BS"

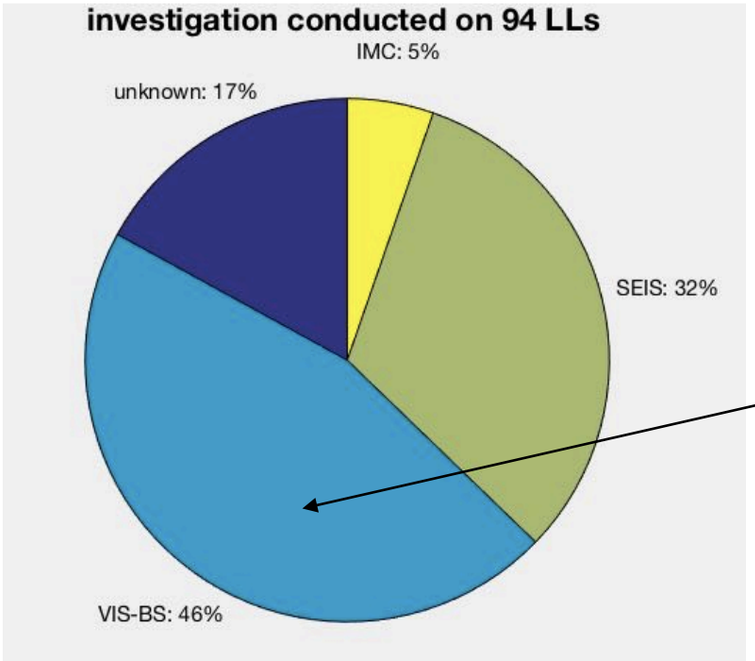
① BS trip --> Lock Loss

② Lock Loss --> BS trip

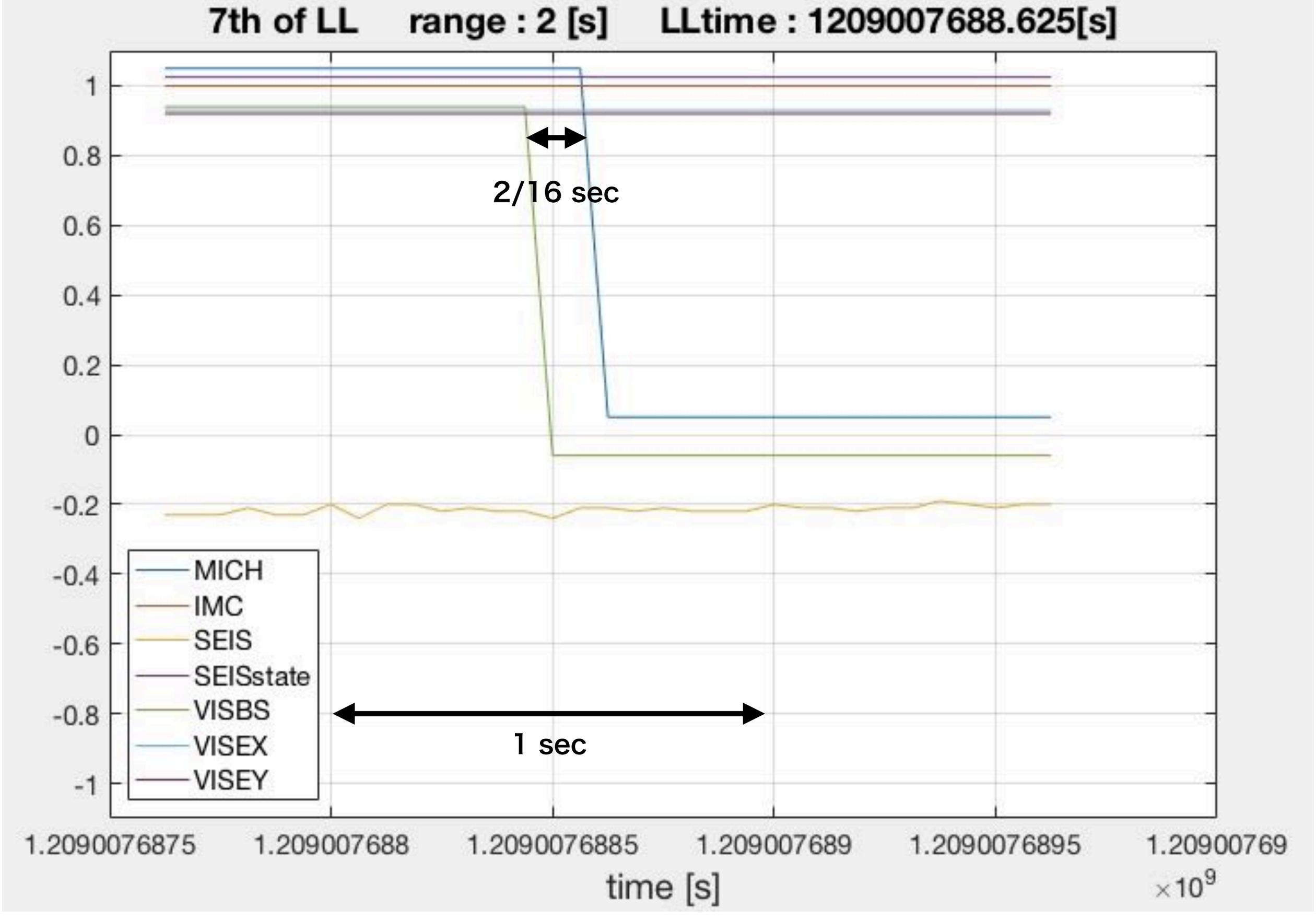
We cannot distinguish completely these 2 types!



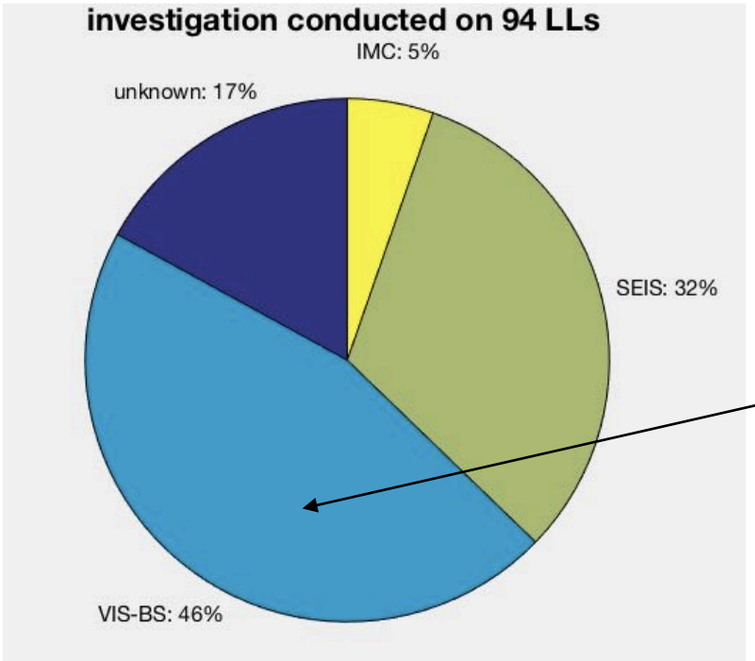
Was the LL due to BS ?



- In data, ALL "LL caused by BS" show MICH went down after BS went down.
- The delay time was (2~4)/16 sec.


7th of LL range : 2 [s] LLtime : 1209007688.625[s]
2/16 sec
1 sec
MICH
IMC
SEIS
SEISstate
VISBS
VISEX
VISEY
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
1.2090076875
1.209007688
1.2090076885
1.209007689
1.2090076895
1.20900769
time [s]
×10^9

Was the LL due to BS ?



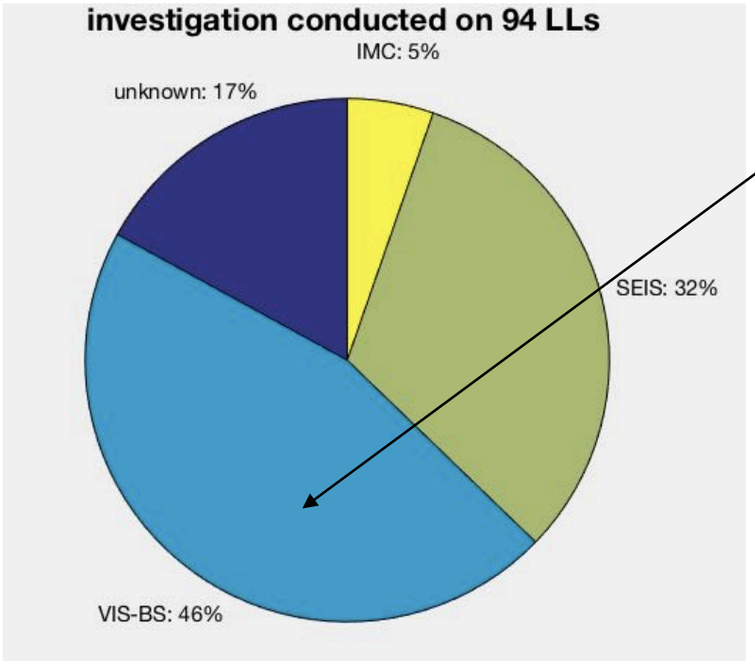
- In data, ALL "LL caused by BS" show MICH went down after BS went down.
- The delay time was (2~4)/16 sec.

What makes the delay?

- Each Guardian runs on independent MEDM.
- MICH Guardian used Samp=16Hz channel to watch other Guardians.
- The delay was due to calculators.

We can't distinguish which actually went down first.

Was the LL due to BS ?

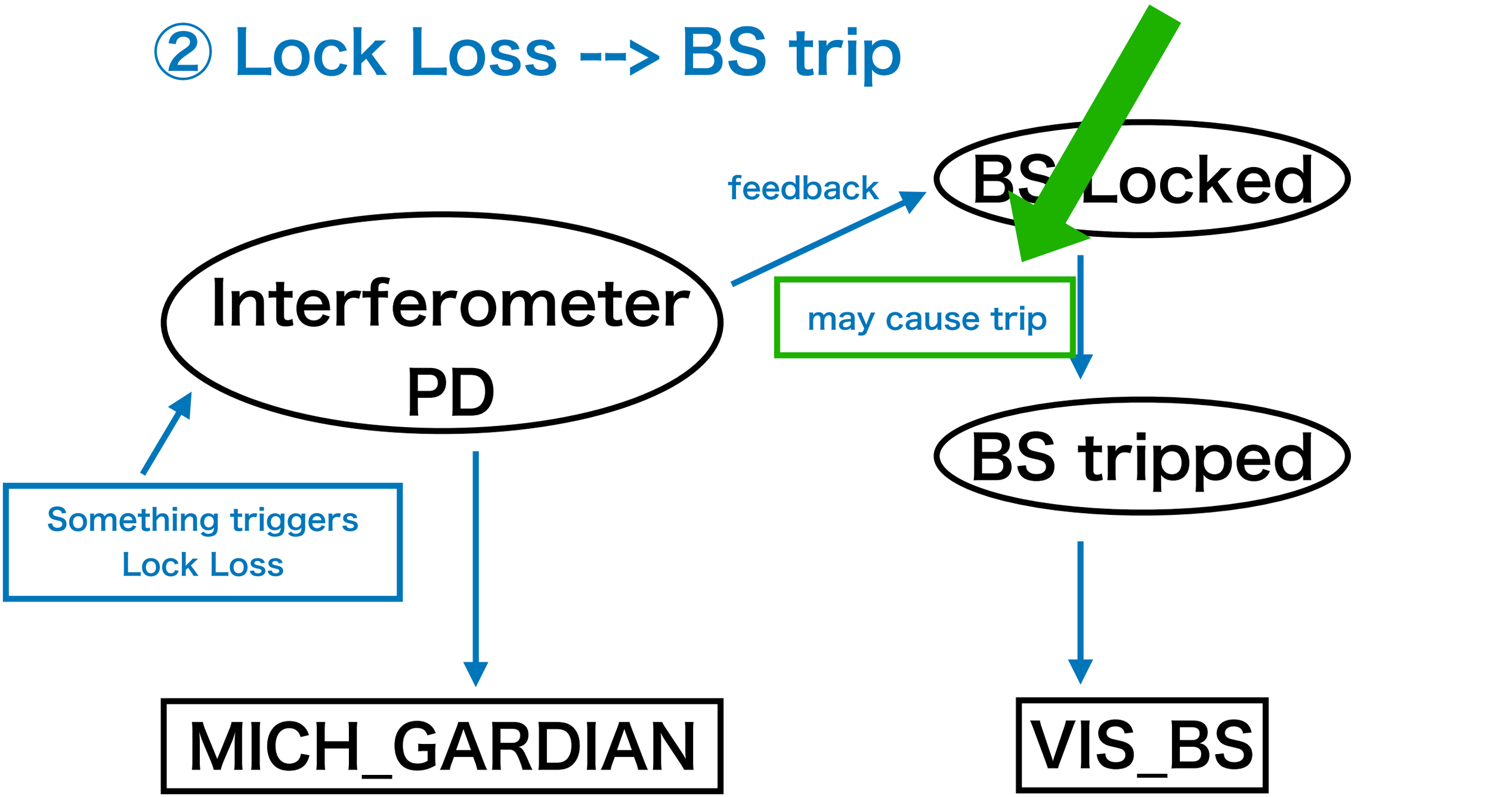


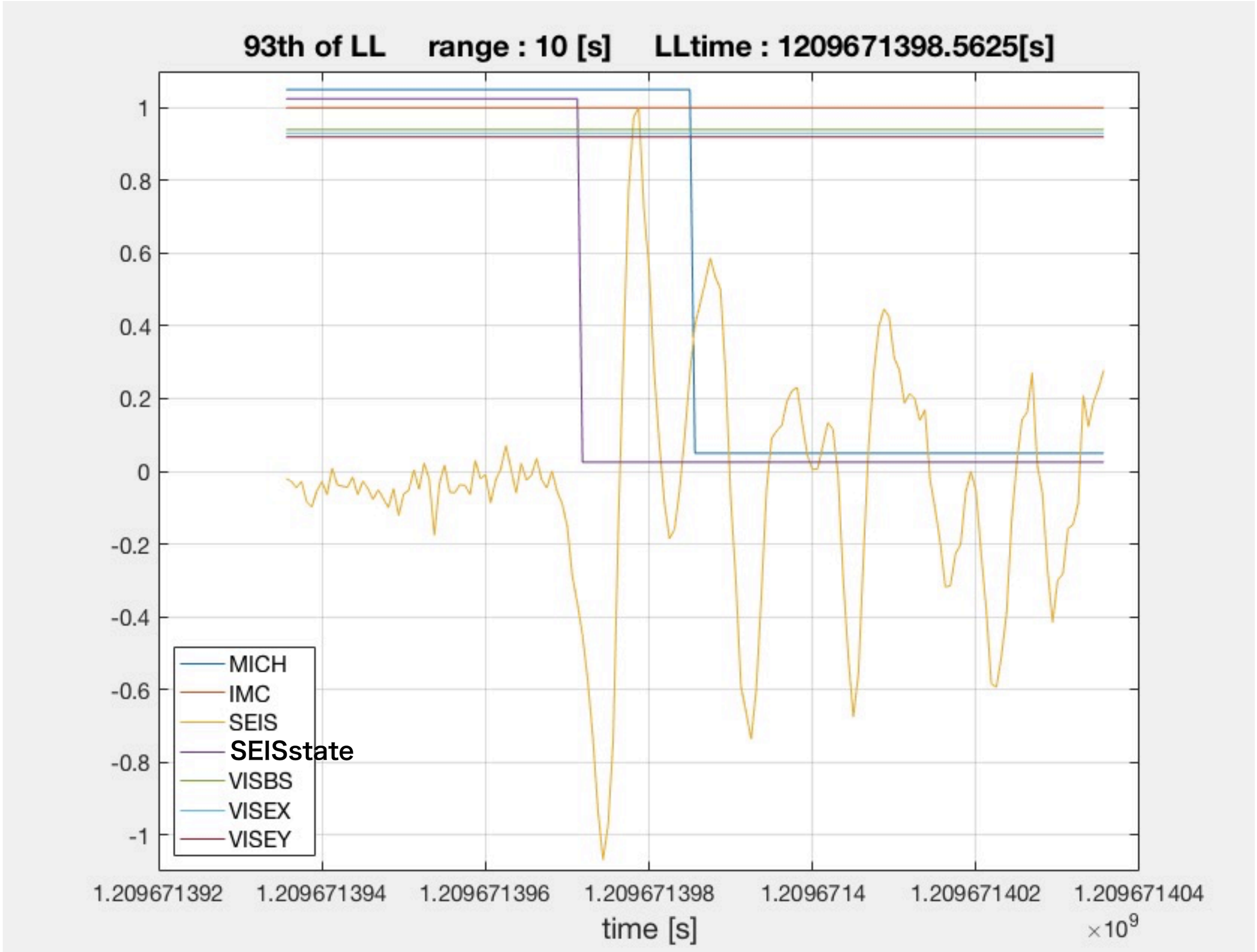
- What percentage of it was due to flow ① and flow ②?
- Flow ①: BS trip is surely accompanied by LL.
- Flow ②: LL is not always accompanied by BS trip.

Relation between "MICH" & "VIS_BS"

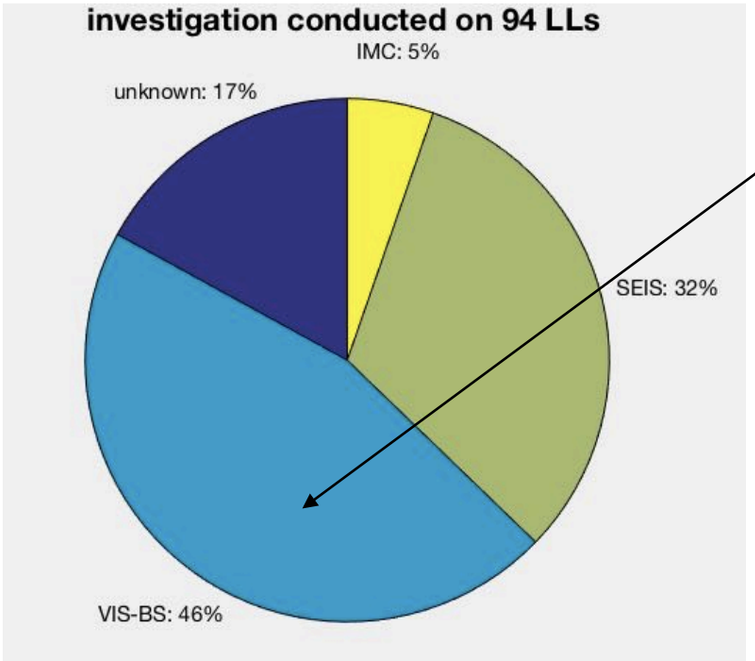
Not always happens!

② Lock Loss --> BS trip




93th of LL range : 10 [s] LLtime : 1209671398.5625[s]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
MICH
IMC
SEIS
SEISstate
VISBS
VISEX
VISEY
1.209671392
1.209671394
1.209671396
1.209671398
1.2096714
1.209671402
1.209671404
time [s]
×10^9

Was the LL due to BS ?



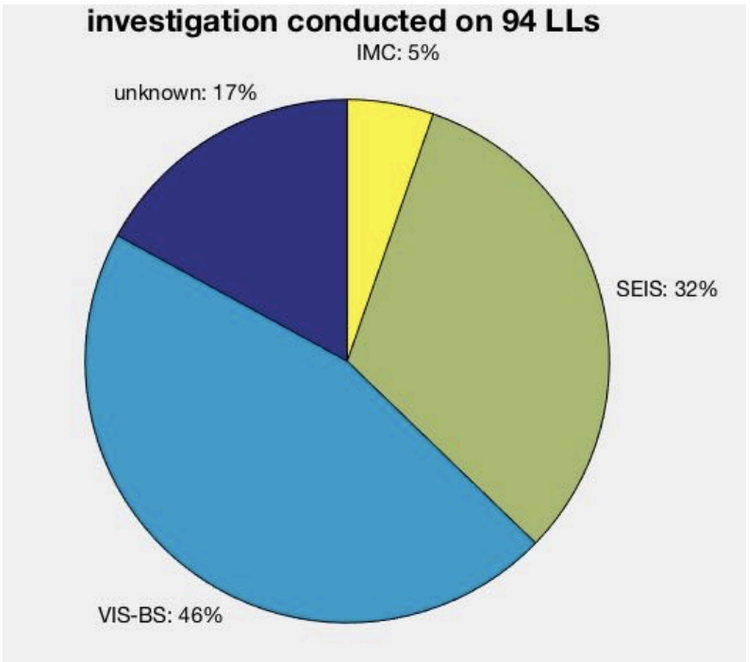
- What percentage of it was due to flow ① and flow ②?
- Flow ①: BS trip is surely accompanied by LL.
- Flow ②: LL is not always accompanied by BS trip.

Discuss!

about whether this 46% was due to BS trip.

Please give me some advice...

Was the LL due to BS ?



I think the most was due to BS.

- MICH down was so delayed compared to BS down.

- LL is not always accompanied by BS trip.

What do you think?

Discuss!

about whether this 46% was due to BS trip.

Please give me some advice...

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2. The ratio of cause of Lock loss

3. What kind of EQ causes Lock loss?
   (Classifying EQs as to its safeness)

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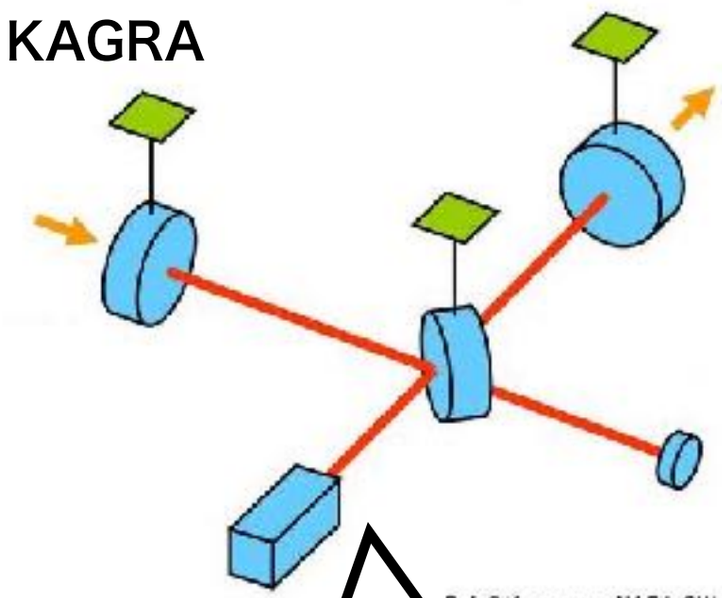
   (Classifying EQs as to its safeness)

LL caused by EQ

KAGRA



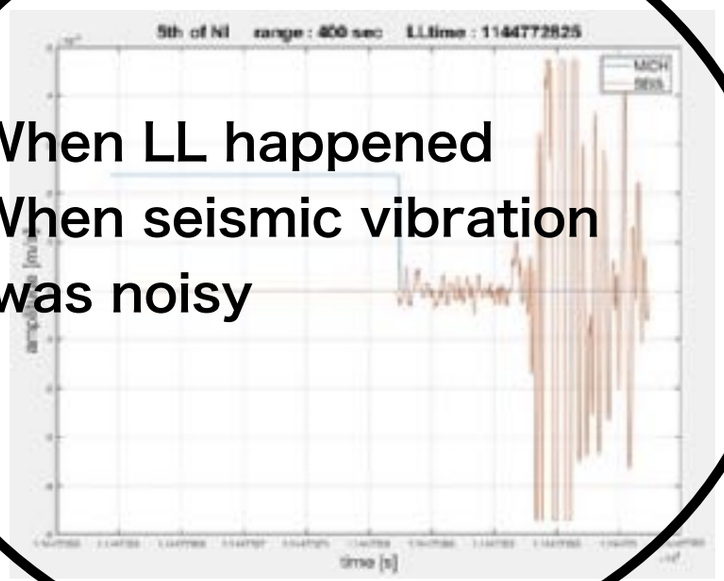
Ref: S.Kawamura, NAOJ, GW antenna DECIGO

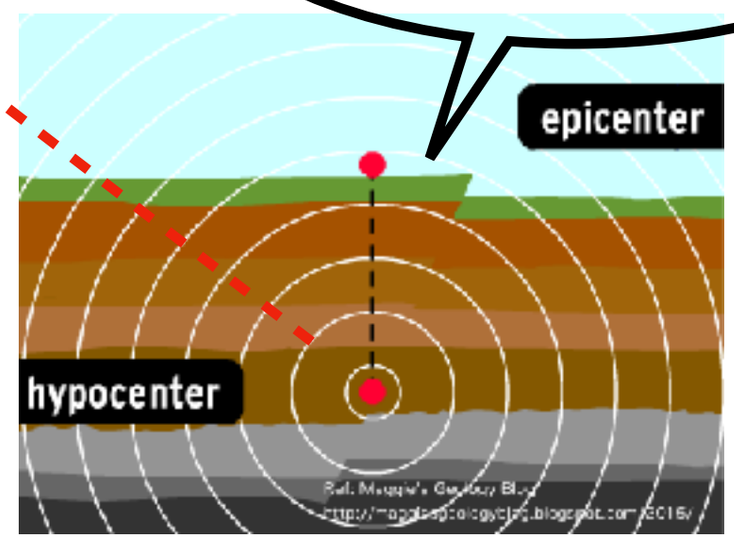
- distance (in a straight line)
- arrival time range
  (when EQ came)

- Place
- Magnitude
- happened time

EQ propagates

- When LL happened
- When seismic vibration
  was noisy

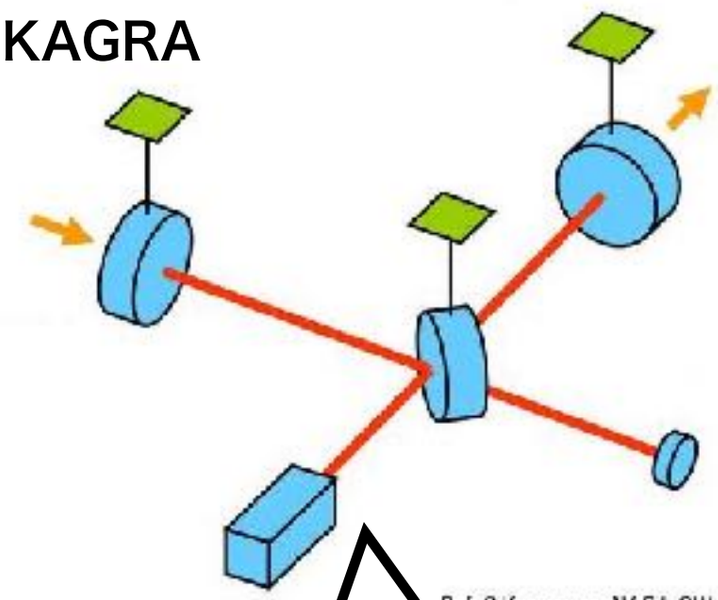




Earthquake

LL caused by EQ

KAGRA



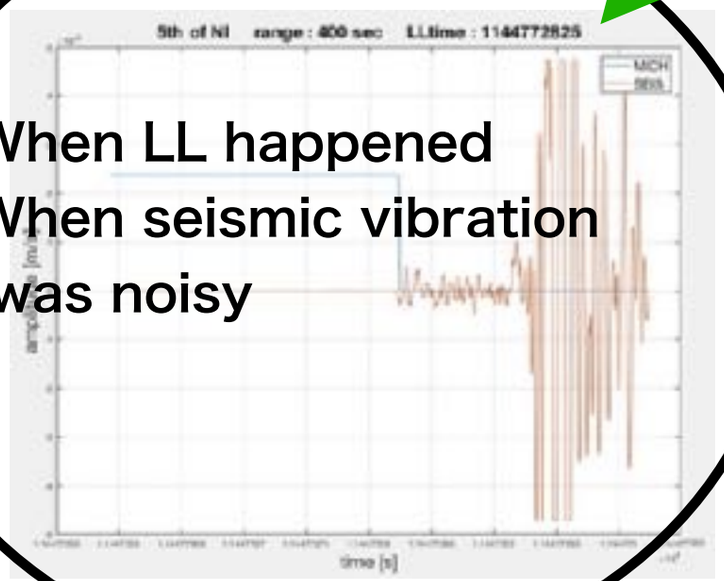
Ref: S.Kawamura, NAOJ, GW antenna DECIGO

- distance (in a straight line)
- arrival time range
  (when EQ came)

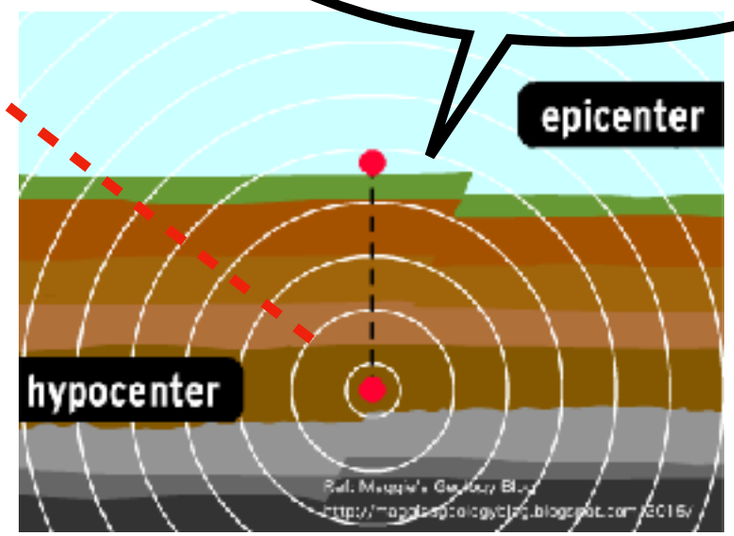
By comparing,
we can conclude
which EQ was danger!

- Place
- Magnitude
- happened time

- When LL happened
- When seismic vibration
  was noisy



EQ propagates



Earthquake

Importance of this study

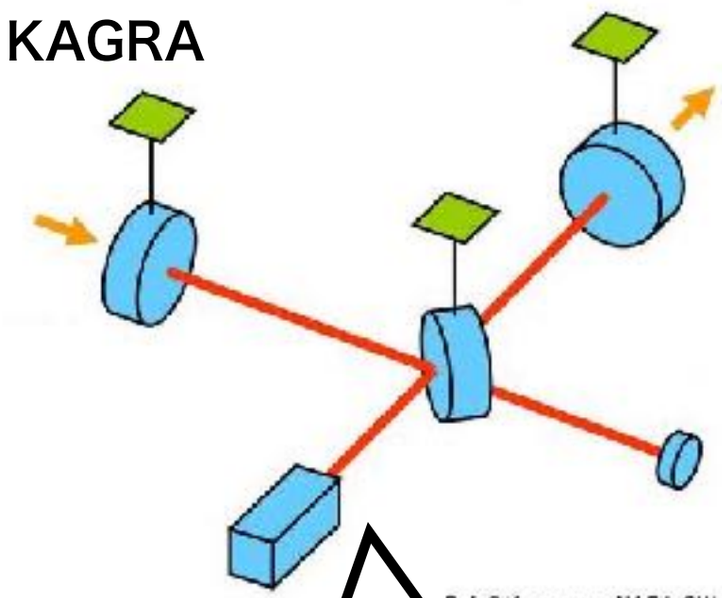
We can know which EQ should be danger for KAGRA

→ If EQ happens while operating, getting information of EQ, we can cope with it appropriately

- **keep operating if the EQ is weak**
- **control interferometer strongly**
- **stop control intentionally to save interferometer**

LL caused by EQ

KAGRA



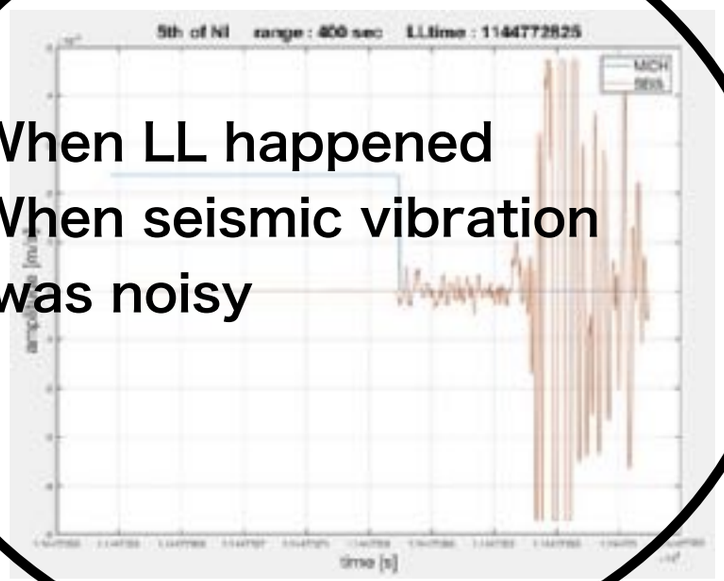
Ref: S.Kawamura, NAOJ, GW antenna DECIGO

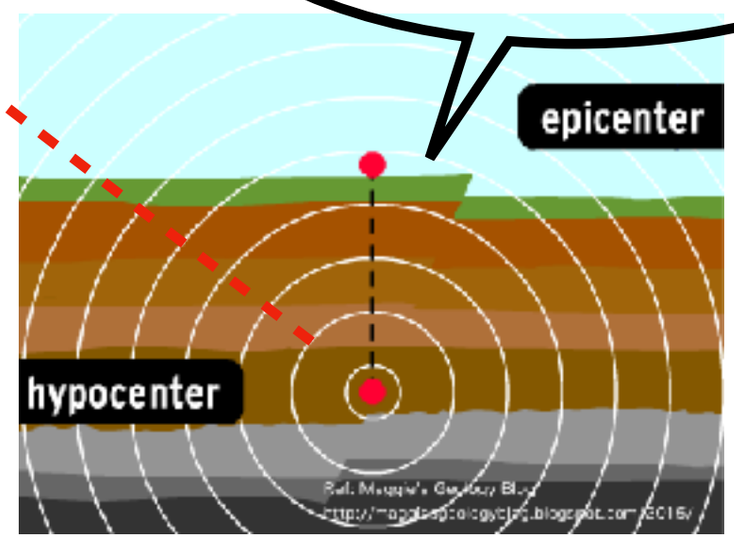
- distance (in a straight line)
- arrival time range
  (when EQ came)

- Place
- Magnitude
- happened time

EQ propagates

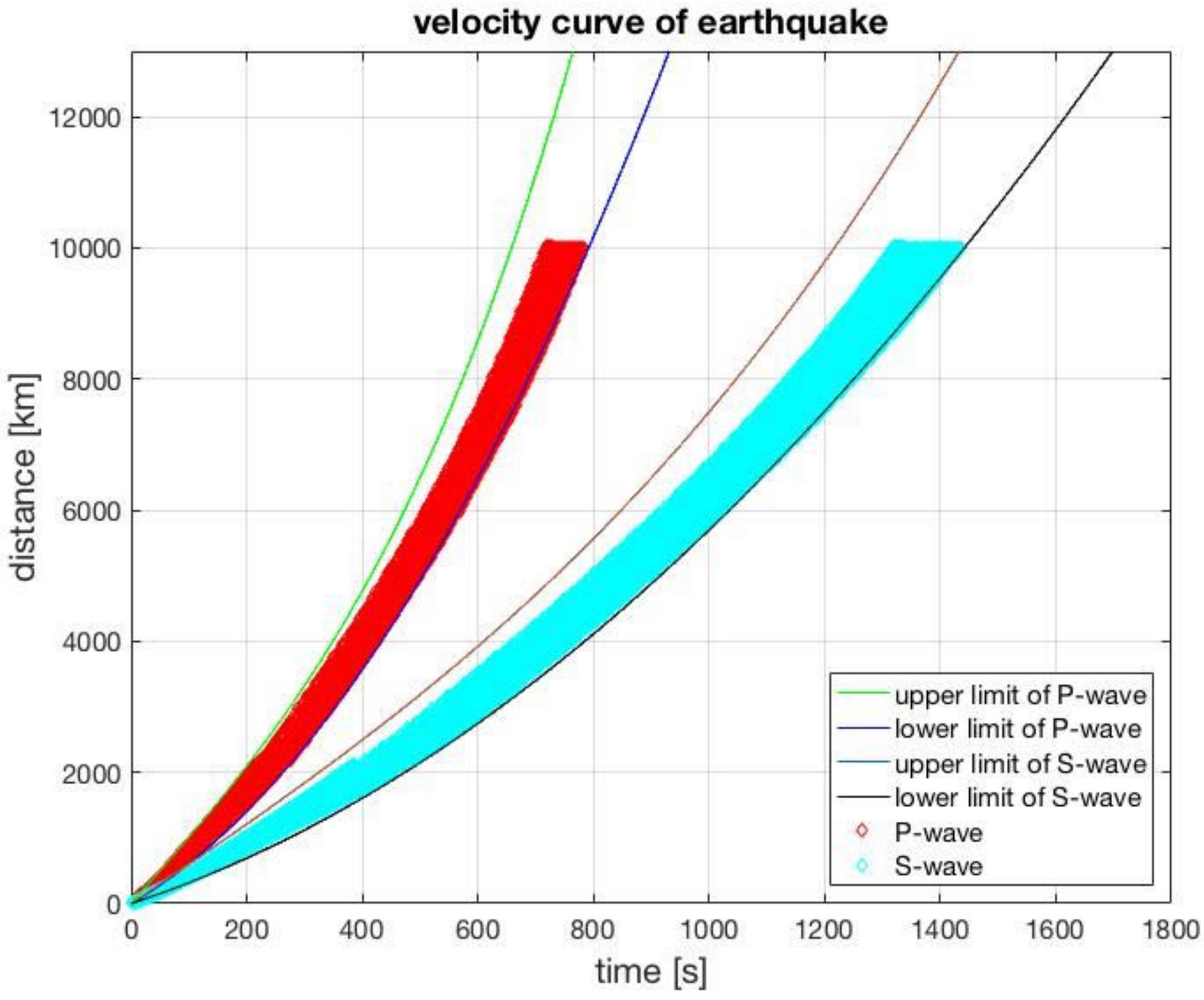
- When LL happened
- When seismic vibration
  was noisy





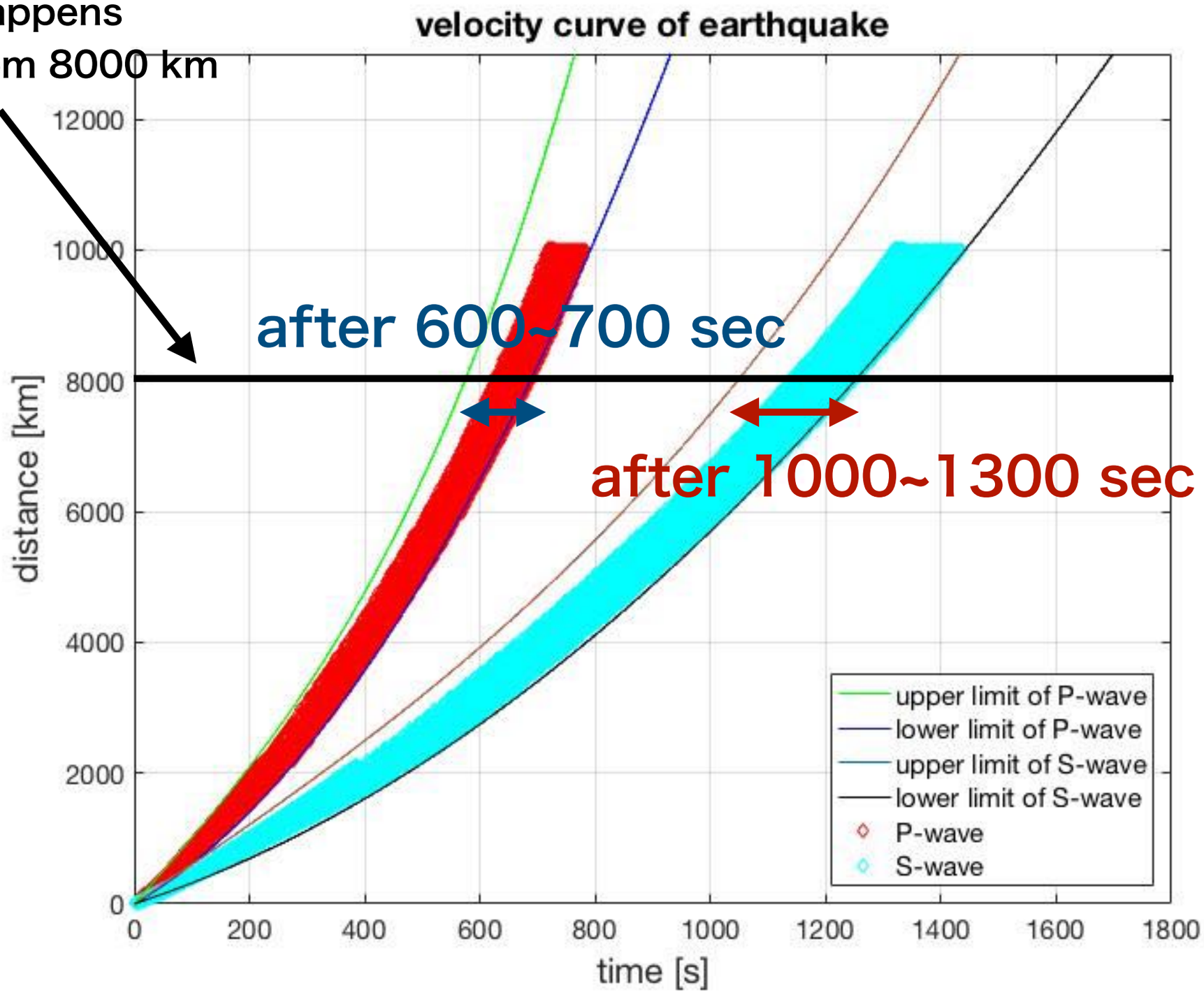
Earthquake

Velocity of Earthquake



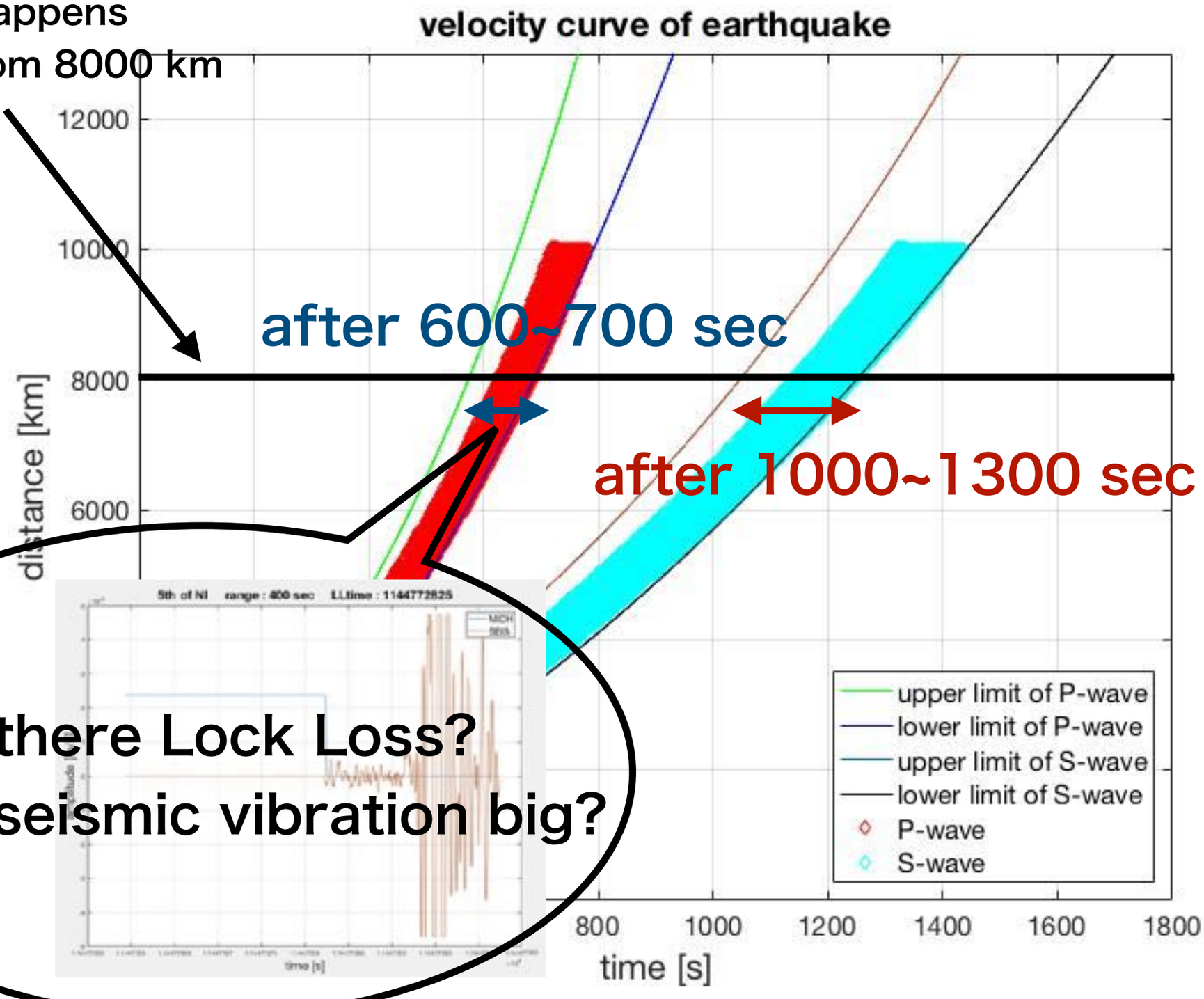
Velocity of Earthquake

EQ happens
distant from 8000 km



Velocity of Earthquake

EQ happens
distant from 8000 km



- Was there Lock Loss?
- Was seismic vibration big?

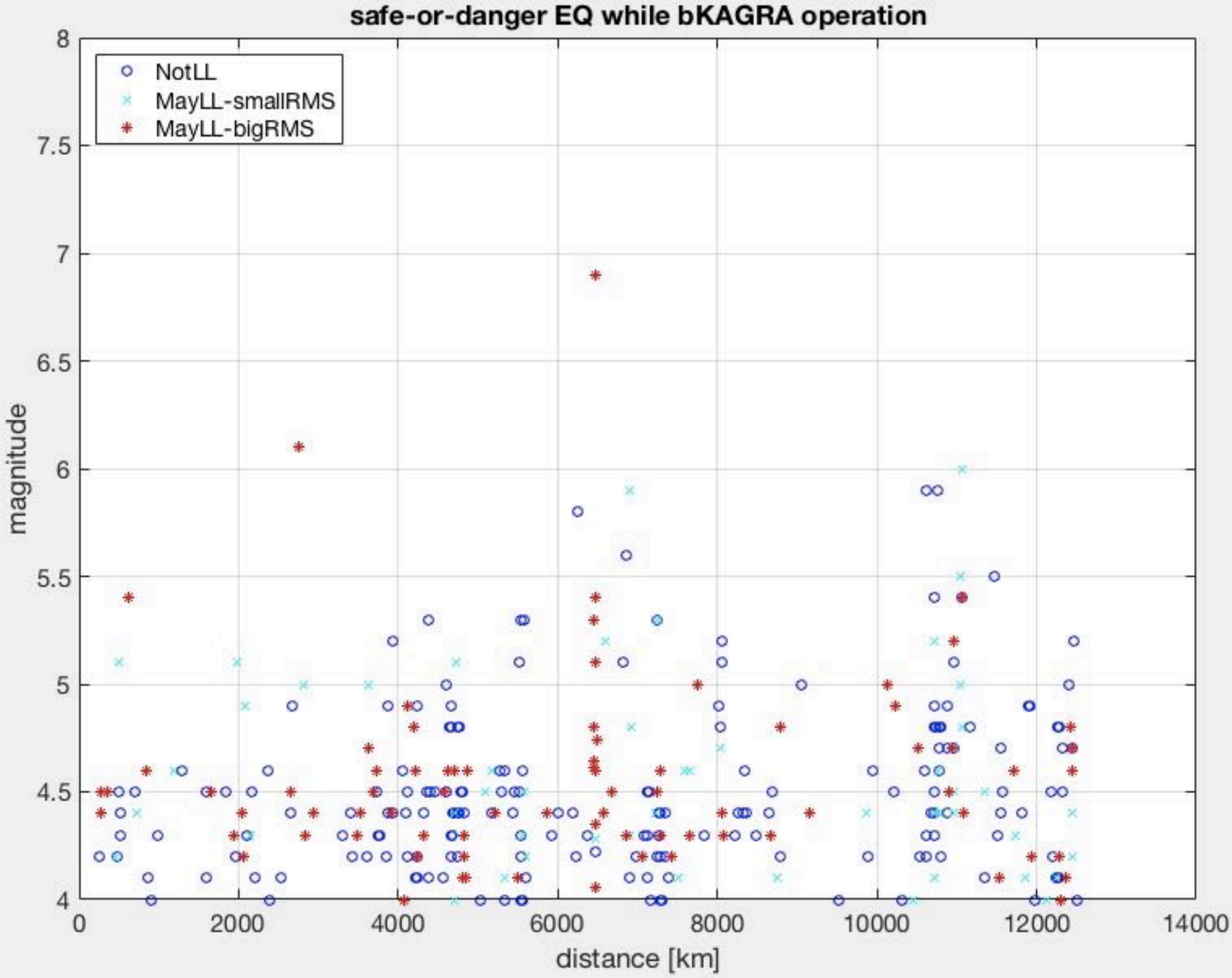
Notice

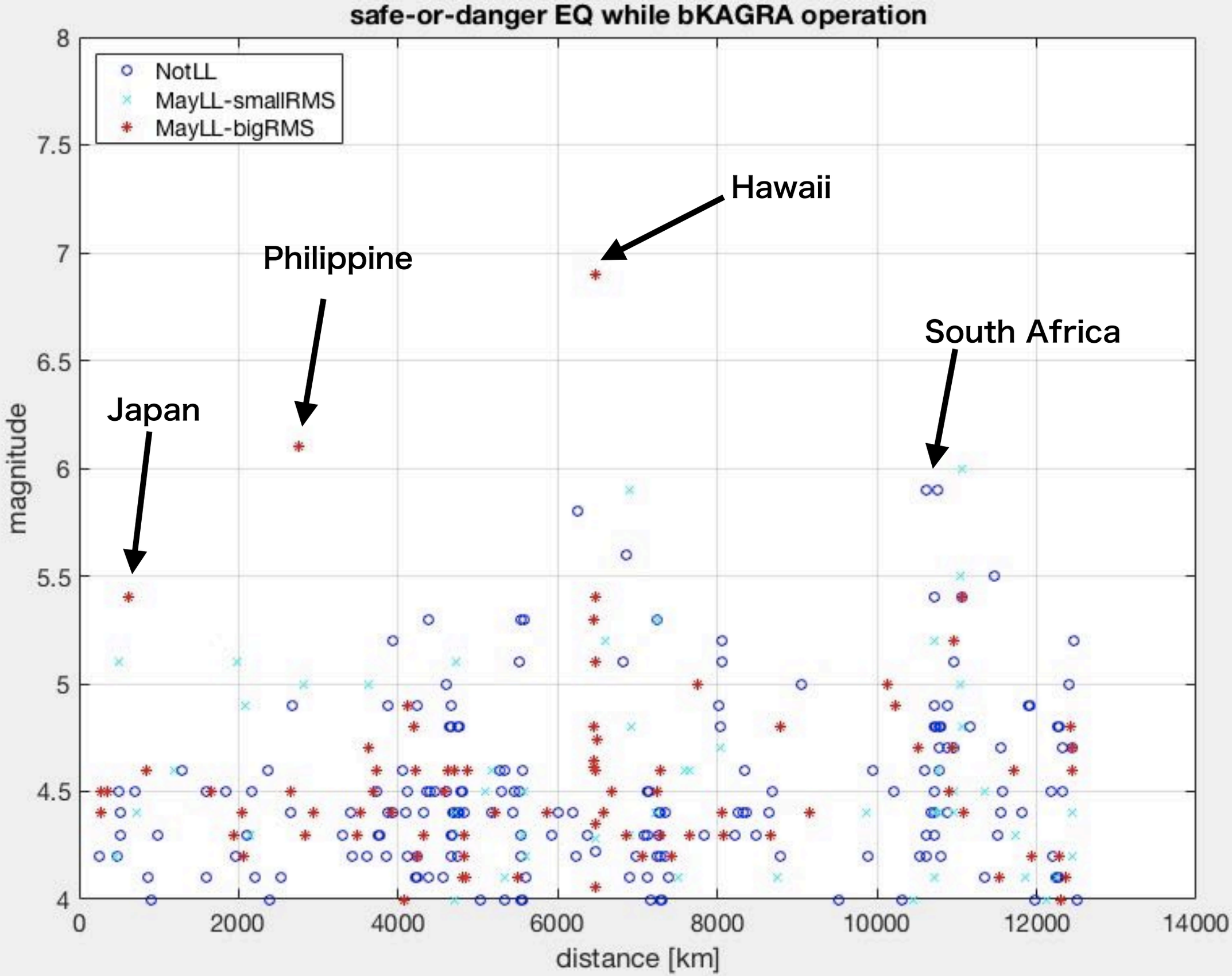
- From many EQs, we want to separate them into safe EQ and danger EQ.
- However, by seeing signal of seismometer, we cannot conclude which EQ made this seismic vibration because the expected time of arrival has some range and many of them was overlapped.
- It is usual some EQs come simultaneously, so we cannot distinguish completely.

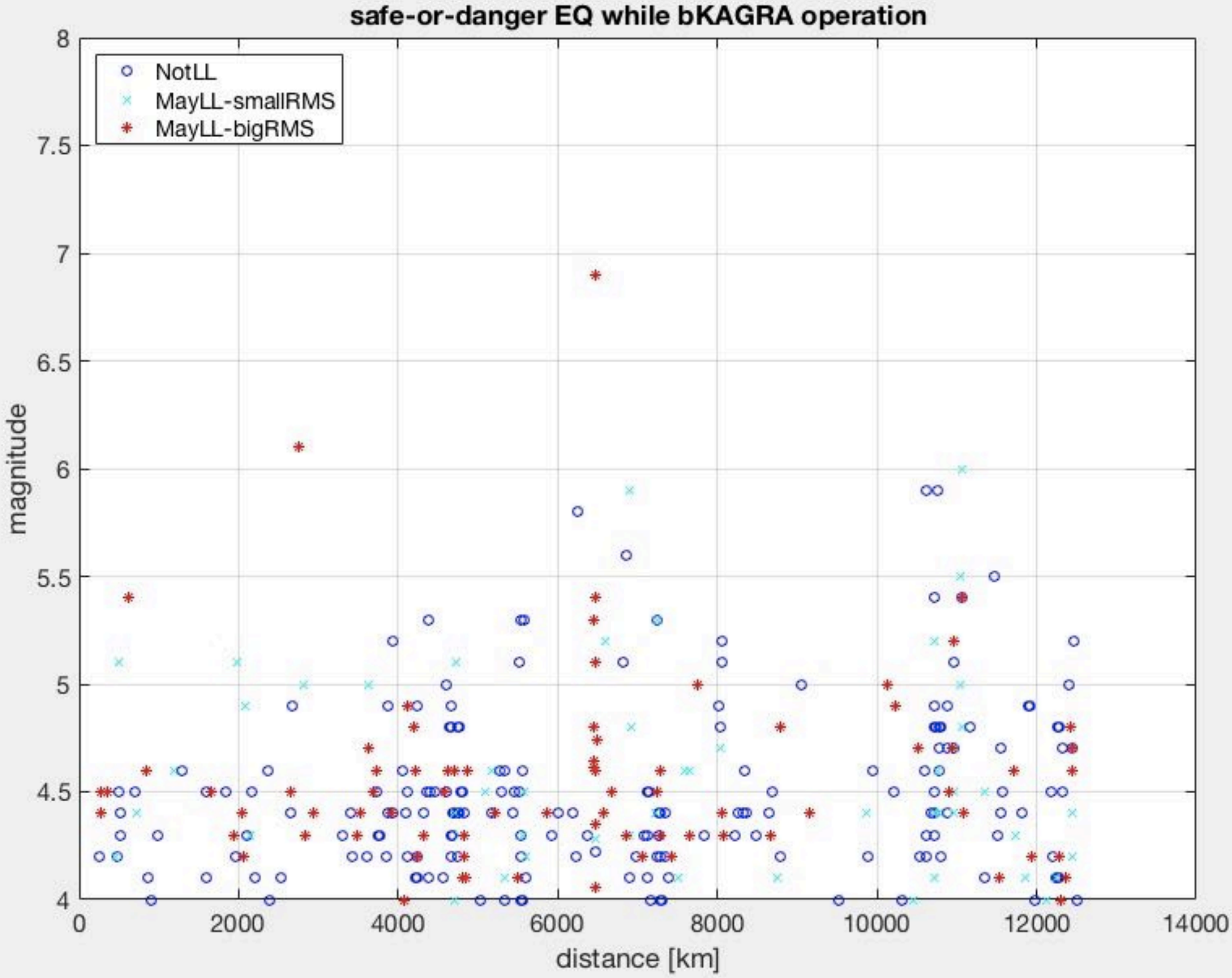
Notice

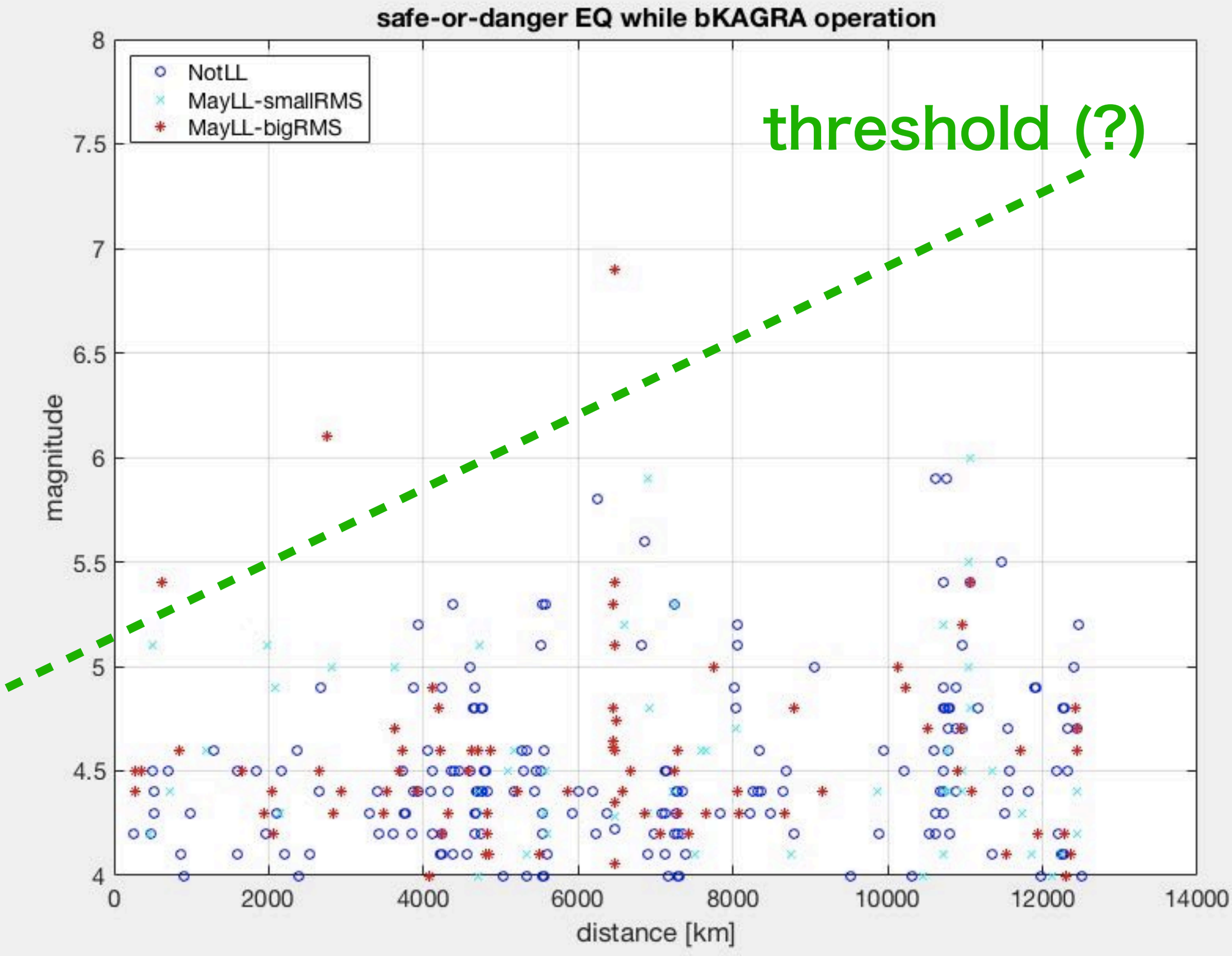
- So I separated EQs into 3 types. While each arrival time range, I checked whether LL happened and whether RMS of seismic vibration was big.

	RMS big	RMS small
LL happened	May cause LL with big RMS	May cause LL with small RMS
LL DIDNOT happen	Must not cause LL	Must not cause LL


safe-or-danger EQ while bKAGRA operation
NotLL
MayLL-smallRMS
MayLL-bigRMS
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000
14000


safe-or-danger EQ while bKAGRA operation
NotLL
MayLL-smallRMS
MayLL-bigRMS
Hawaii
Philippine
South Africa
Japan
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000
14000


safe-or-danger EQ while bKAGRA operation
NotLL
MayLL-smallRMS
MayLL-bigRMS
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000
14000


safe-or-danger EQ while bKAGRA operation
NotLL
MayLL-smallRMS
MayLL-bigRMS
threshold (?)
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000
14000

Summary of this study

- We can separate EQs into safe one and danger one roughly.
- This study will teach us how we cope with EQs according to their distance and magnitude.

Table of contents

1. About lock loss study

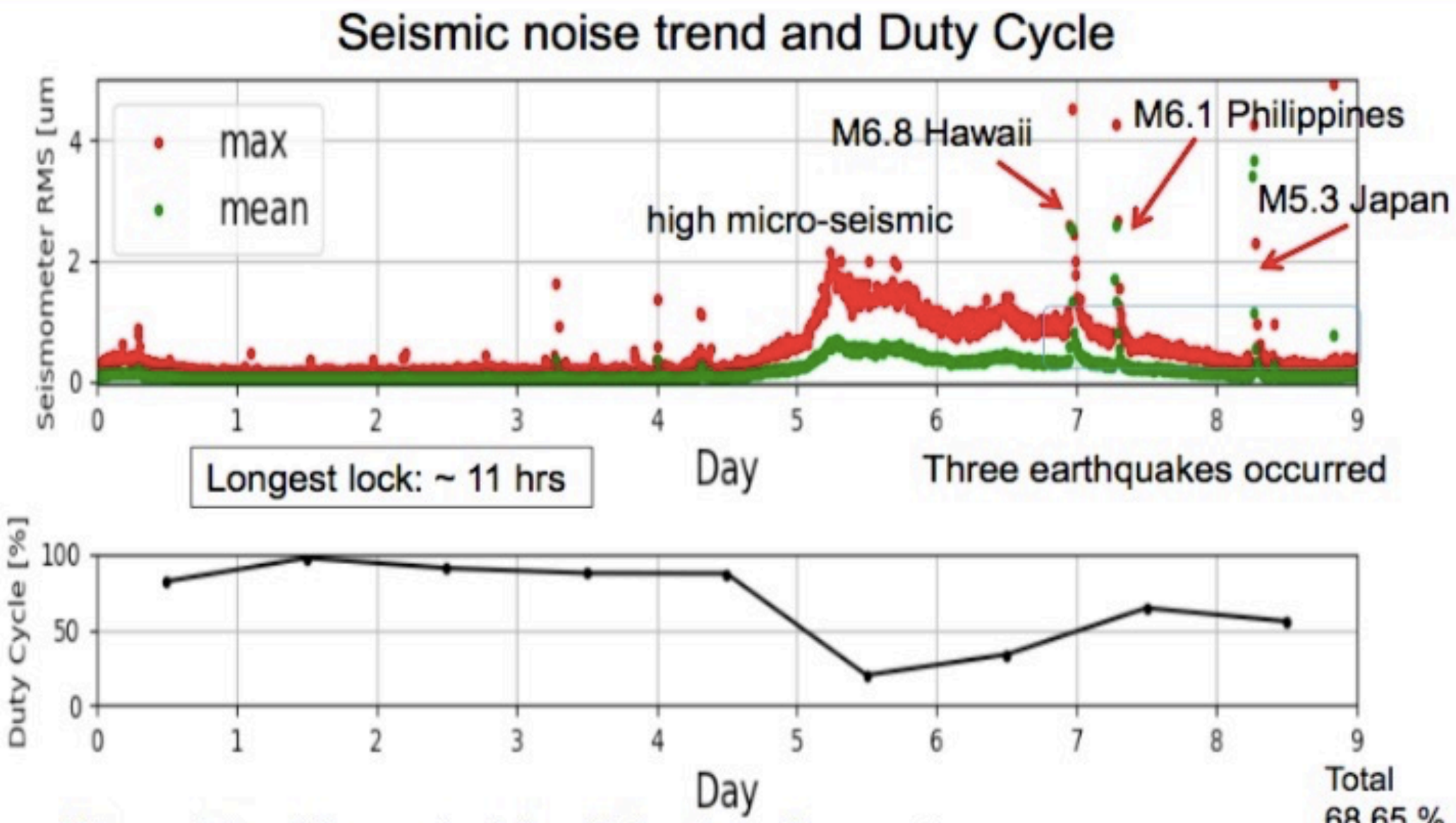
2. The ratio of cause of Lock loss

3. What kind of EQ causes Lock loss?
   (Classifying EQs as to its safeness)

End.

supplemental slide

Duty cycle of bKAGRA phase-1

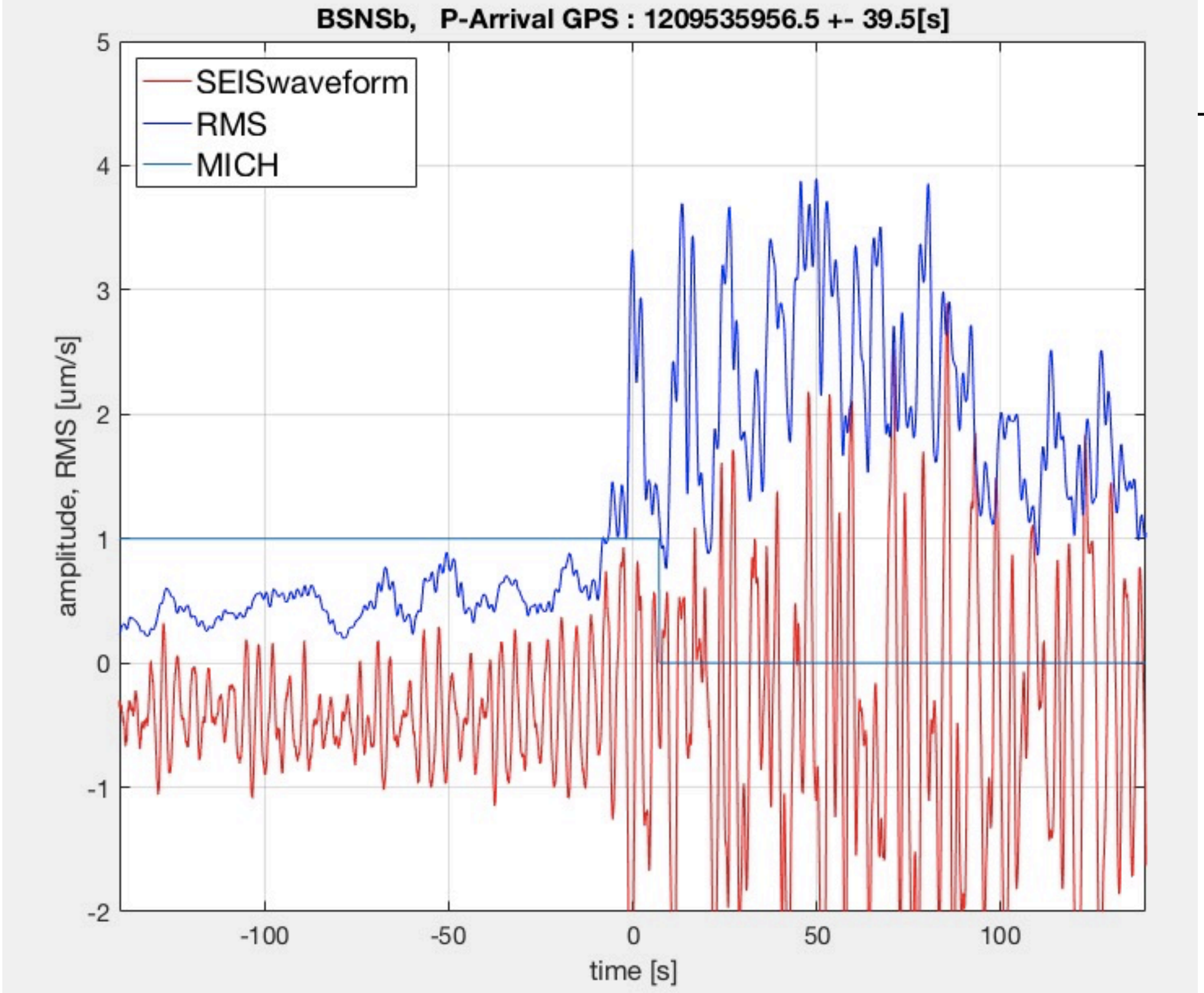


- We archived to control (lock) the interferometer.
- After 5th day, there were 3 big earthquakes and high micro-seismic day.
- Longest lock was 11.3 hours.

Ref: Yuzurihara "bKAGRA phase1 operation" Area Workshop 2018 Early Summer

The value of threshold

- This value have some arbitrariness.
- It should have been decided on the RMS when LL happens.
- But ...


BSNSb, P-Arrival GPS : 1209535956.5 +- 39.5[s]
SEISwaveform
RMS
MICH
amplitude, RMS [um/s]
time [s]
5
4
3
2
1
0
-1
-2
-100
-50
0
50
100

The value of threshold

- This value have some arbitrariness.
- It should have been decided on the RMS when LL happens.
- It is difficult to decide precisely the threshold of RMS which cause LL.
- I set the value with some reason.

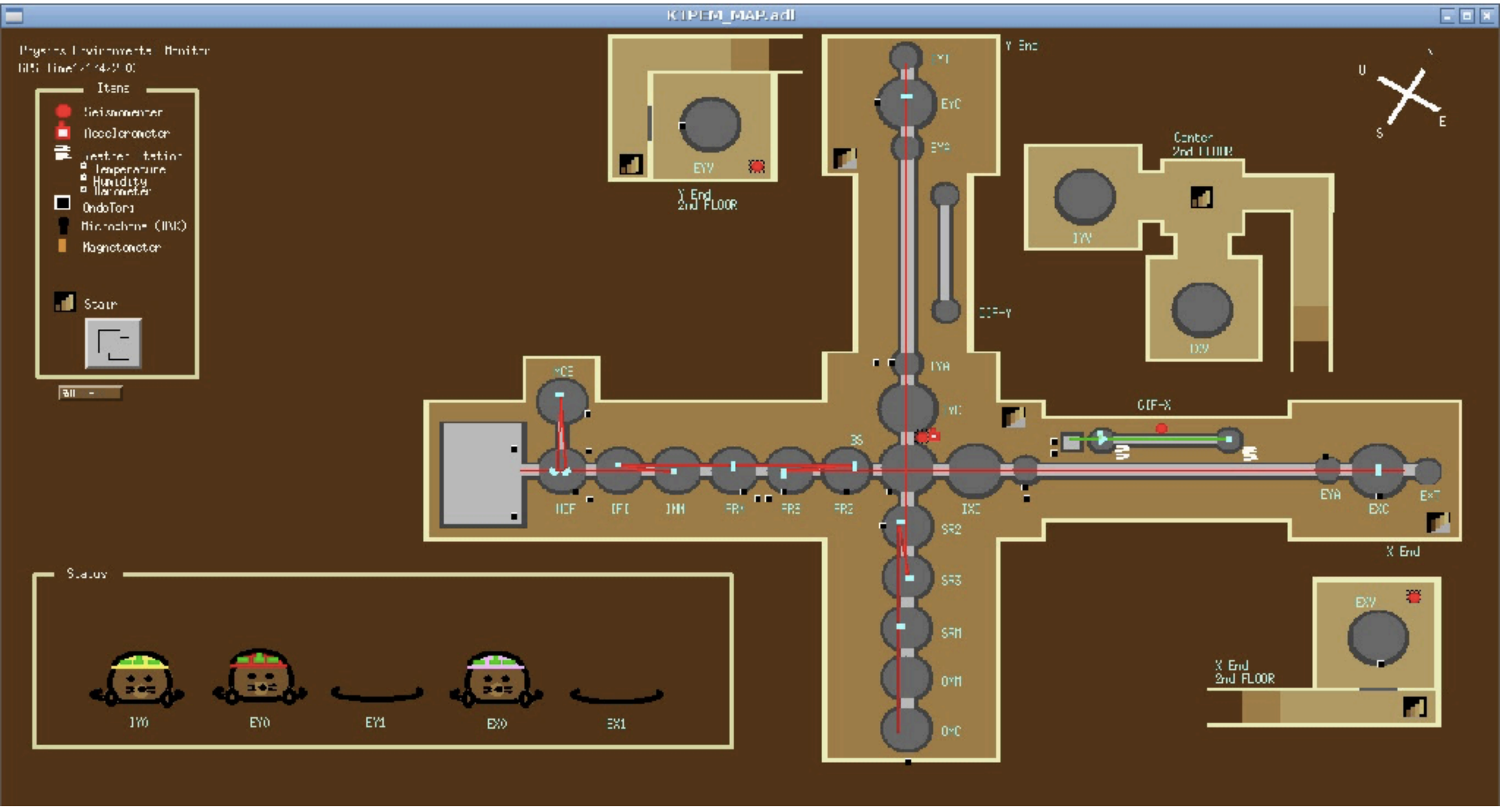
① The big EQ exceeds the threshold.

② All EQs whose RMS was bigger make LL.

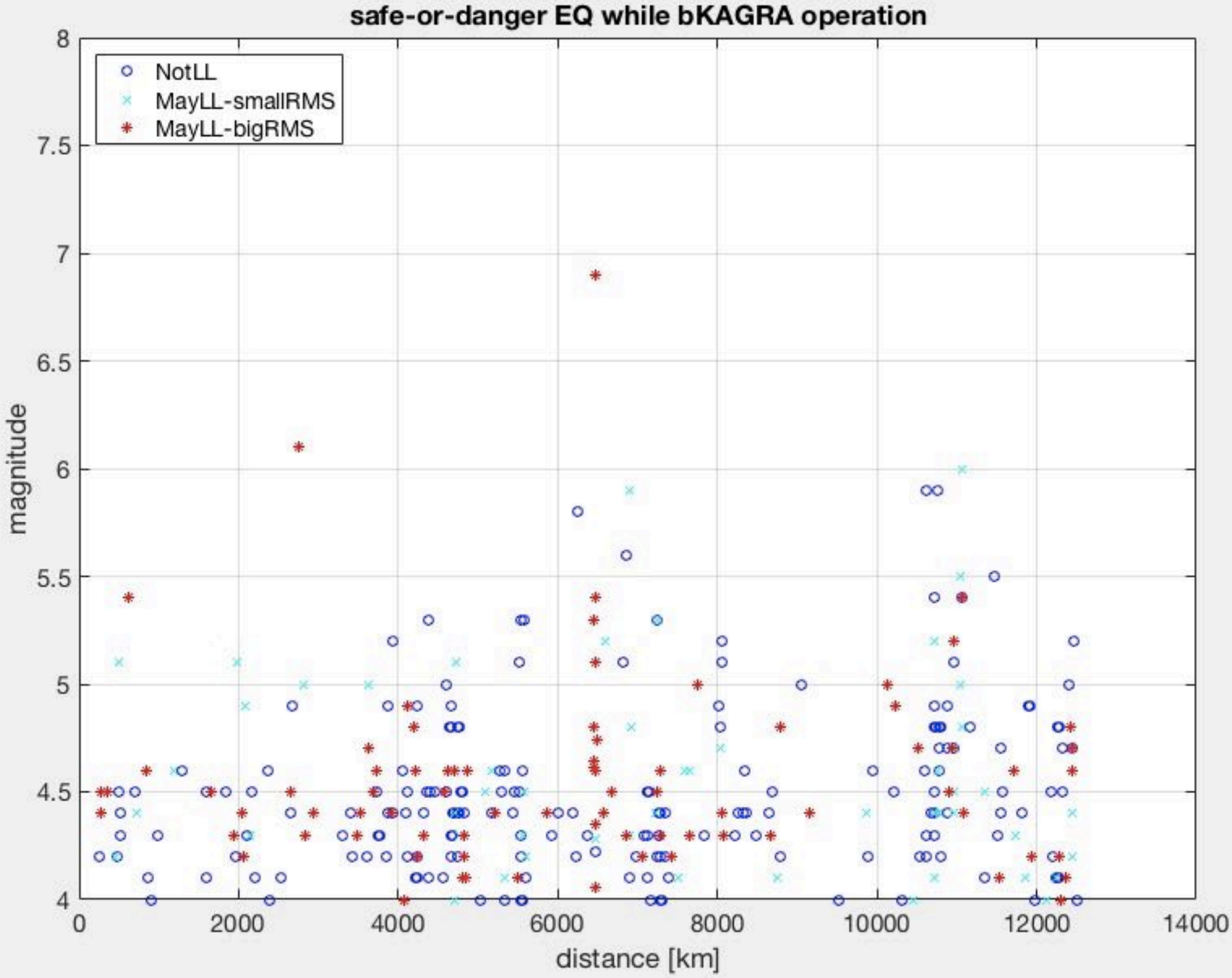
→ The value does not too small

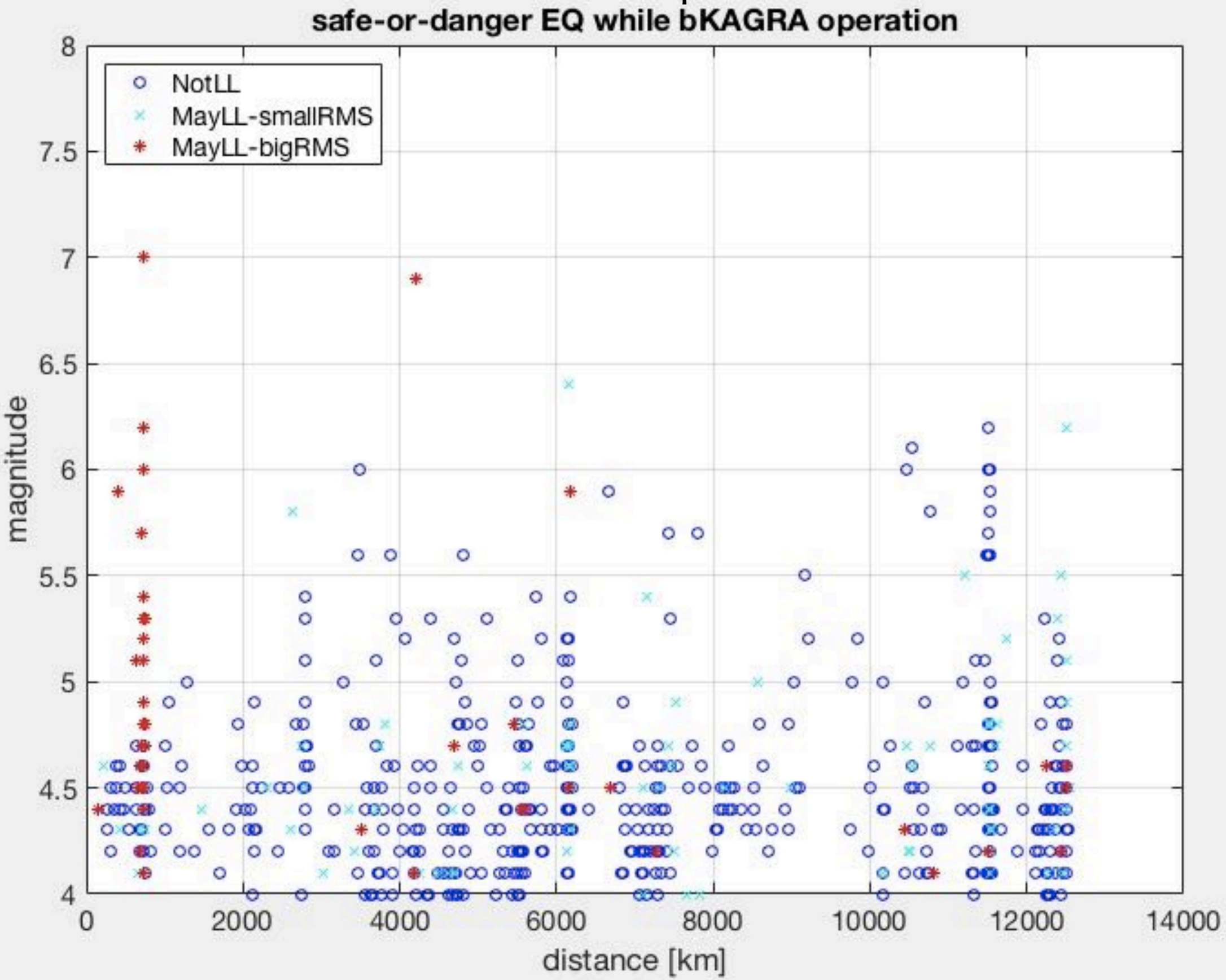
③ This is as same as the threshold of ...

PEM Site Map



Ando Lab. Seminar (June 22th, 2018)


safe-or-danger EQ while bKAGRA operation
NotLL
MayLL-smallRMS
MayLL-bigRMS
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000
14000

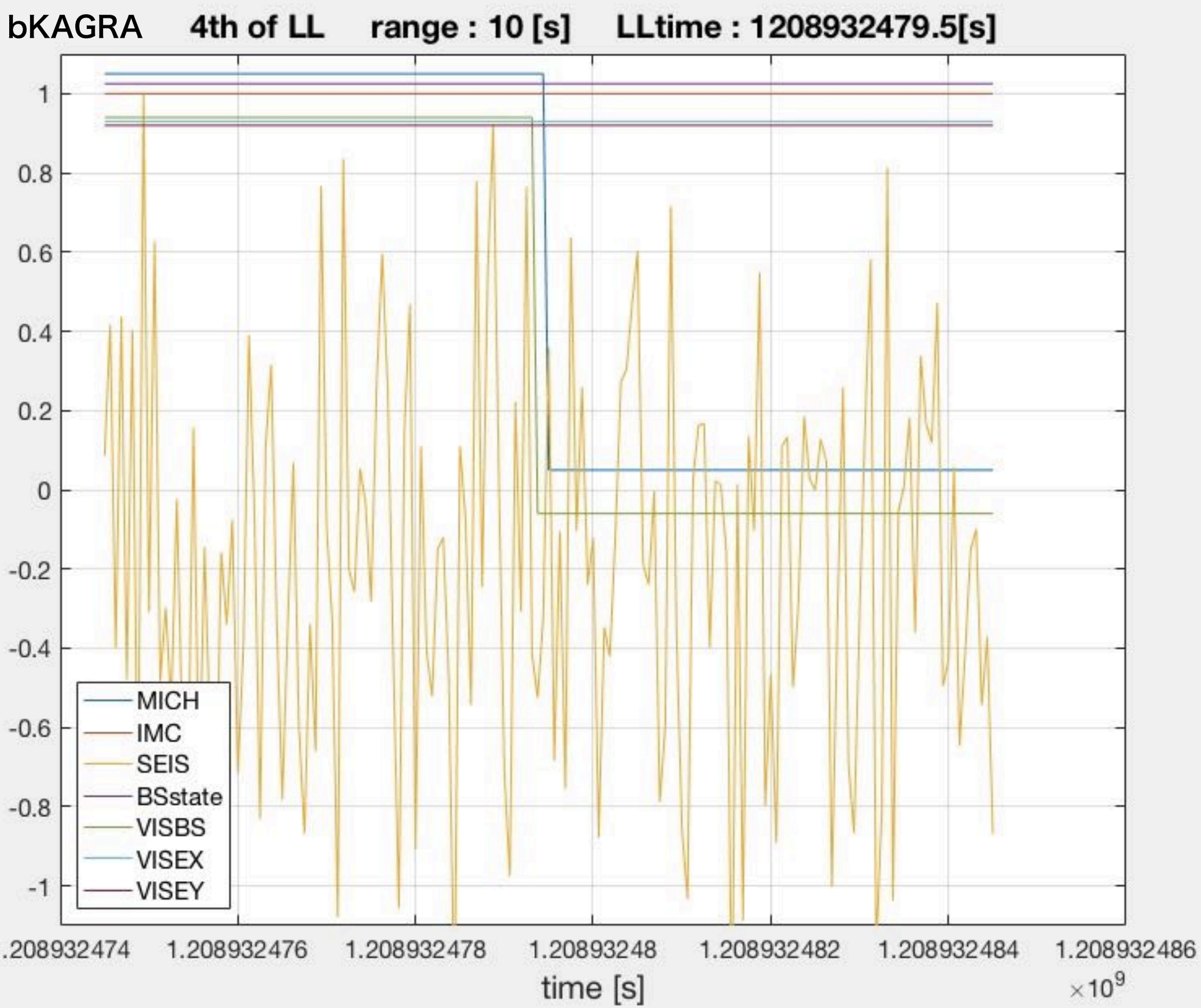

safe-or-danger EQ while bKAGRA operation
NotLL
MayLL-smallRMS
MayLL-bigRMS
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000
14000

Future plan of this topic

The most cause of LL seems VIS_BS, but it cannot be concluded.

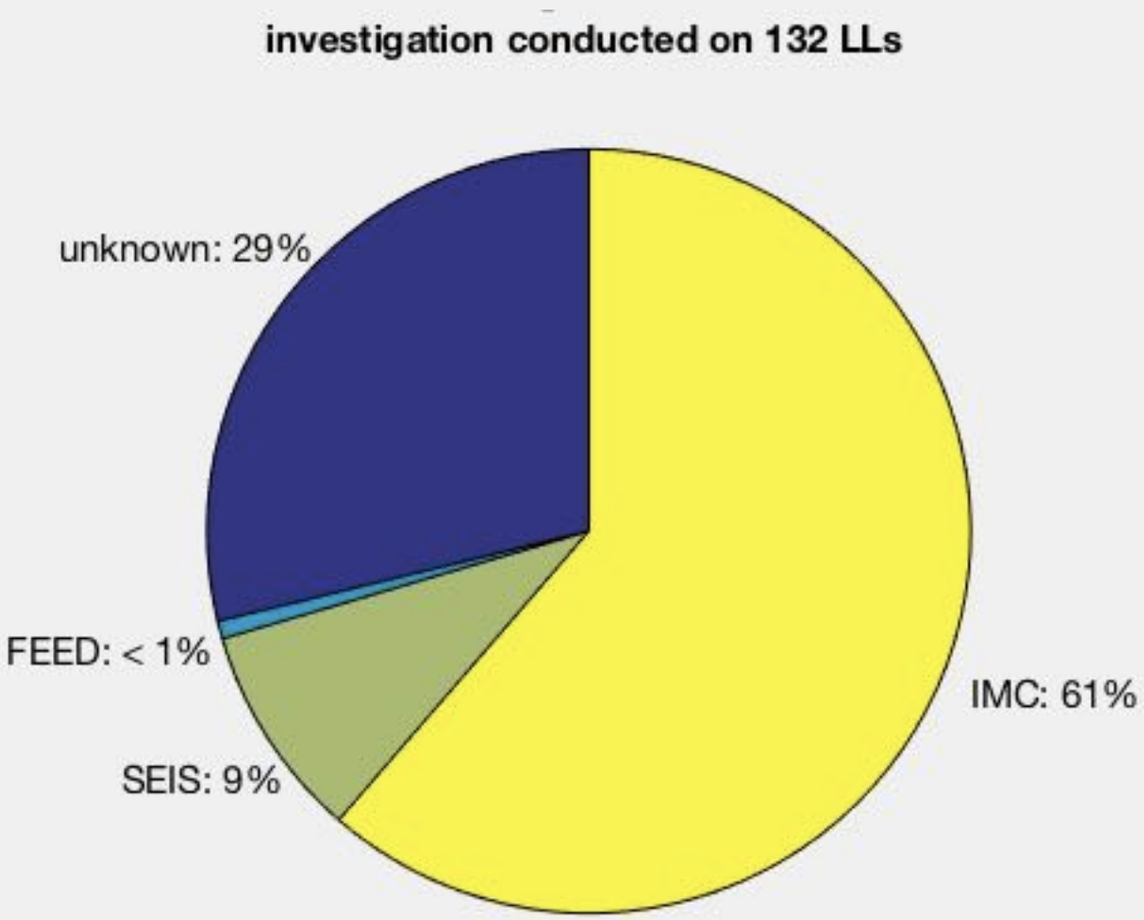
I have to check other channels.

- VIS-ETM{X/Y}_TM_OPLEV_TILT_{PIT/YAW}_OUT
- GRD-VIS_{PR2/PR3}_STATE_N


bKAGRA 4th of LL range : 10 [s] LLtime : 1208932479.5[s]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
MICH
IMC
SEIS
BSstate
VISBS
VISEX
VISEY
1.208932474
1.208932476
1.208932478
1.20893248
1.208932482
1.208932484
1.208932486
time [s]
×10^9

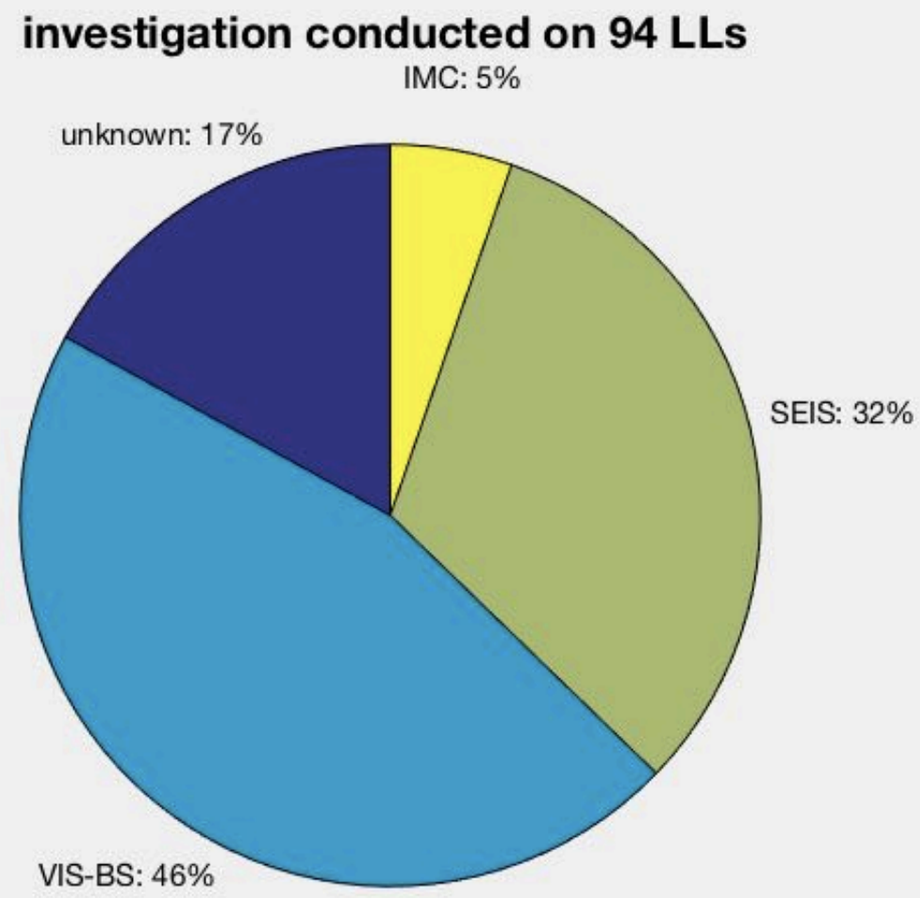
Ratio of LockLoss

iKAGRA



Most: IMC 61%

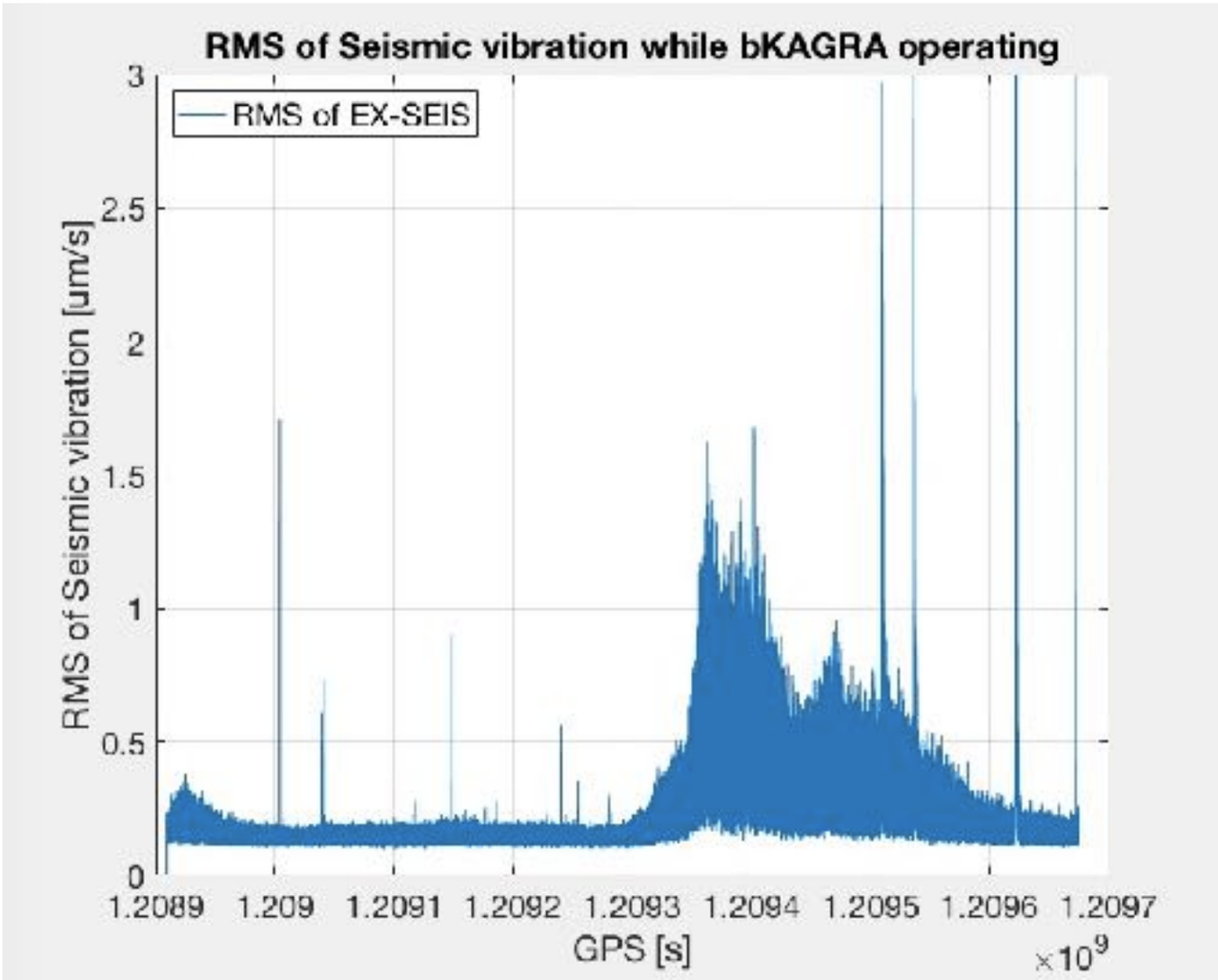
bKAGRA

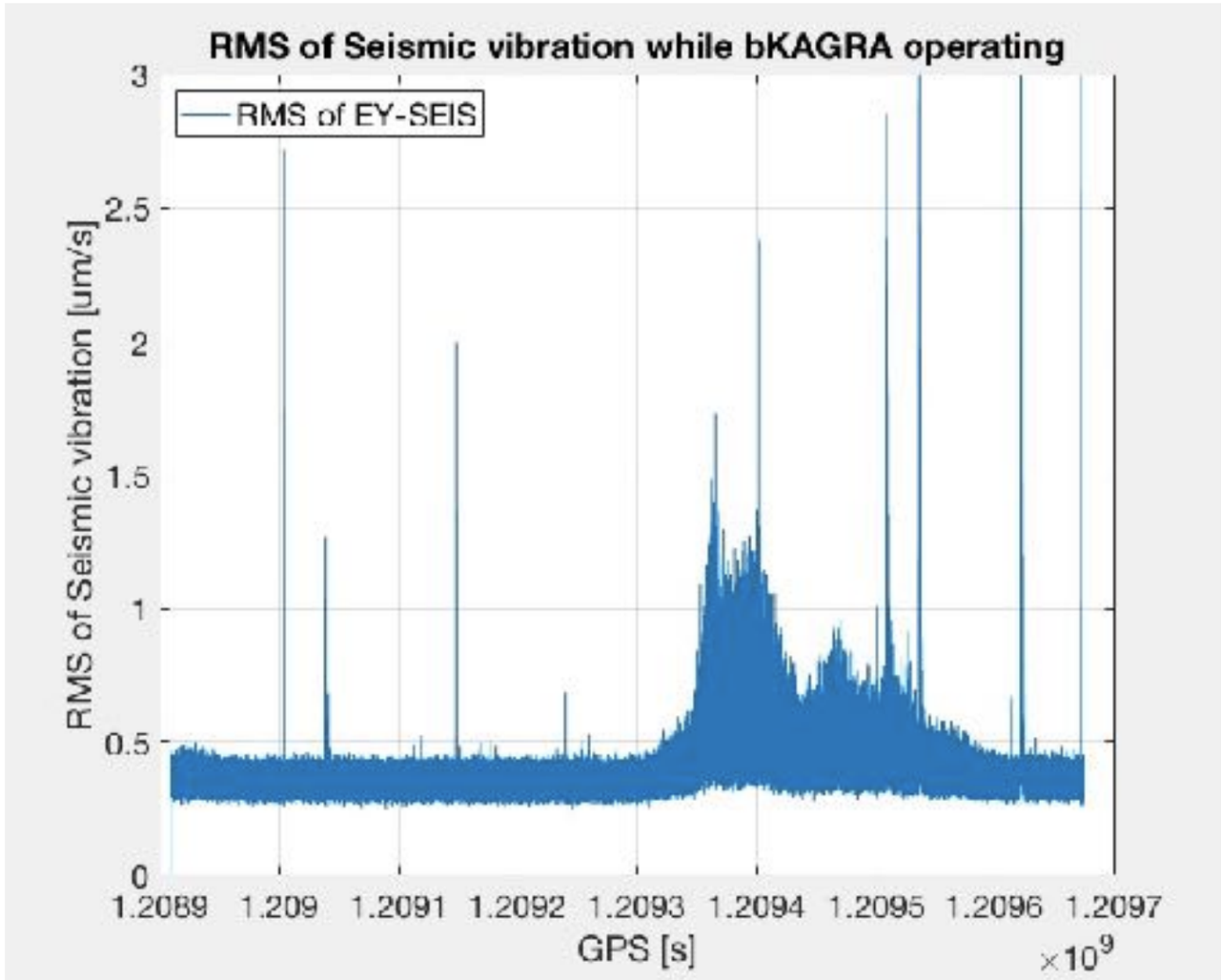


Most: VIS-BS 46%

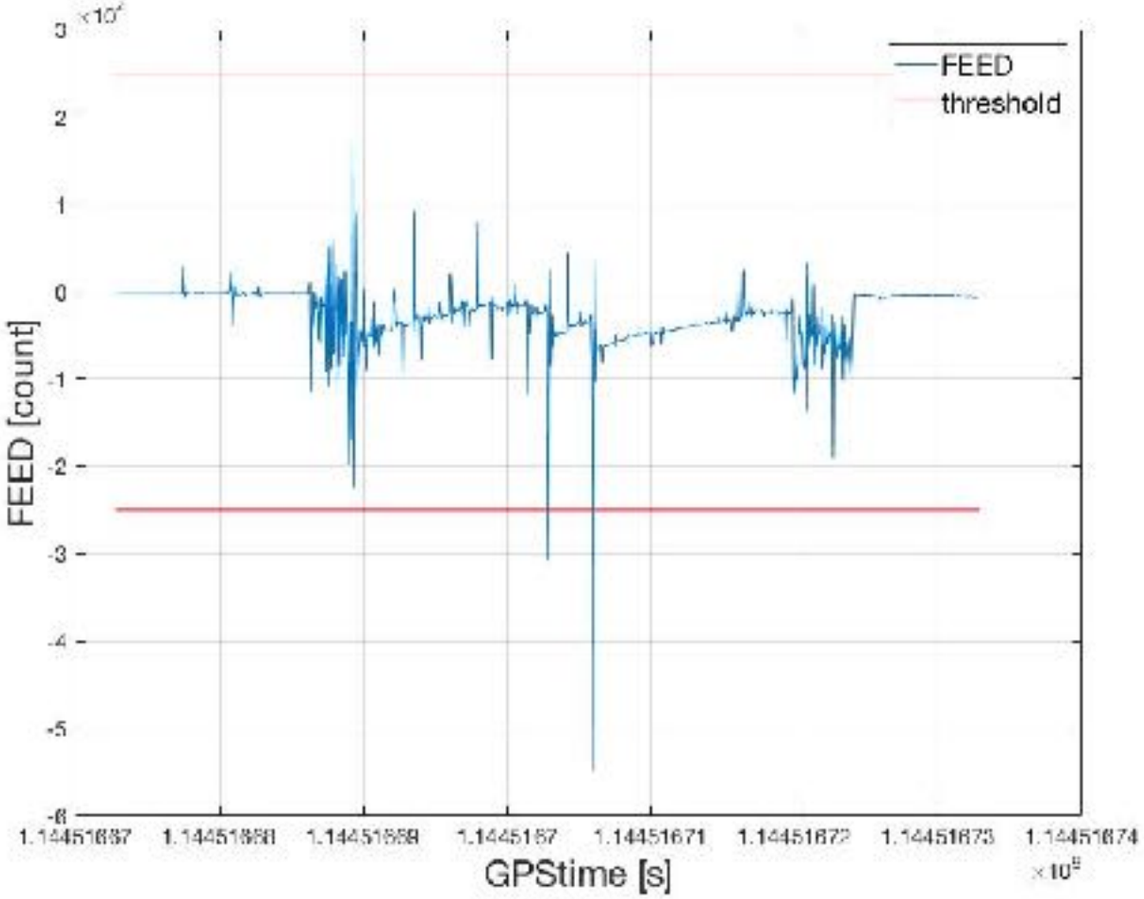
RMS of EX-SEIS EY-SEIS

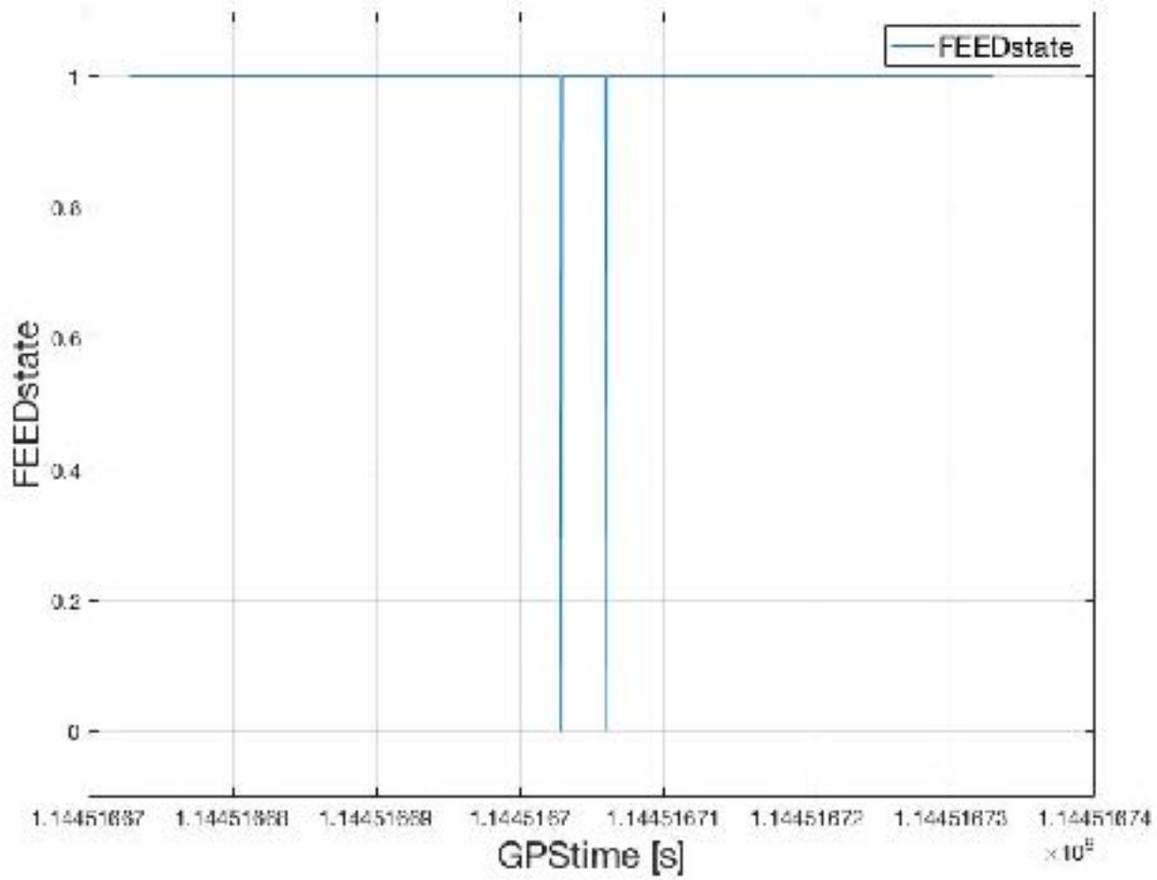
mistook selecting channel!





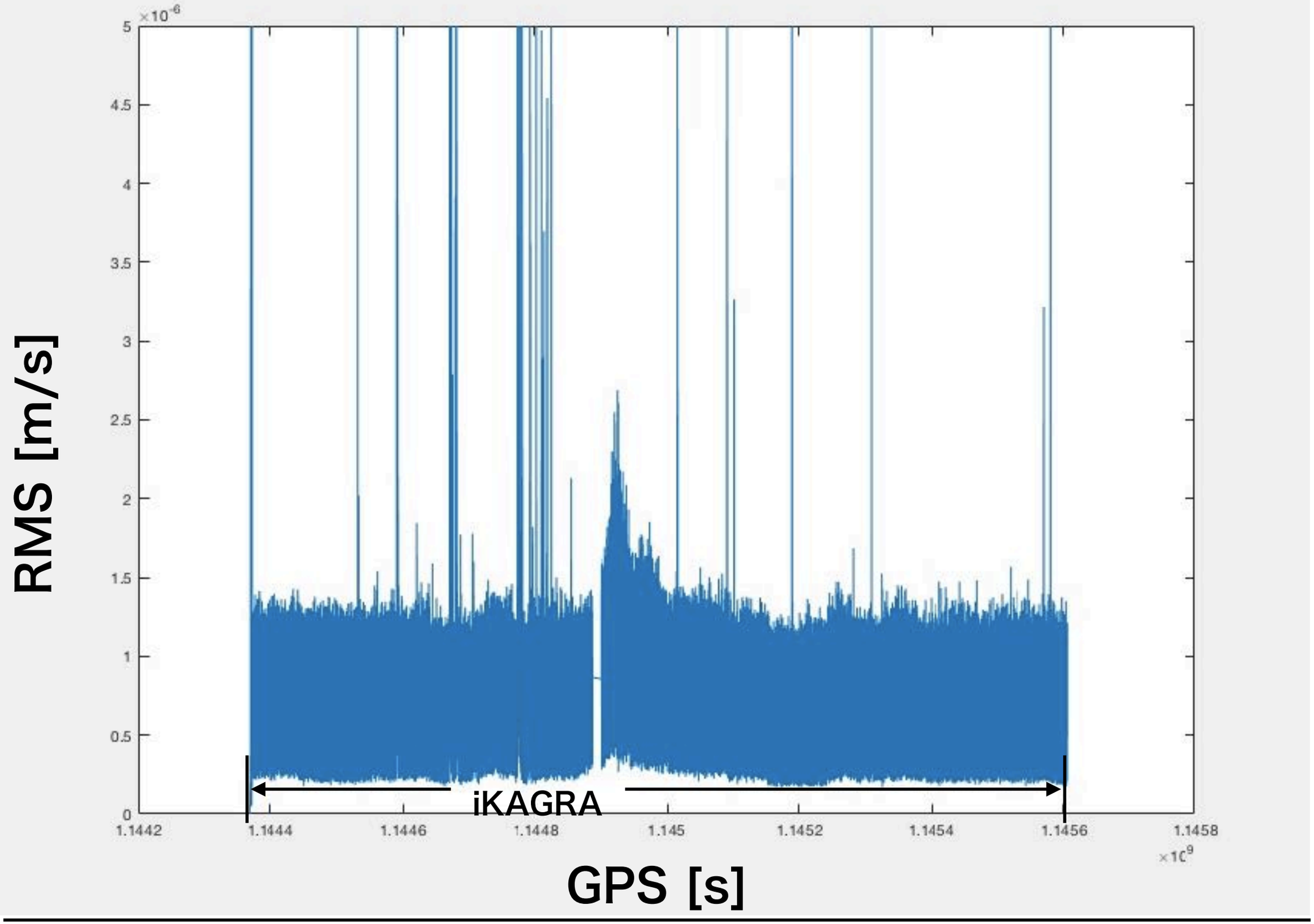
Boolean of feedback (iK)





RMS of SEIS (iKAGRA)

mistook selecting channel!



EQ leading to LL (iKAGRA)

GPS	波形	mag	magtype	place
1144590935	P	6.9	mww	75km SE of Mawlaik, Burma
1144672013	P	6.2	mww	3km W of Kumamoto-shi, Japan
1144681444	P	6.0	mww	5km ENE of Uto, Japan
1144772723	P&S	7.0	mww	1km E of Kumamoto-shi, Japan
1144778608	S	5.4	mwr	15km ENE of Ozu, Japan
1145091152	S?	5.3	mww	6km NNE of Yatsushiro, Japan
1145190001	S?	5.9	mww	65km ENE of Namie, Japan
1145581243	S?	4.4	mb	29km N of Shinshiro, Japan

表1　ロックロスを引き起こした地震の情報をまとめたもの.

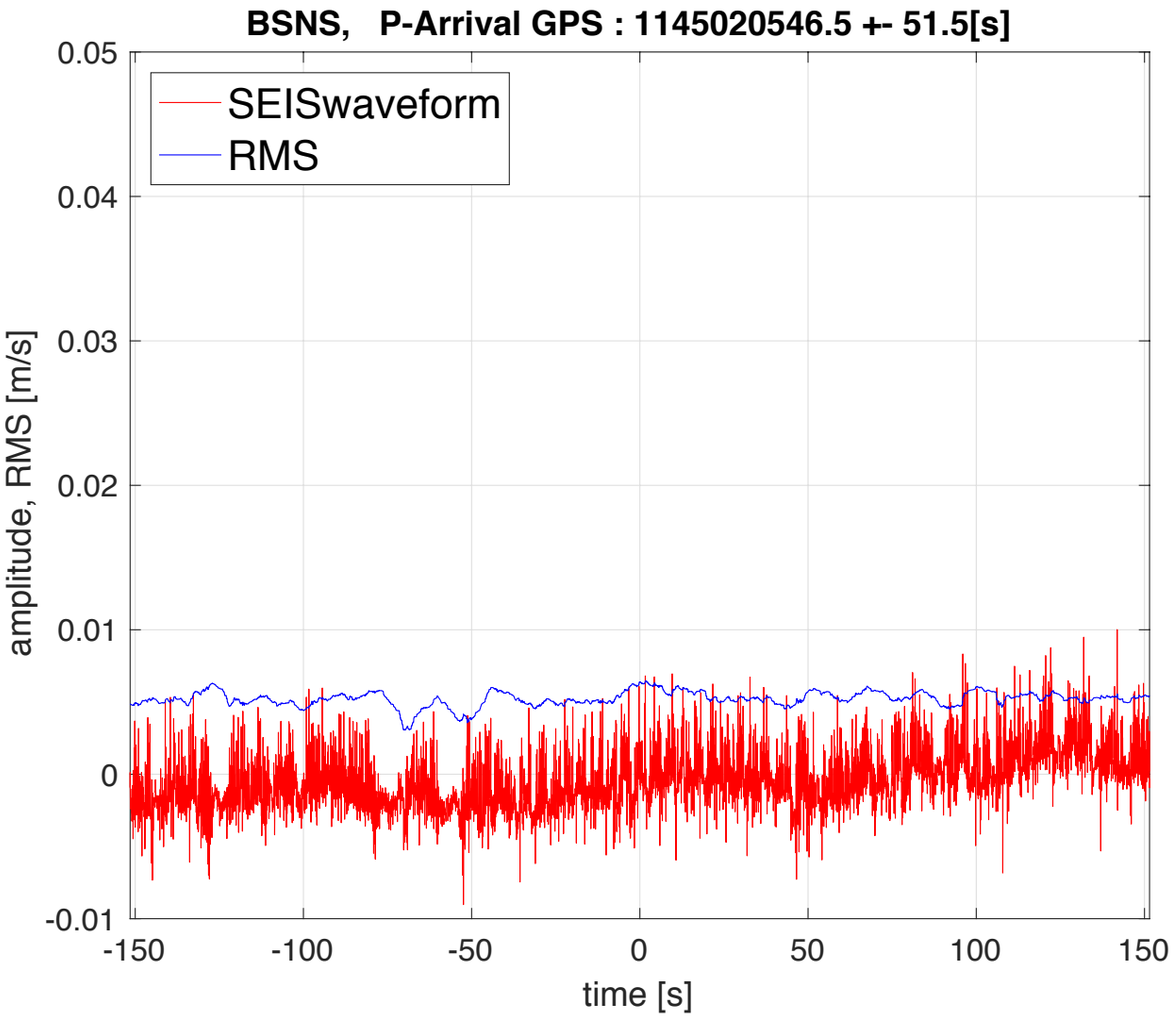
GPS:地震発生時刻, mag:マグニチュード, magtype:マグニチュードの定義, place:震源場所

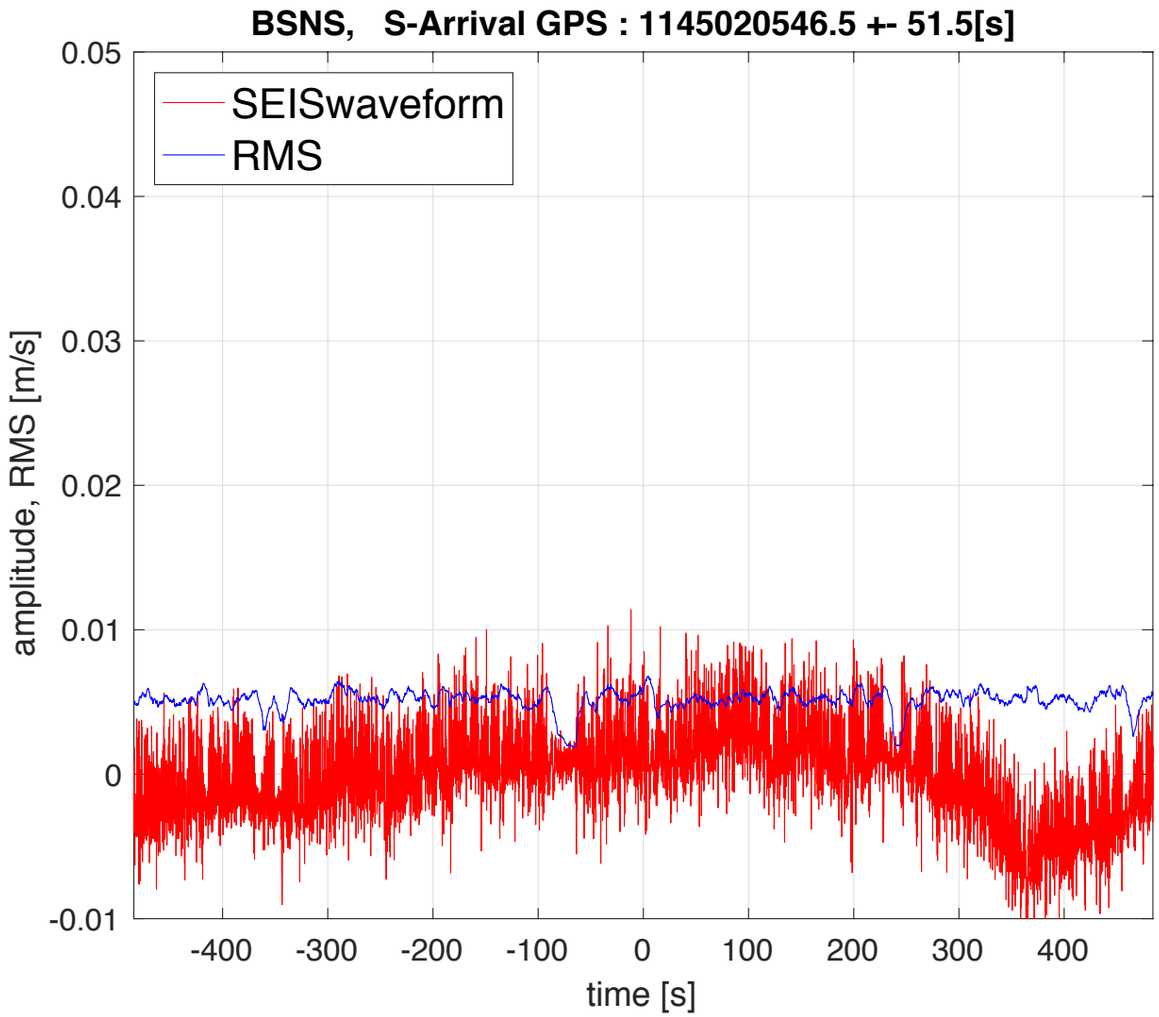
The USGS Earthquake Hazards Program のデータを使用.

マグニチュードの定義は, mww:centroid moment tensor から計算したモーメントマグニチュード, mwr:moment tensor から計算したモーメントマグニチュード, mb:短期間の表面波に対して振幅から計算したマグニチュード

EQJi_13574

縦軸が違う

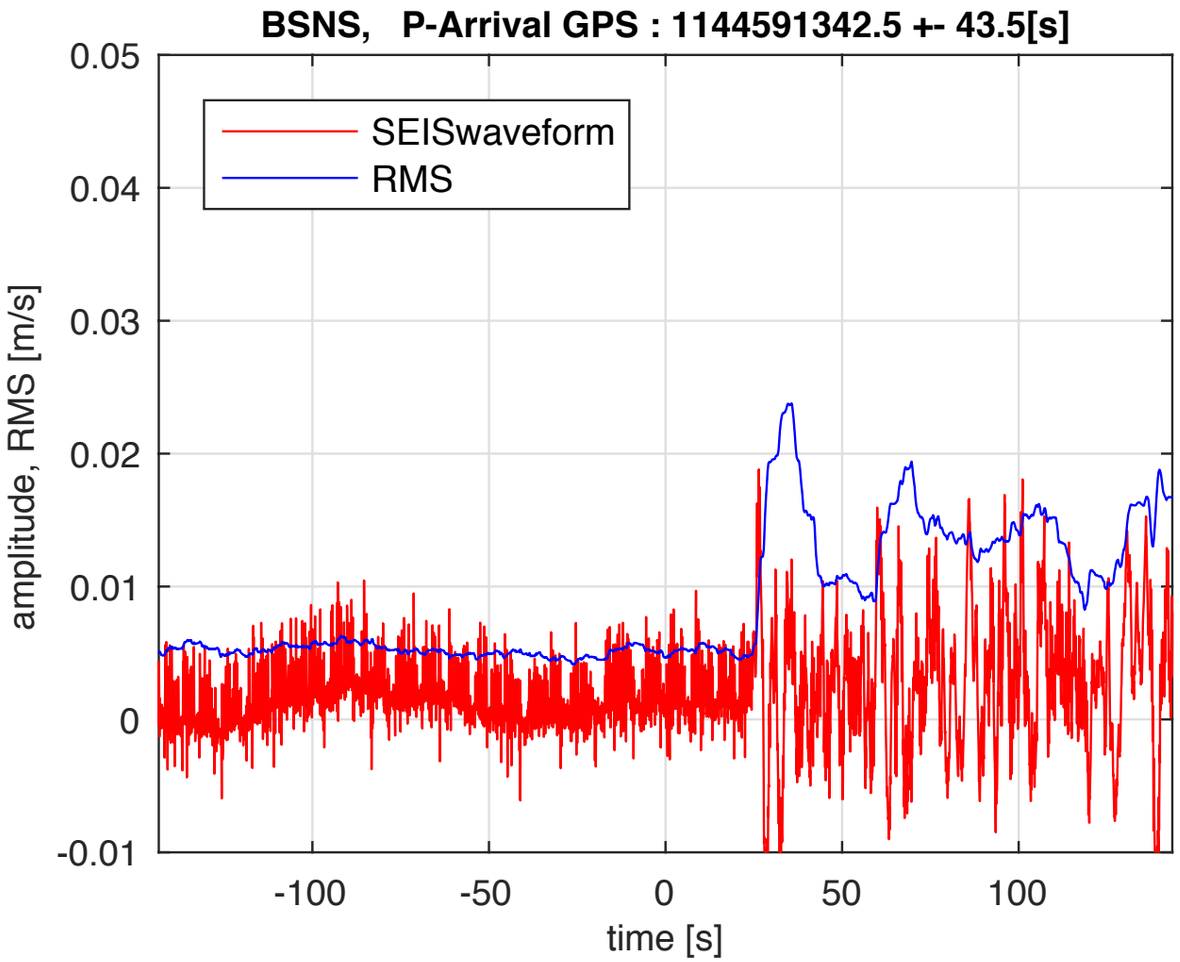


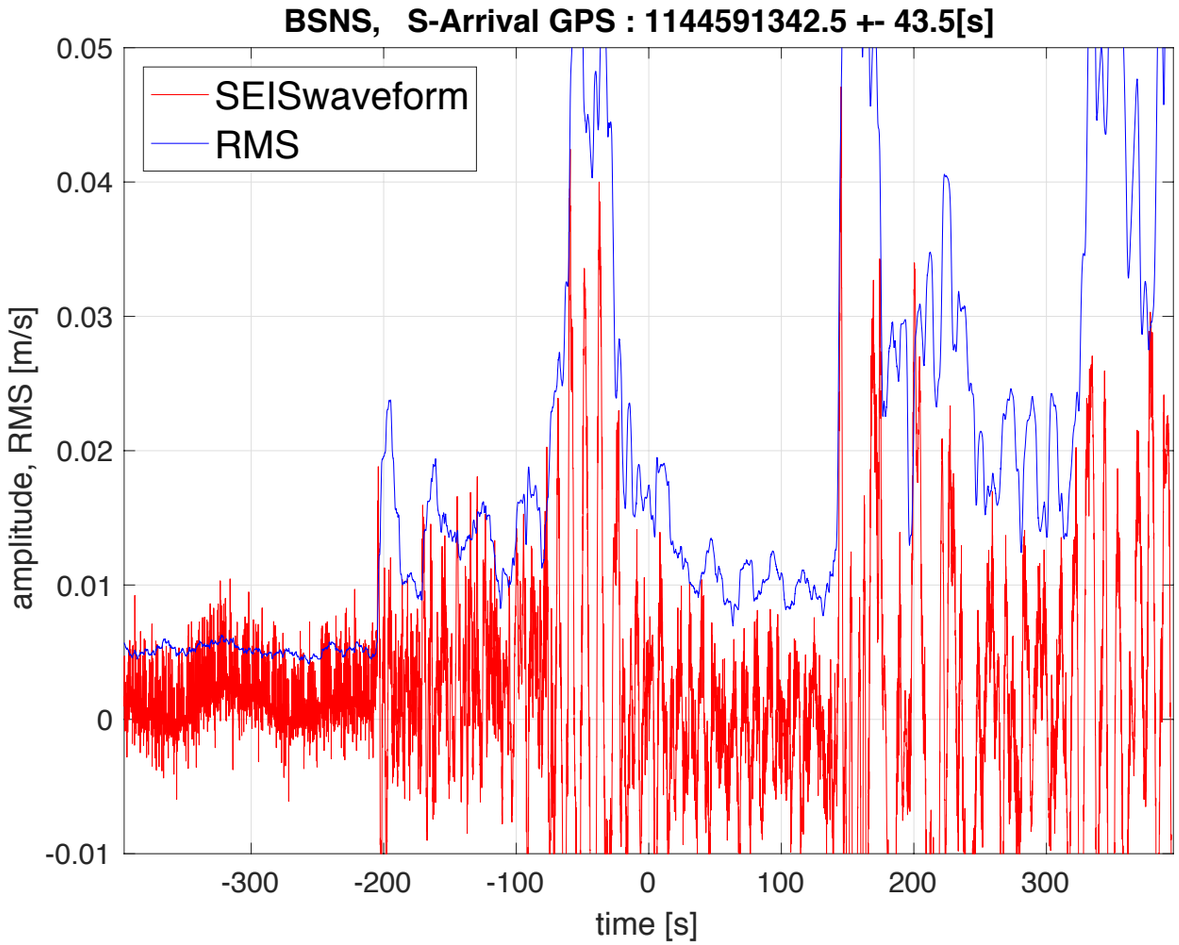


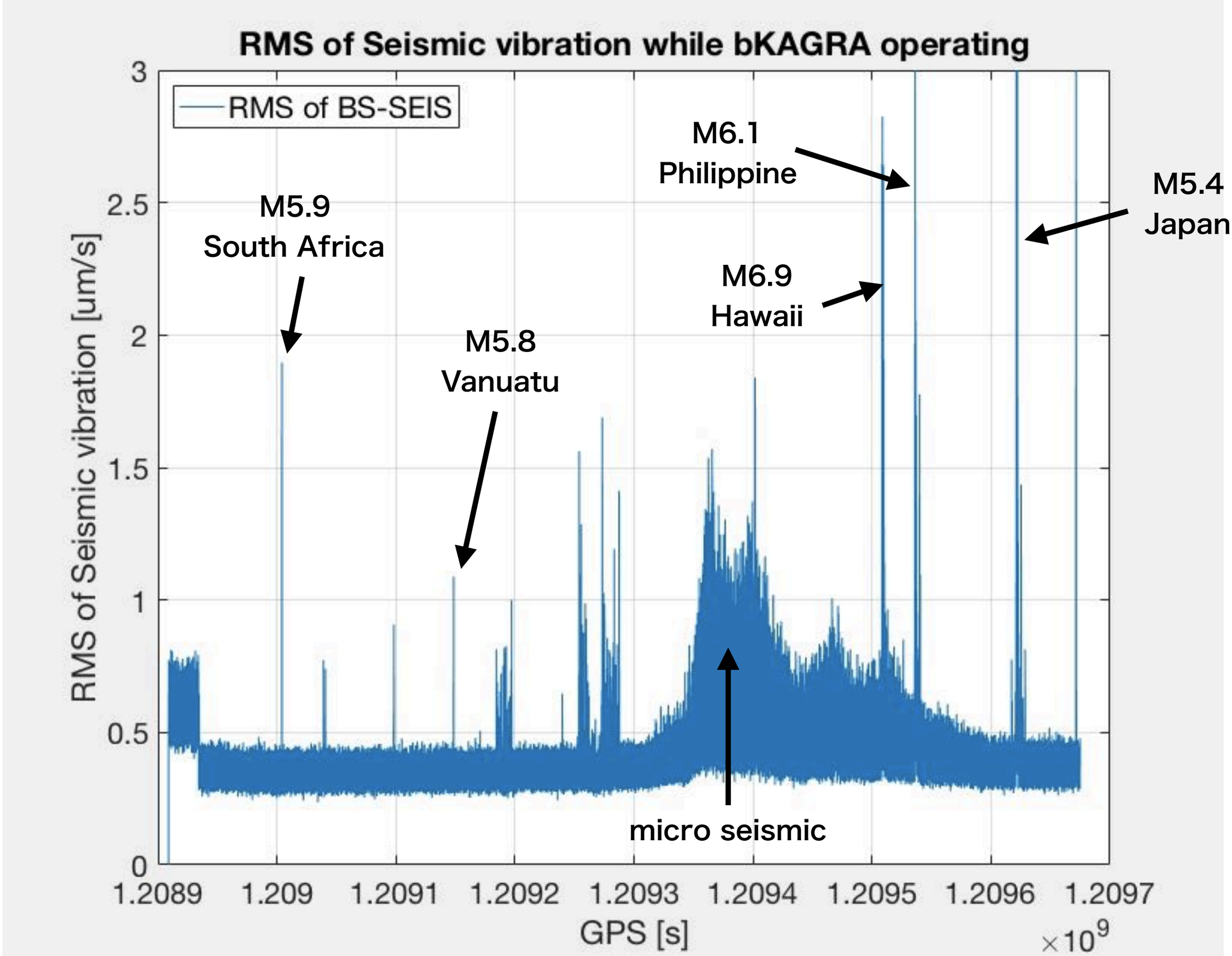
どの地震を表しているのか図示してわかりやすく

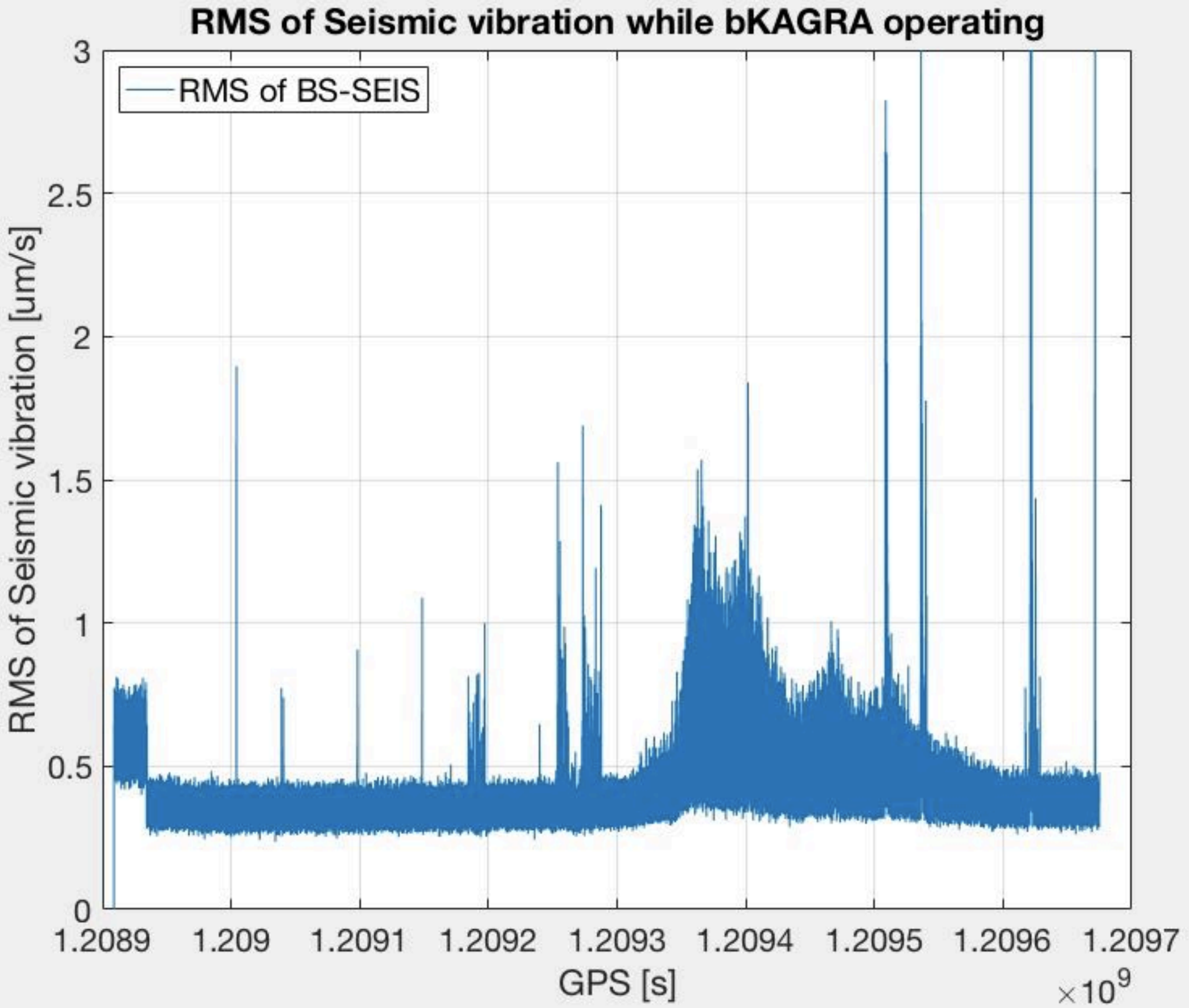
EQJi_1435

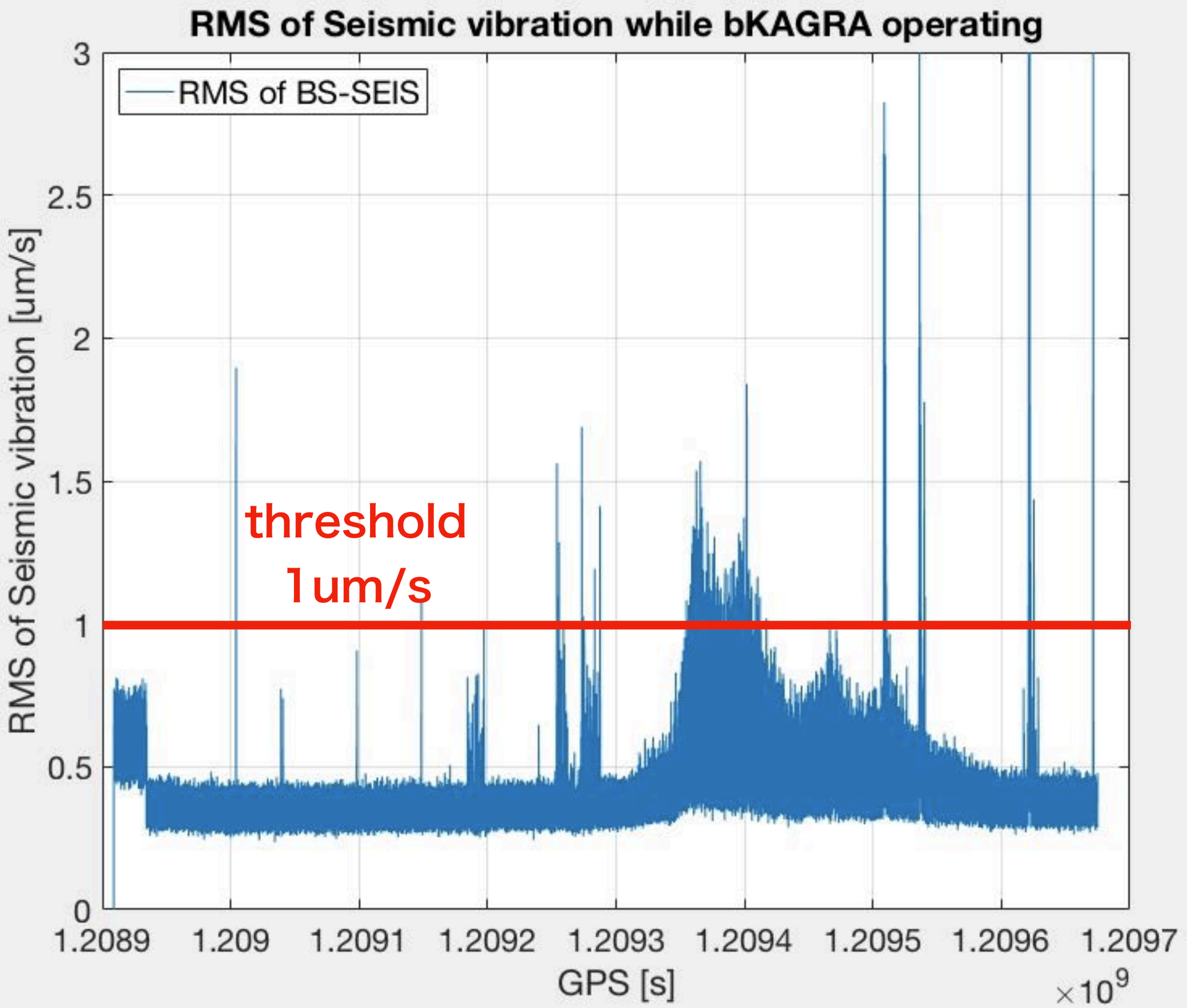
縦軸が違う

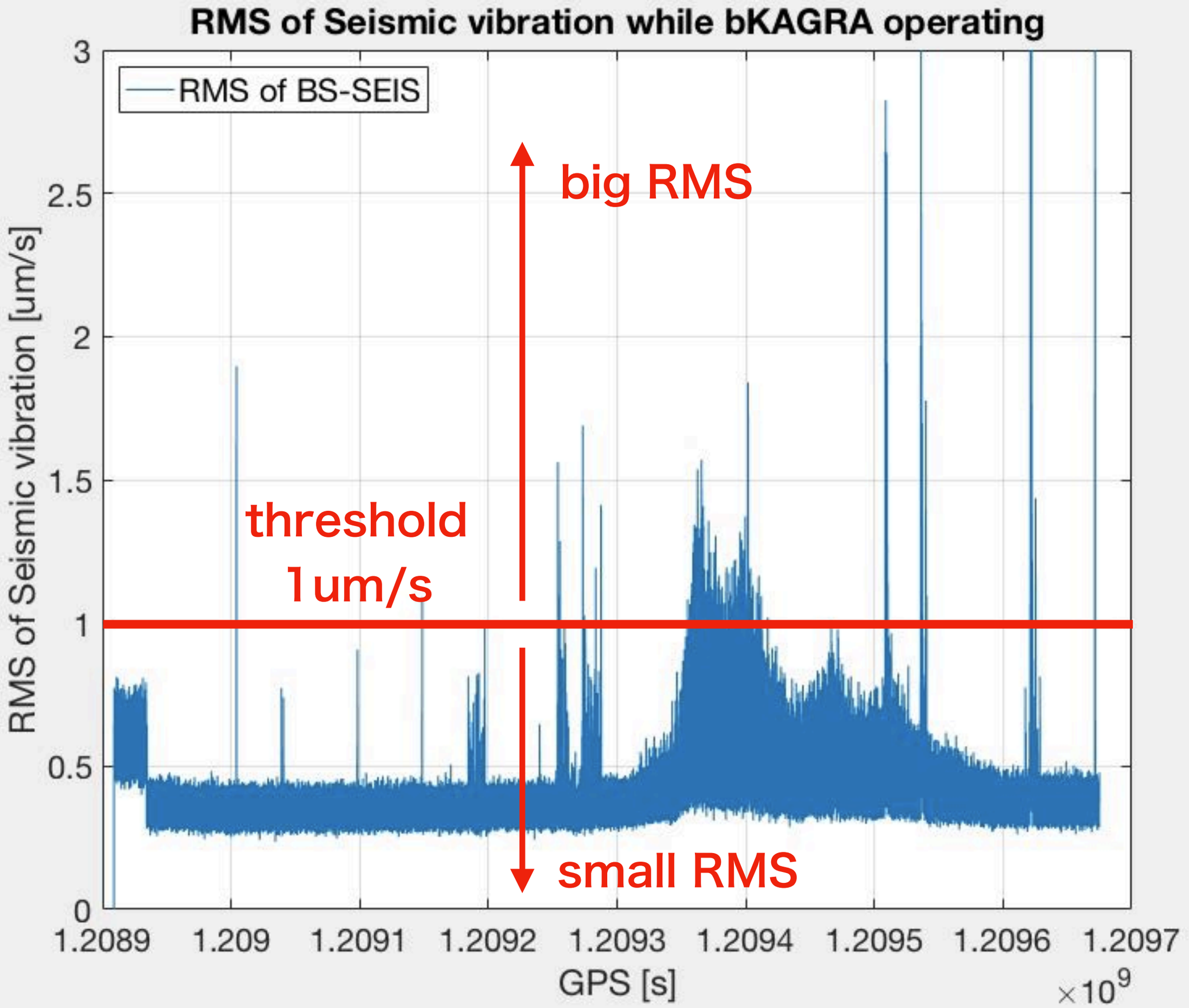


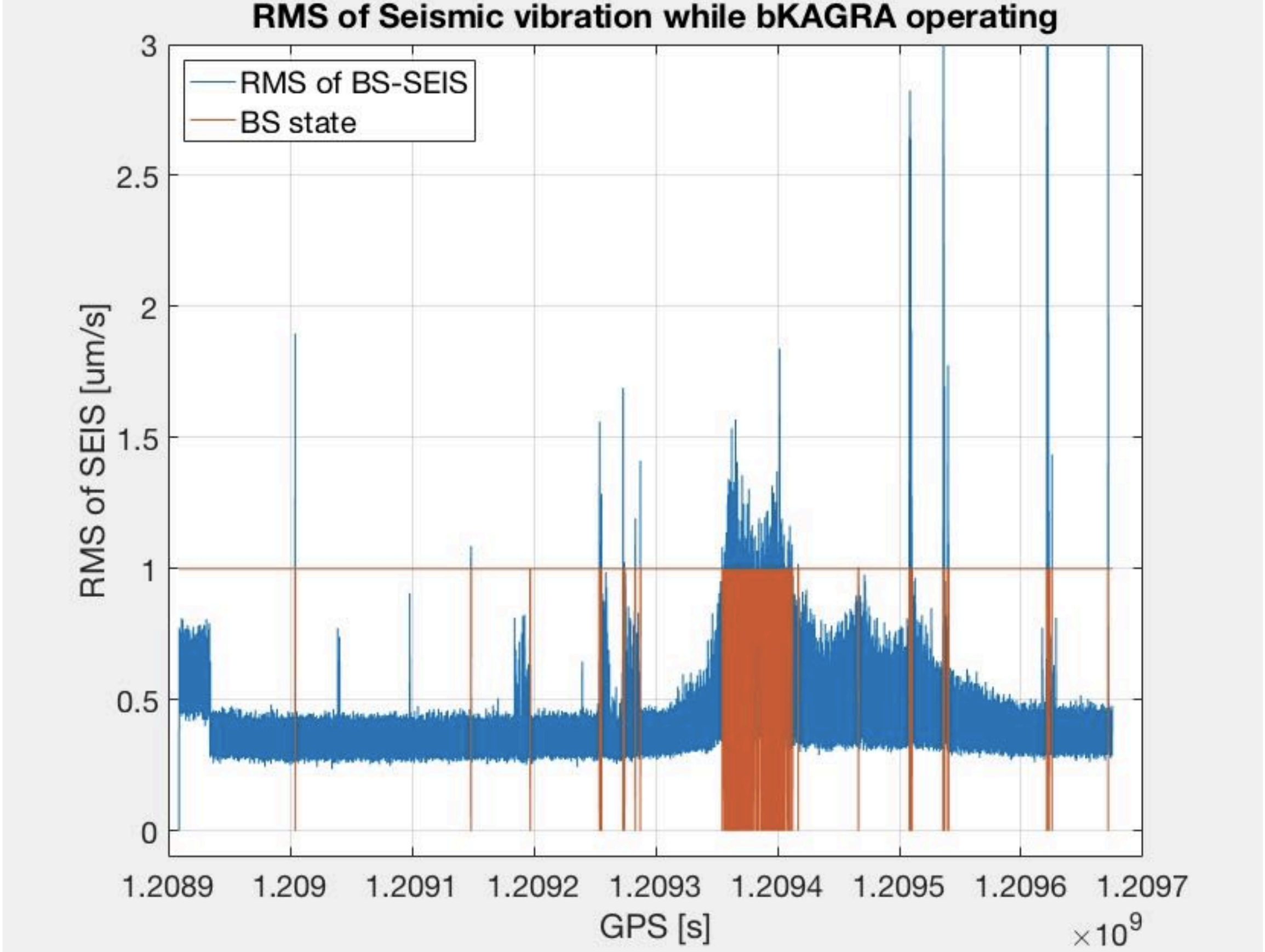



RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
M5.9
South Africa
M5.8
Vanuatu
M6.1
Philippine
M6.9
Hawaii
M5.4
Japan
micro seismic
RMS of Seismic vibration [um/s]
GPS [s]
×10^9
0
0.5
1
1.5
2
2.5
3
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097


RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
RMS of Seismic vibration [um/s]
3
2.5
2
1.5
1
0.5
0
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097
GPS [s]
×10^9

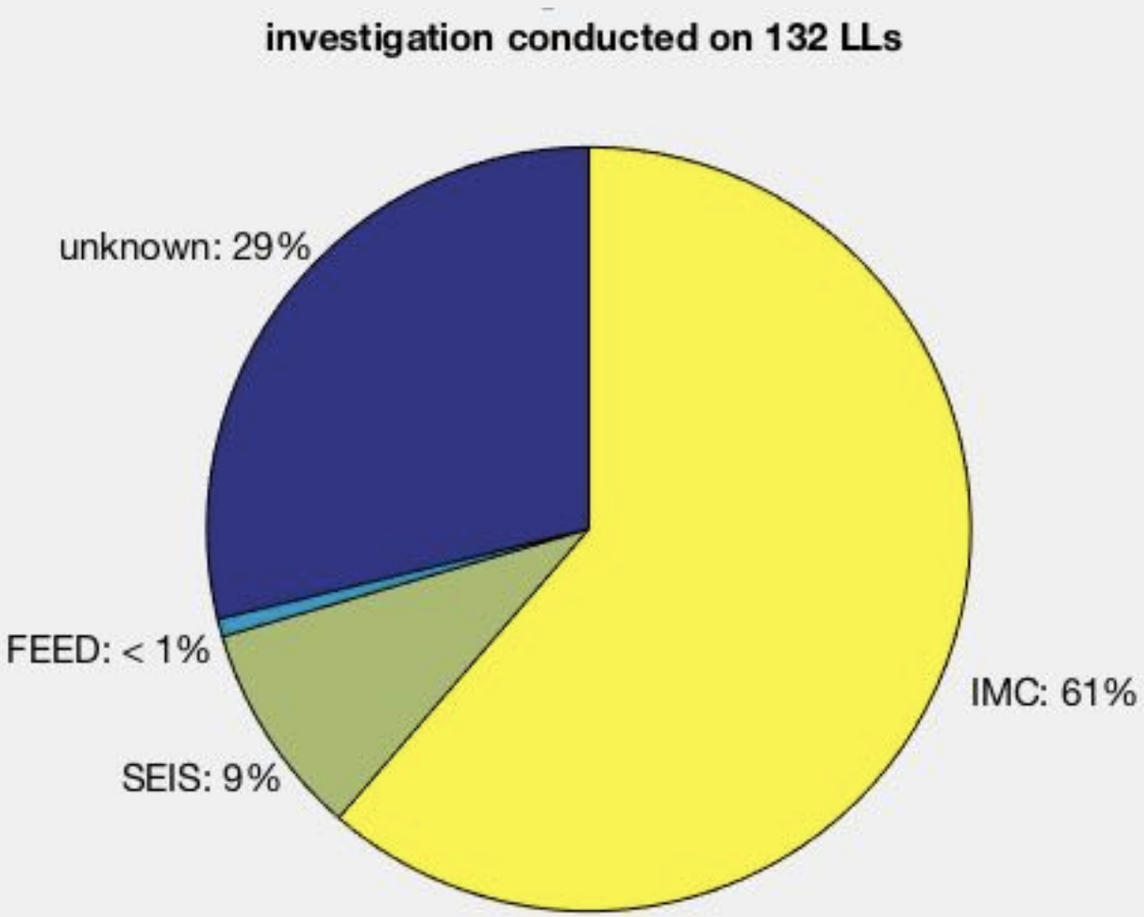

RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
threshold
1um/s
RMS of Seismic vibration [um/s]
GPS [s]
×10^9
0
0.5
1
1.5
2
2.5
3
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097


RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
big RMS
threshold
1um/s
small RMS
RMS of Seismic vibration [um/s]
GPS [s]
×10^9
0
0.5
1
1.5
2
2.5
3
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097


RMS of Seismic vibration while bKAGRA operating
RMS of BS-SEIS
BS state
RMS of SEIS [um/s]
3
2.5
2
1.5
1
0.5
0
1.2089
1.209
1.2091
1.2092
1.2093
1.2094
1.2095
1.2096
1.2097
GPS [s]
×10^9

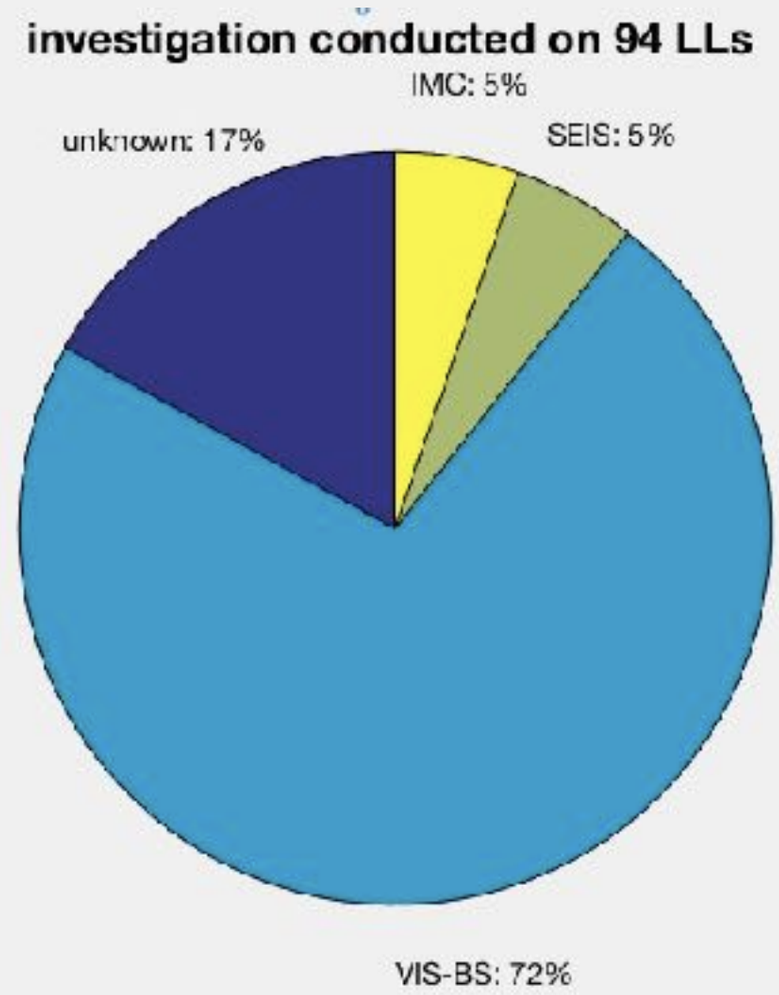
Ratio of LockLoss

iKAGRA



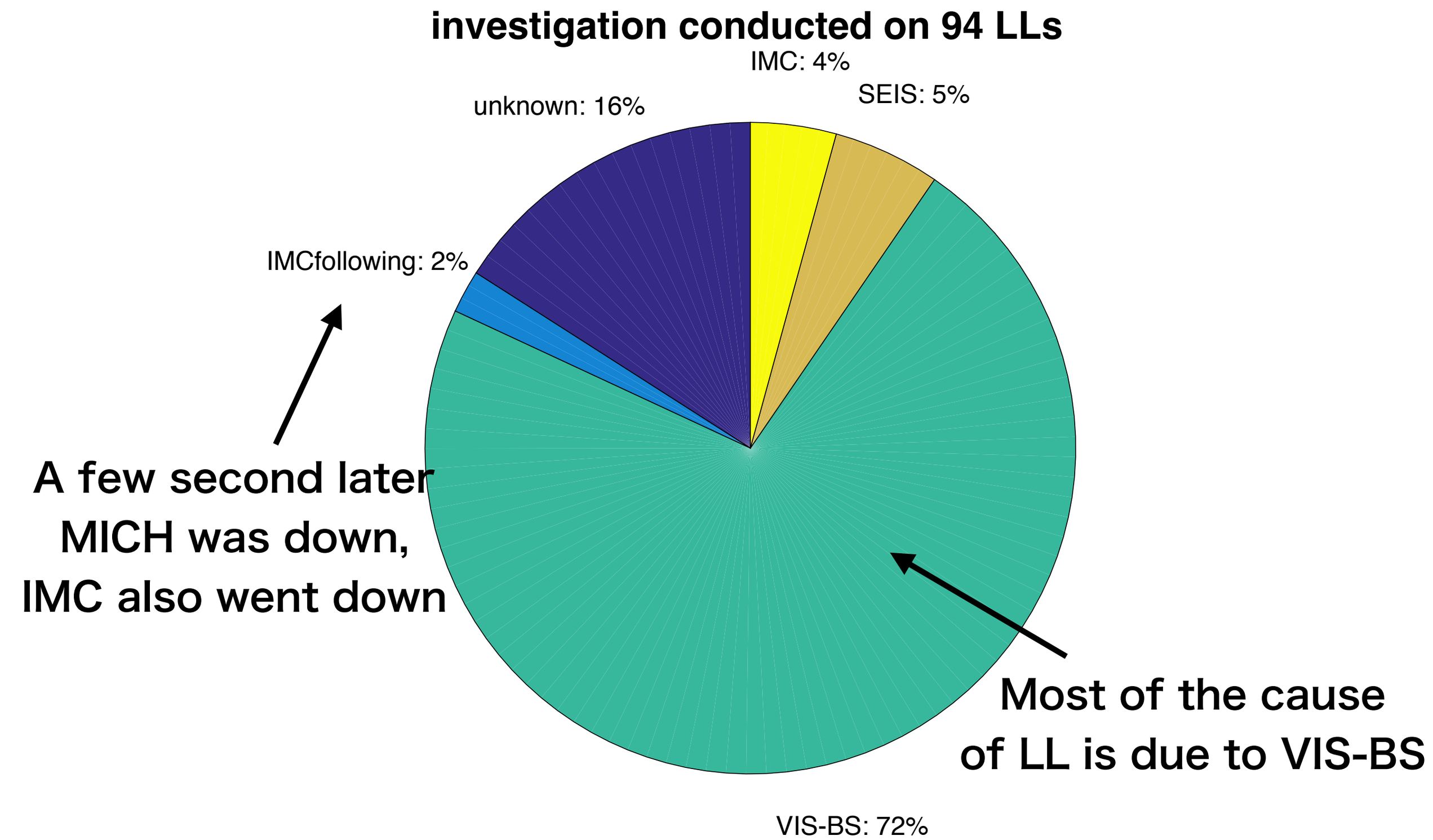
Most: IMC 61%

bKAGRA

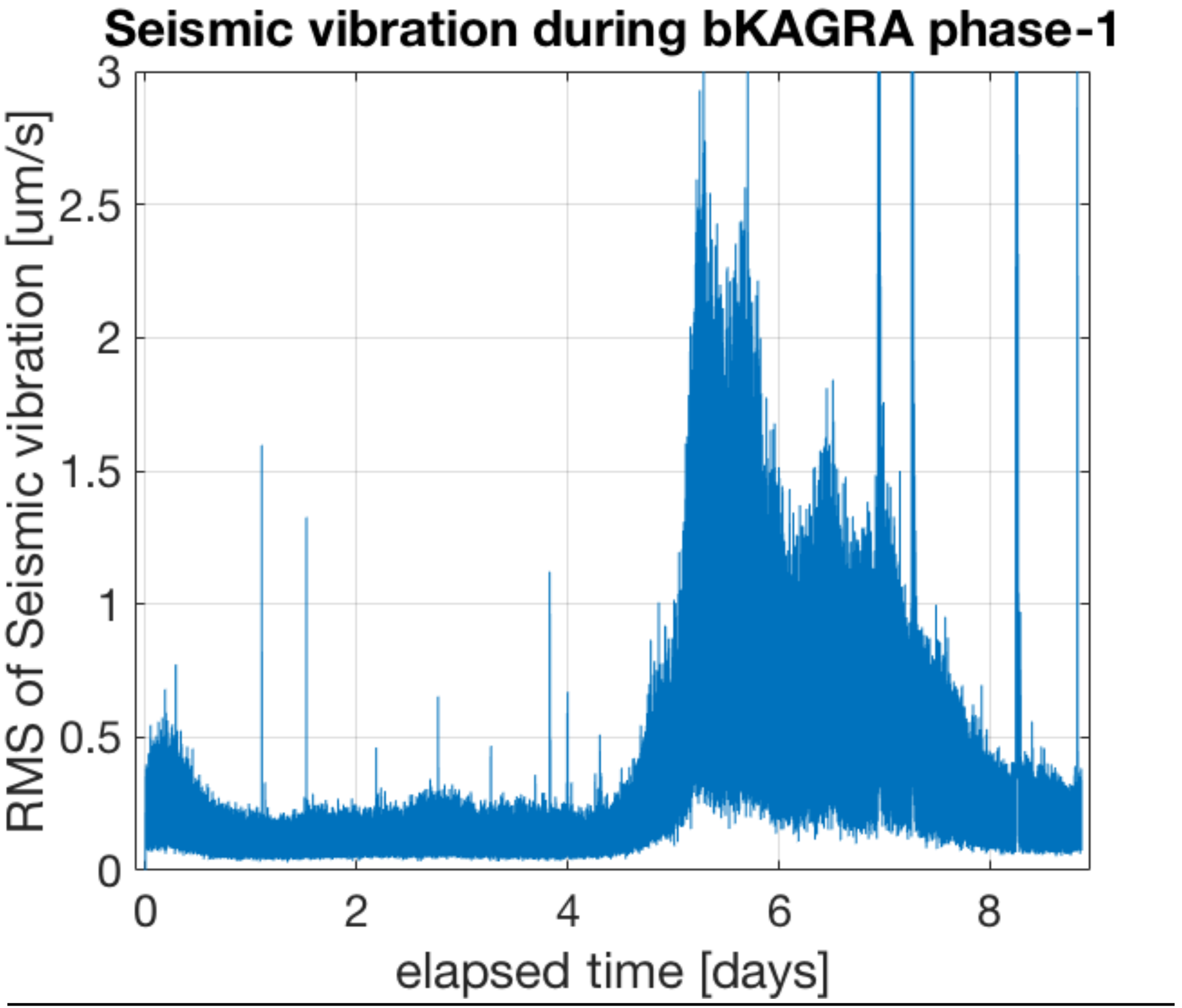


Most: VIS-BS 72%

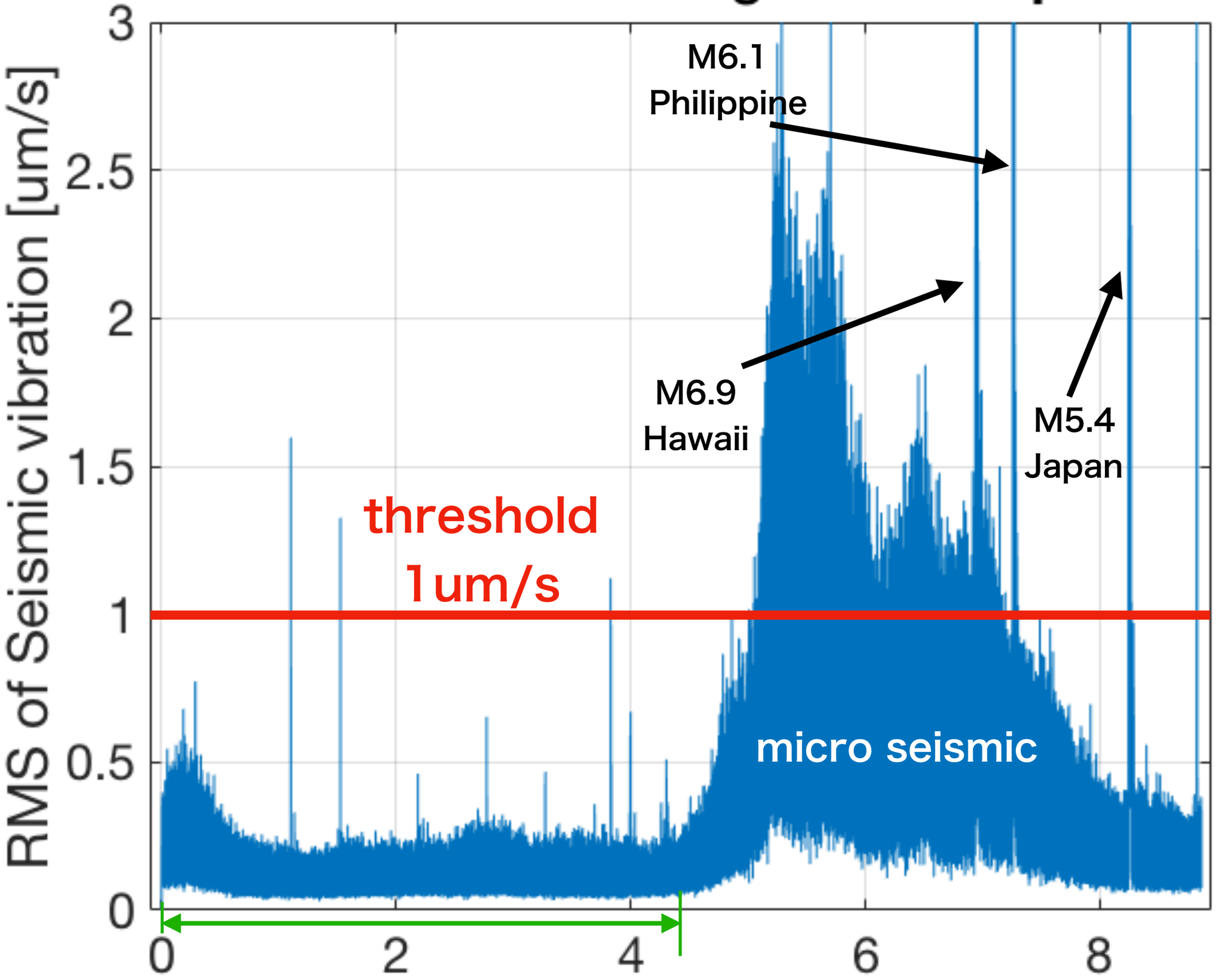
Ratio of LockLoss

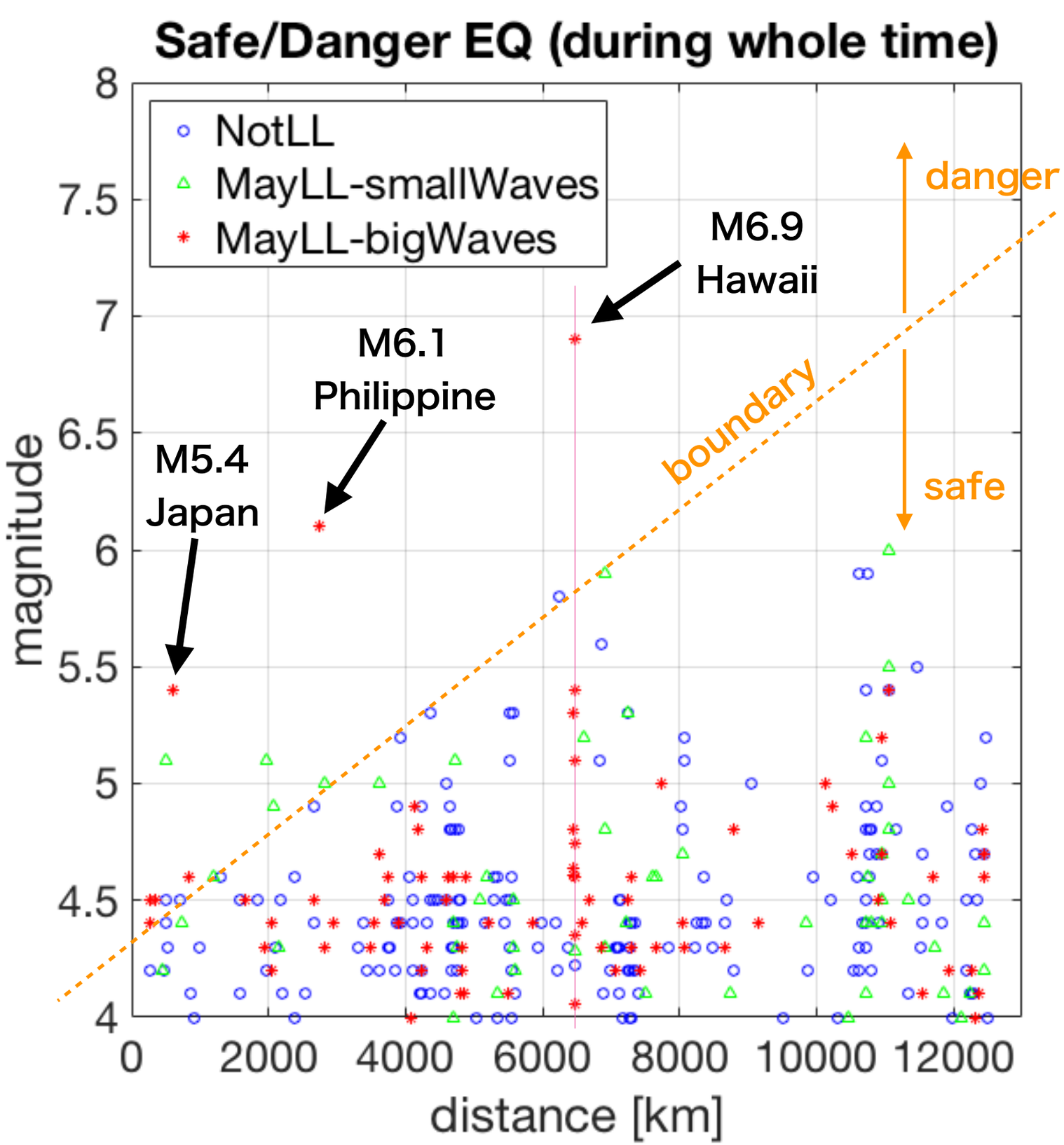


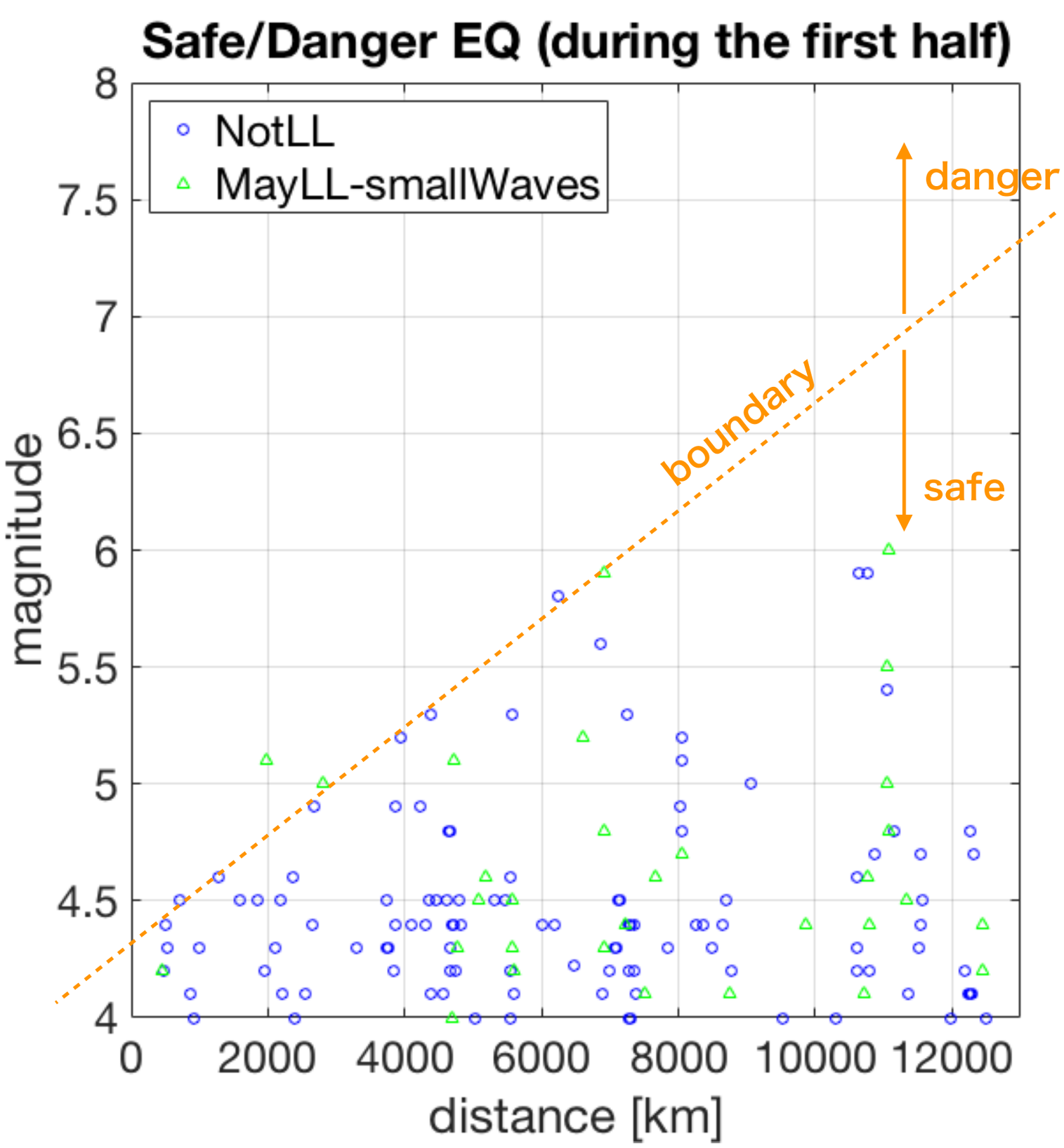
For KIW4 poster

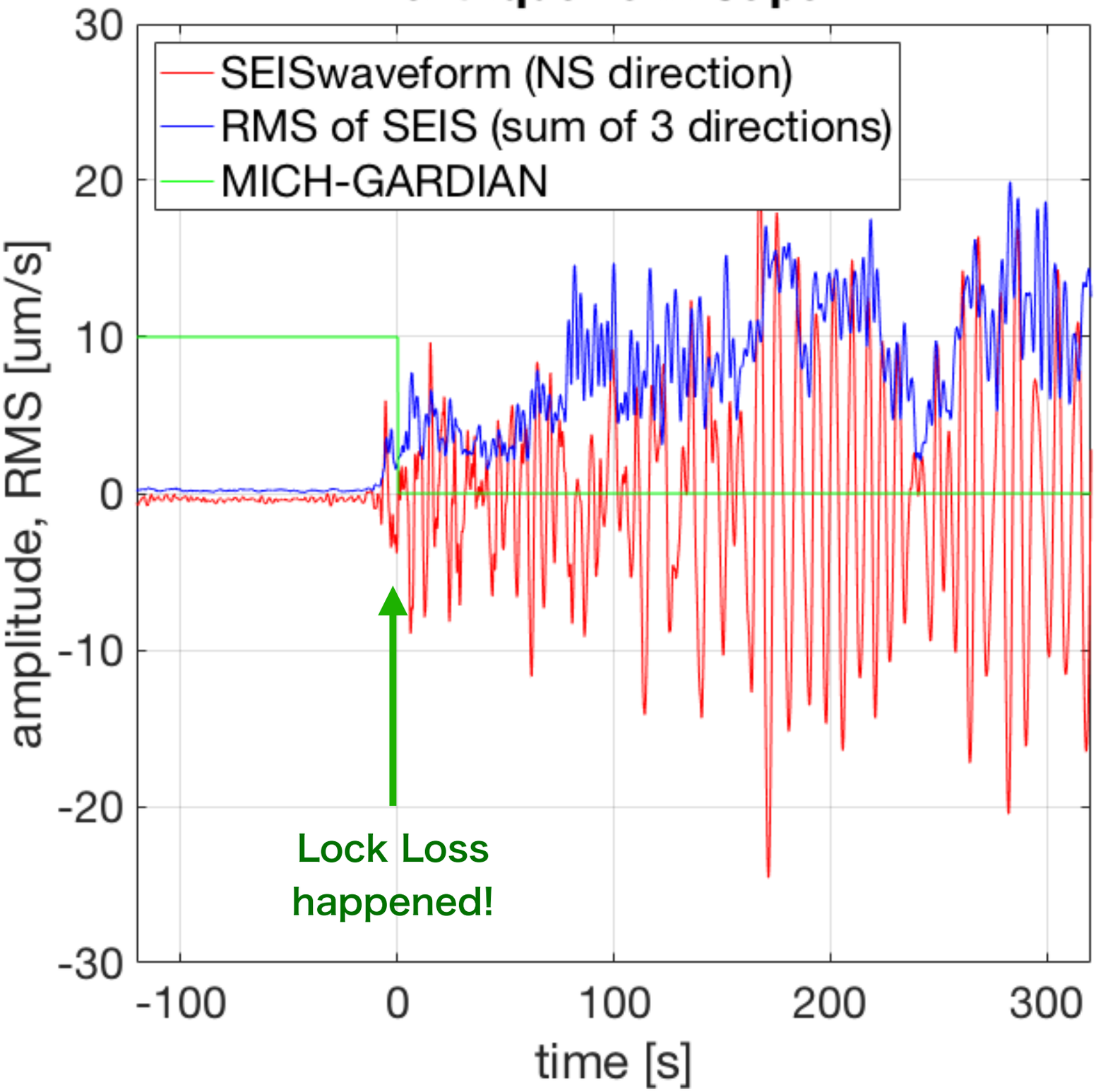

Seismic vibration during bKAGRA phase-1
RMS of Seismic vibration [um/s]
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
elapsed time [days]

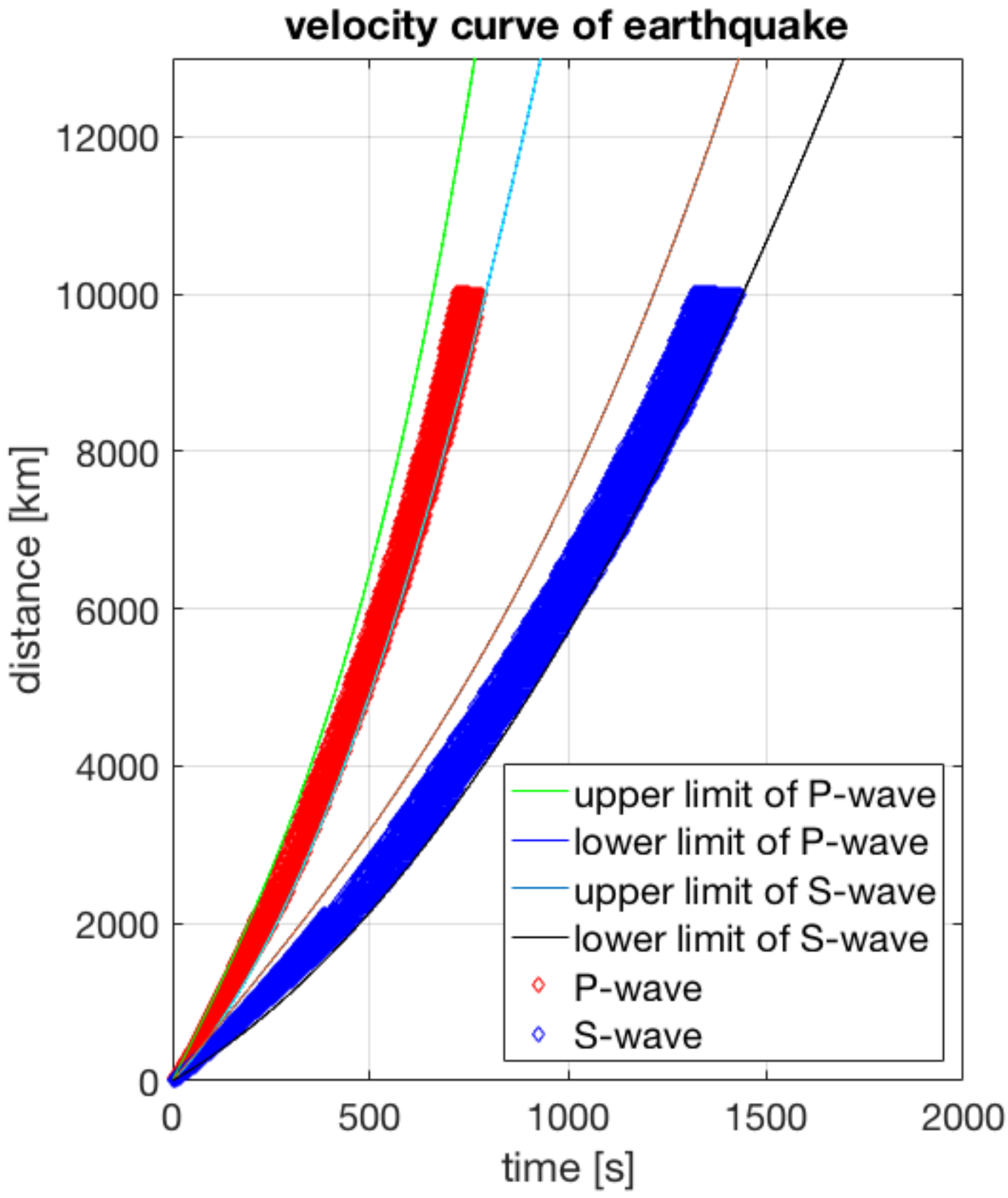
Seismic vibration during bKAGRA phase-1




Safe/Danger EQ (during whole time)
NotLL
MayLL-smallWaves
MayLL-bigWaves
M6.9
Hawaii
M6.1
Philippine
M5.4
Japan
danger
boundary
safe
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000


Safe/Danger EQ (during the first half)
NotLL
MayLL-smallWaves
danger
boundary
safe
magnitude
distance [km]
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2000
4000
6000
8000
10000
12000


Earthquake in Japan
SEISwaveform (NS direction)
RMS of SEIS (sum of 3 directions)
MICH-GARDIAN
Lock Loss
happened!
amplitude, RMS [um/s]
time [s]
30
20
10
0
-10
-20
-30
-100
0
100
200
300


velocity curve of earthquake
distance [km]
time [s]
0
2000
4000
6000
8000
10000
12000
0
500
1000
1500
2000
upper limit of P-wave
lower limit of P-wave
upper limit of S-wave
lower limit of S-wave
P-wave
S-wave