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bKAGRA PSL Design Study

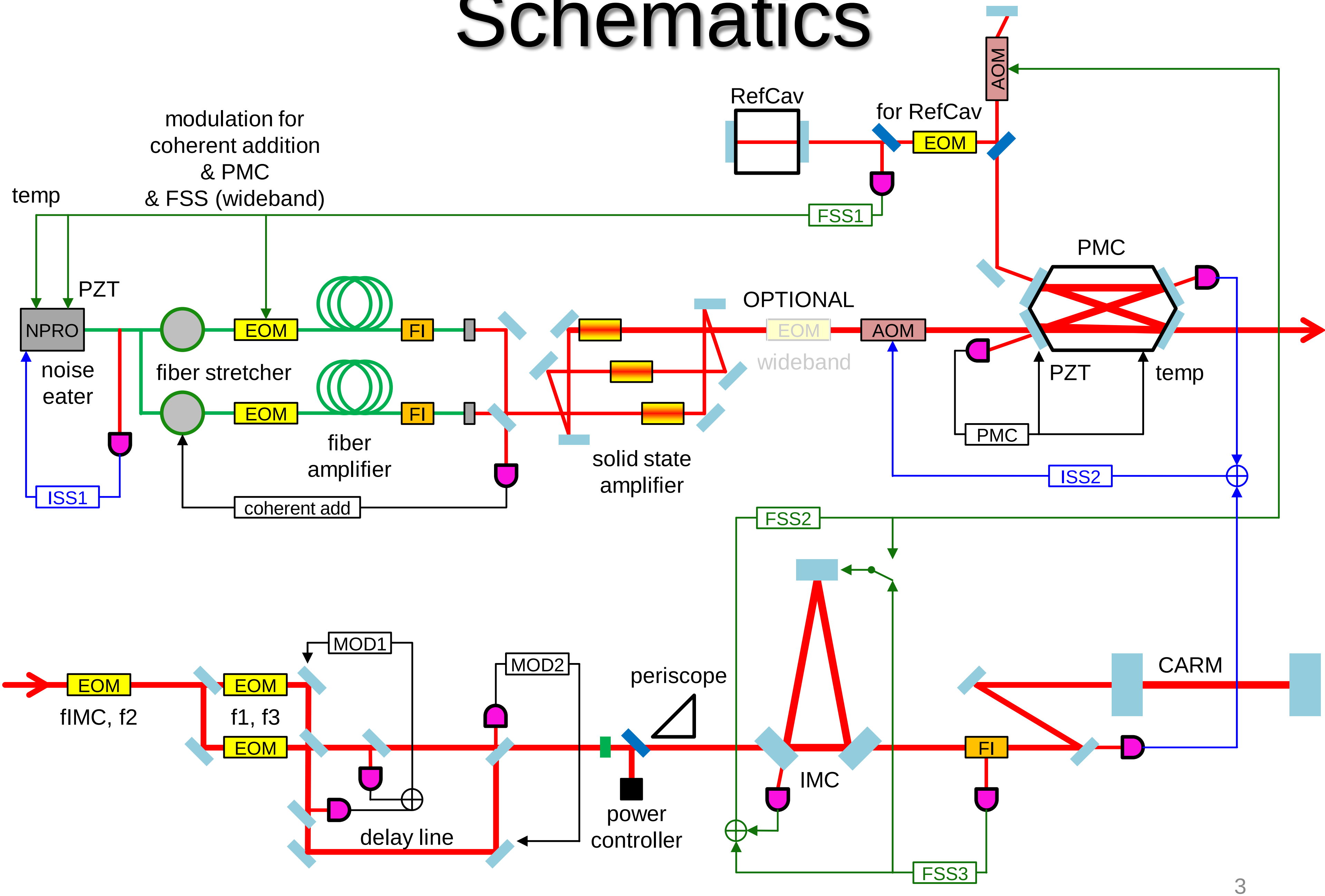
Yuta Michimura
Department of Physics, University of Tokyo

Scope

- Collect information for bKAGRA PSL
- Give first proposal for bKAGRA PSL design
- Start discussion on noises and control loops
  PMC, FSS, ISS

- References:
  - JGW-G1503293, JGW-G1402866 (laser setup)
  - JGW-T1402349 (iKAGRA PMC)
  - JGW-G1503515 (bKAGRA PMC)
  - JGW-T1503330 (FSS modeling)
  - JGW-D1503389 (ISS plan)
  - JGW-D1503189 (EOM layout plan)
  - JGW-T1402332 (beam jitter requirement at PSL)
  - LIGO-T0900649 (aLIGO PSL Final Design)
  - N. Ohmae, PhD Thesis (2010)

Schematics



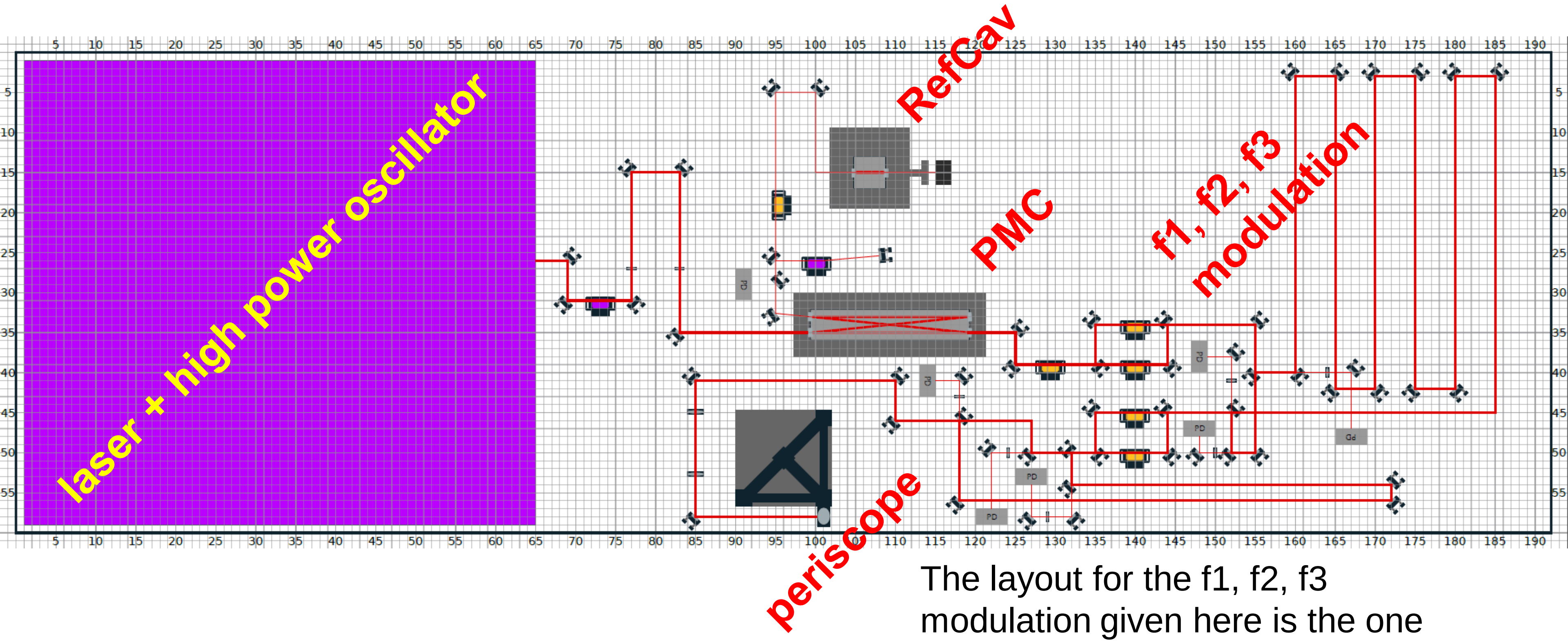
RefCav
for RefCav
EOM
AOM
modulation for
coherent addition
& PMC
& FSS (wideband)
temp
FSS1
PMC
PZT
NPRO
EOM
FI
OPTIONAL
EOM
AOM
wideband
noise
eater
fiber stretcher
EOM
FI
PZT
temp
PMC
fiber
amplifier
solid state
amplifier
ISS1
coherent add
ISS2
FSS2
MOD1
MOD2
EOM
fIMC, f2
EOM
f1, f3
EOM
periscope
CARM
IMC
FI
delay line
power
controller
FSS3

Concept

- RefCav after PMC to reduce beam jitter
  -> wideband EOM after fiber amplifier to avoid phase delay
  (Another possibility is to put RefCav and wideband EOM both before the fiber amplifiers. In this case, we don’t have to use high power wideband EOM, and RefCav servo stay locked when PMC is unlocked. However, beam jitter might be a problem.)
- Use PMC auxiliary transmissions for RefCav and ISS to save power
- Simple, but loss less f1(PM-AM), f2(PM), f3(AM) modulation
  -> PM-AM switchable for f1
  loses some f3 AM, but doesn’t matter much
  since f3 AM is used only for the lock acquisition
- Use less EOMs as possible
  -> use same EOM for coherent addition and PMC servo
  use same EOM (doubly-resonant) for f2 and IMC
  use same EOM (doubly-resonant) for f1 and f3

Actual Layout

- all fit in 4.8 m x 1.5 m bKAGRA PSL table
- see JGW-D1503484 for the updated layout

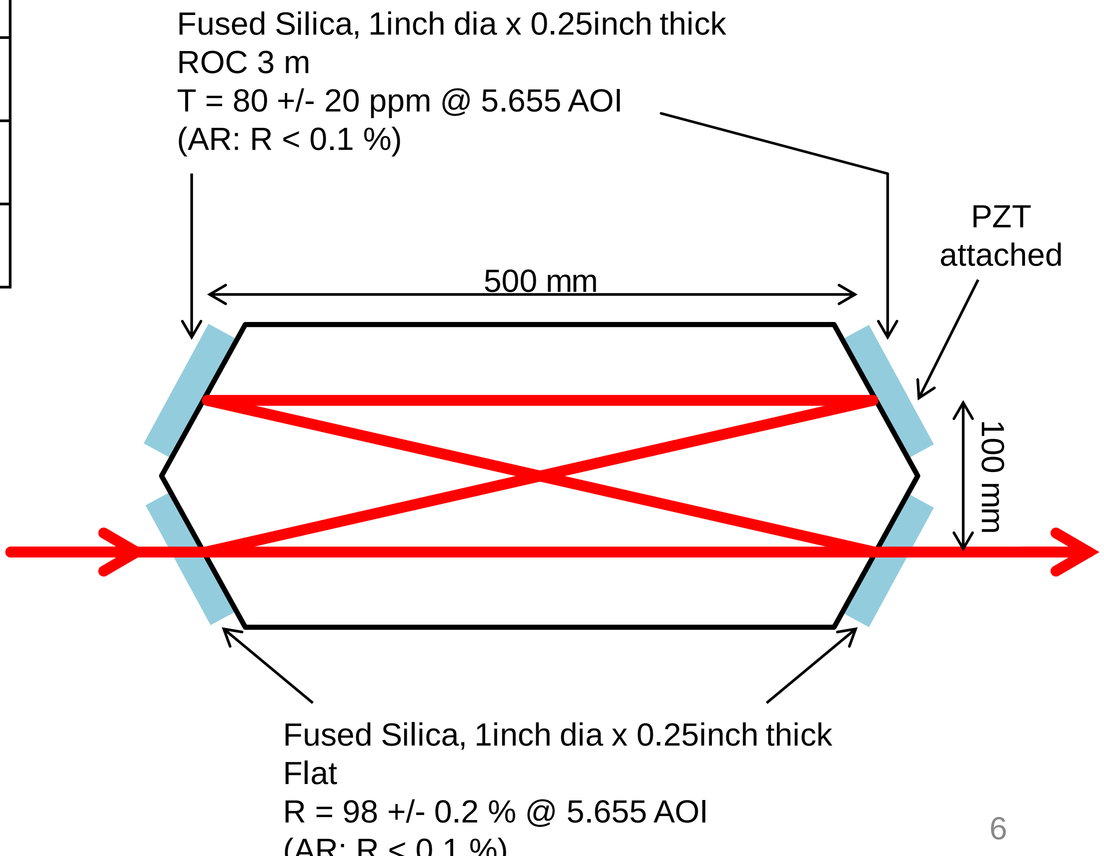


The layout for the f1, f2, f3 modulation given here is the one which takes up the most space. We are thinking of using a different layout as given in p.3

Pre-Mode Cleaner

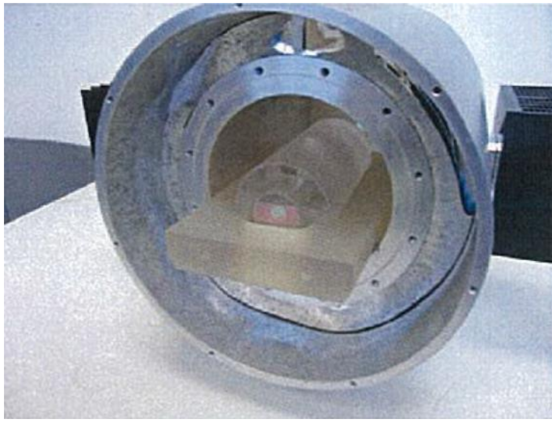
- bow-tie cavity, aluminum spacer (aLIGO-like)
- at design phase (see [JGW-G1503515])

finesse	155
round trip length	2.02 m
FSR	150 MHz
cavity pole	480 kHz
TMS	42 MHz



FSR: free spectral range
TMS: transverse mode spacing

Reference Cavity



- linear cavity, ULE spacer
- already made (currently at Kashiwa)
  including Zerodur support,
  thermally insulated vacuum can,
  temperature control
- Specsheet available
  from JGW-T1503493

finesse	3e4
round trip length	2*100 mm
FSR	1.5 GHz
cavity pole	22 kHz
TMS	0.22 GHz

- we call it a RefCav or FRC (frequency reference cavity; it stands for fiber ring cavity in iKAGRA!)

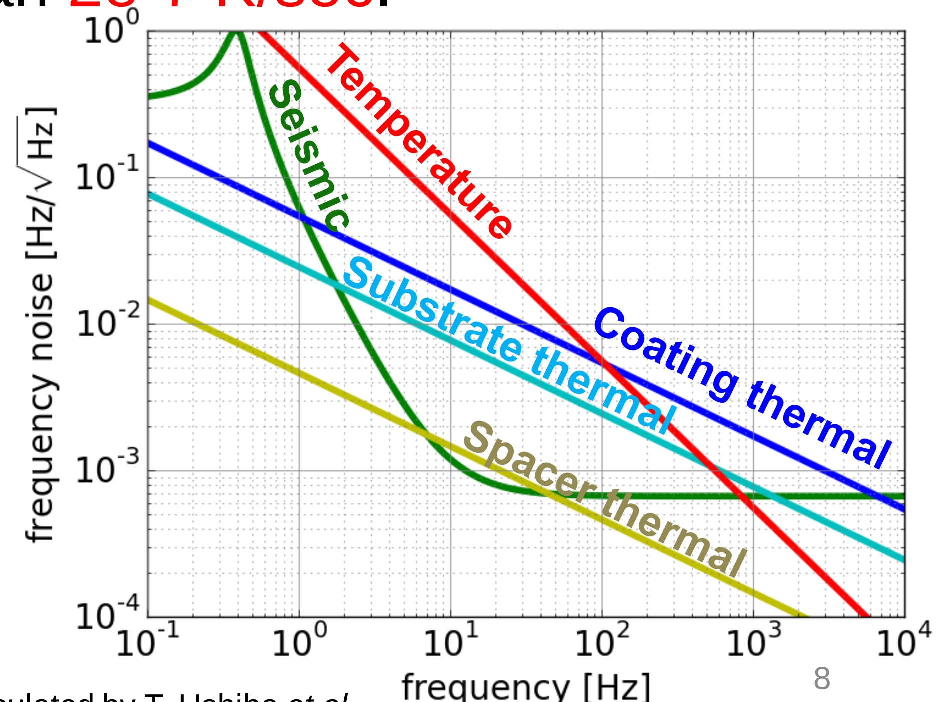
Photo from N. Ohmae

RefCav Frequency Stability

- long term drift should be smaller than ~100 mHz/sec
  It corresponds to 8.4 kHz/day and the daily drift will be smaller than the arm cavity FSR (50 kHz). So, we can lock the arm cavity at the same fringe every day.
- this can be achieved by stabilizing the temperature within +/- 1 K at the thermal expansion zero crossing point (this gives < 2e-9 /K of the thermal expansion), and making the temperature drift smaller than 2e-7 K/sec.
- estimated frequency stability is shown right
  seismic: 1e-9 (1Hz/freq)**2 m/rtHz
  vibration sensitivity: 3e-8
  vibration isolation: 1x Minus K

  thermal expansion: 2e-9
  cavity temperature: (1Hz/freq) uK/rtHz

  coating Q: 2500
  substrate Q: 1e6
  spacer Q: 6e4
  coating thickness: 4 um



Calculated by T. Ushiba *et al.*

Frequency Stabilization Servo

- Modeling on going
- See JGW-T1503330 for preliminary result
- It looks like the current PSL design basically meet the requirements

Intensity Stabilization Servo

- No modeling yet
- See JGW-D1503389

Wideband EOM for FSS

- We will use wideband EOMs before fiber amplifiers as a default plan (suggested by Rana Adhikari and Rick Savage)
  so, these wideband EOMs will be used for
  - coherent addition
  - PMC sidebands
  - FSS
- In case phase delay is a problem for FSS, we will put another wideband EOM after solid state amplifier. This wideband EOM should be compatible with high power.

EOM Layout for f1,f2,f3 Modulations

- Calculation for deciding the layout on going
- See JGW-D1503189
  (we are considering of choosing layout 3)

- Sideband amplitudes we need
  f1 PM: J1(0.15) [J1(0.2) at maximum]
  f1 AM: 0.65*J1(0.15) [optional for DRSE; 65% of PM]
  f2 PM: J1(0.05) [J1(0.1) at maximum]
  f3 AM: 0.05 [only used for lock acquisition]
- Unwanted sidebands
  f1 harmonics: requirements to be calculated
  f3 harmonics: requirements to be calculated
  unwanted f1 AM: requirements to be calculated
  unwanted f2 AM: requirements to be calculated

Beam Jitter

- Requirements for PSL periscope mirror displacement/tilt are

$$\delta x < (5 \times 10^{-10} + 5 \times 10^{-3}\ \mathrm{Hz}/f^4)\,\mathrm{m}/\sqrt{\mathrm{Hz}}$$
$$\delta \theta < (2 \times 10^{-11} + 2 \times 10^{-4}\ \mathrm{Hz}/f^4)\,\mathrm{rad}/\sqrt{\mathrm{Hz}}$$

  (see JGW-T1402332 for derivation)
- We have to design a periscope to meet this requirement

People in Charge

- Overall layout [Nakano]
- PMC [Nakano, Michimura, UToyama]
- RefCav [Michimura?]
- FSS [Michimura]
- ISS [UToyama]
- EOM [Uehara, Shiga, Somiya]
- Periscope [??]