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Study on iKAGRA PMC

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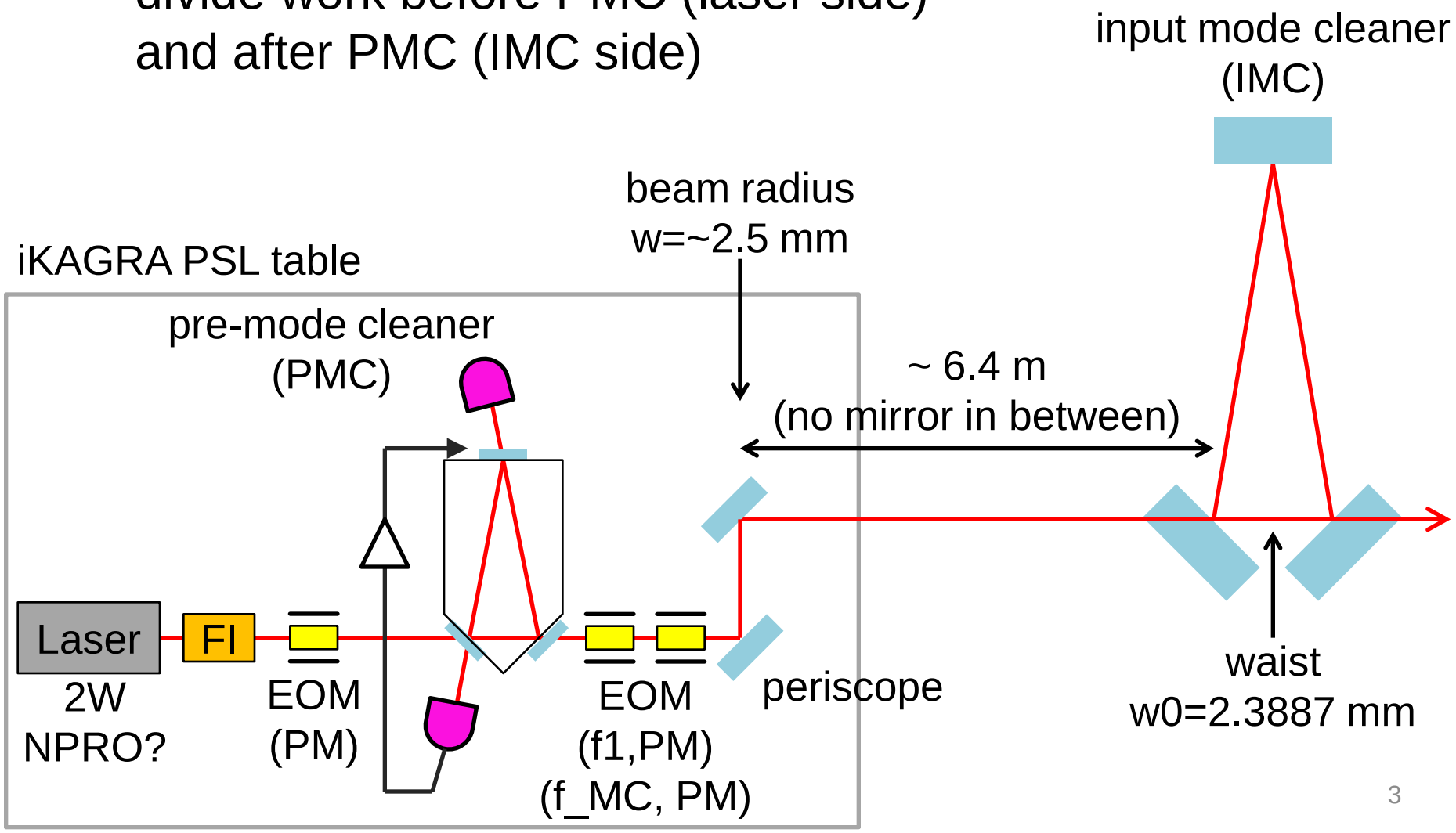
Scope

- Derive some requirements for iKAGRA PMC
- Collect information about iKAGRA PMC candidates

- References:
  - LIGO-T0900649 (aLIGO PSL design)
  - LIGO-T0900577, T0900578 (PMC servo circuits)
  - LIGO-T990025 (iLIGO PSL design)
  - https://wiki-40m.ligo.caltech.edu/PSL/Pre_Mode_Cleaner (eLIGO PMC specs)
  - JGW-D1402348 (drawings of Miyoki-san's PMC)

Why do we want PMC for iKAGRA

- beam pointing reference to IMC
- divide work before PMC (laser side) and after PMC (IMC side)



iKAGRA PMC Requirements

- PZT range
  - larger than ~4 um (assuming thermal expansion of invar: 1e-6, PMC spacer length: ~20 cm, temperature drift: ~10K)
  - if IMC drift makes too much laser frequency drift, we may have to apply temperature servo for PMC (or laser)
- UGF
  - should be smaller than PZT resonant frequency
  - higher than 100 Hz (aLIGO is 10kHz)
  - requirement derivation is shown next 4 pages
- beam pointing drift
  - smaller than ~3 urad/day
  - pointing drift should be smaller than IMC drift and TAMA stack tilt drift was ~3 urad/day
    [R. Takahashi+: RSI 73, 2428 (2002)]
- do not use so much money

UGF Requirement Derivation 1

- higher the better, but cannot be higher than PZT resonance
- frequency noise after PMC shouldn't be larger than that of free running NPRO
- assume PMC length fluctuation is same as seismic noise (too pessimistic)
- assume PMC half round trip length is 20 cm
- cavity length fluctuation will be suppressed by PMC servo
- residual length fluctuation will be converted into frequency noise of the transmitted beam with HPF

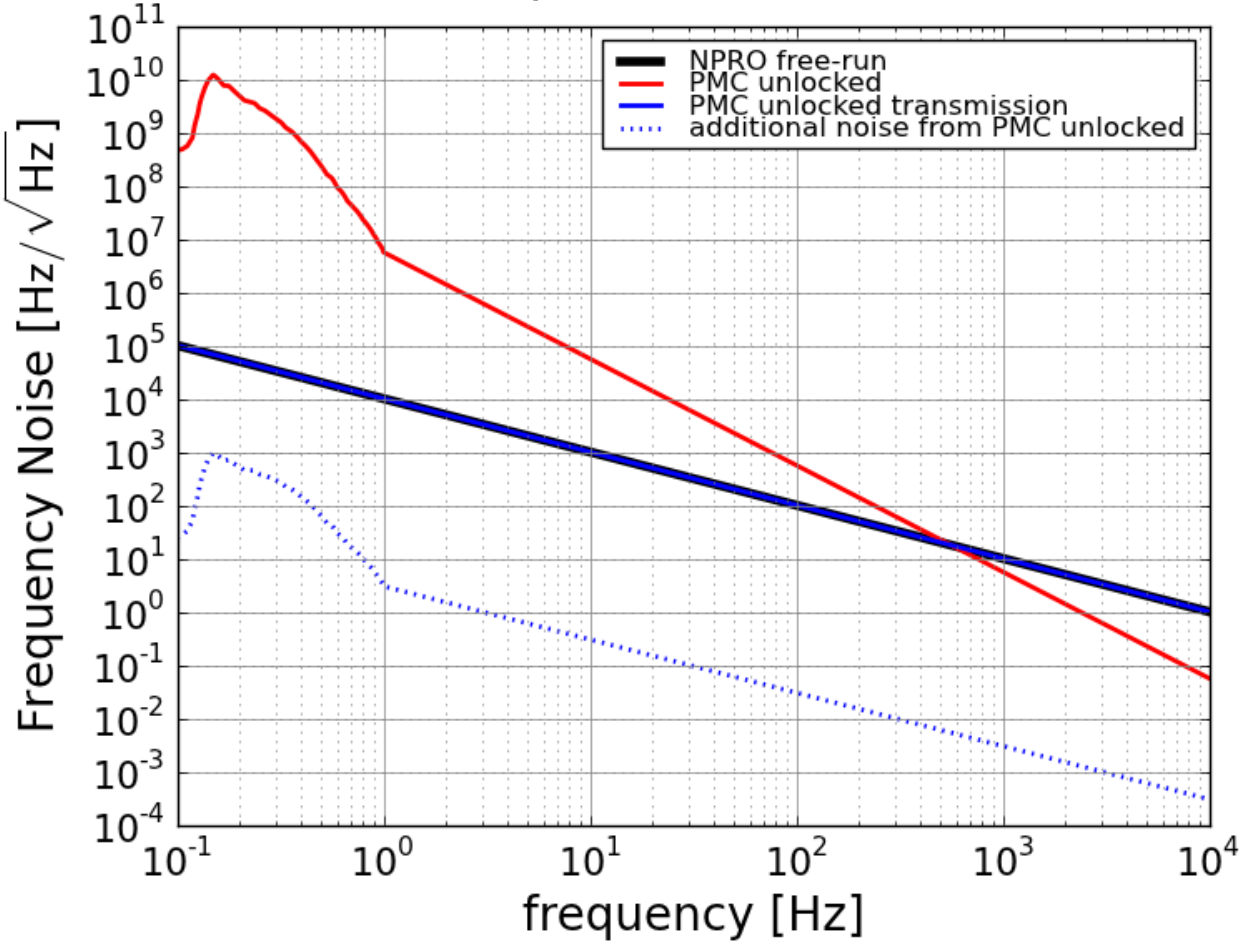
$$H(f) = \frac{1}{1 + i f_{\mathrm{cp}}/f}$$

where fcp is the cavity pole (~2 MHz)
(see JGW-T1201121)

- frequency noise of the input beam will also be added

UGF Requirement 1

- UGF can be very low from frequency noise point of view (frequency noise from residual cavity length fluctuation is high-passed out and frequency noise of the transmitted beam is dominated by the original incident NPRO beam)



UGF Requirement Derivation 2

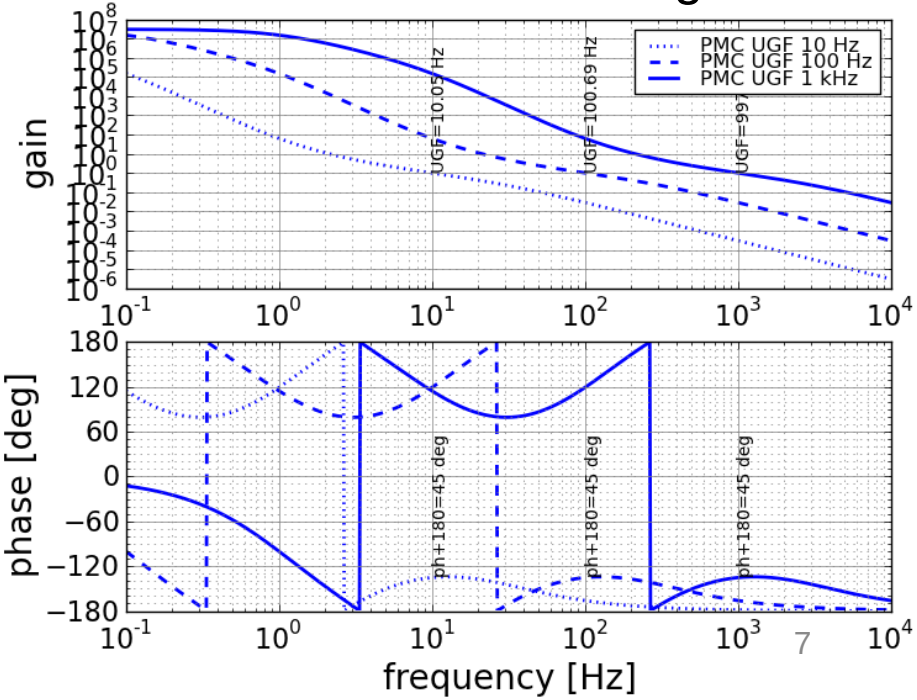
- intensity noise after PMC shouldn't be larger than that of free running NPRO
- residual cavity length fluctuation will be converted into intensity noise of the transmitted beam with

$$\frac{P_{\mathrm{trans}}}{P_{\mathrm{in}}} \simeq 1 - \left(\frac{4\mathcal{F}}{\lambda}\right)^2 \delta L$$

(assuming critically coupled cavity without any loss)

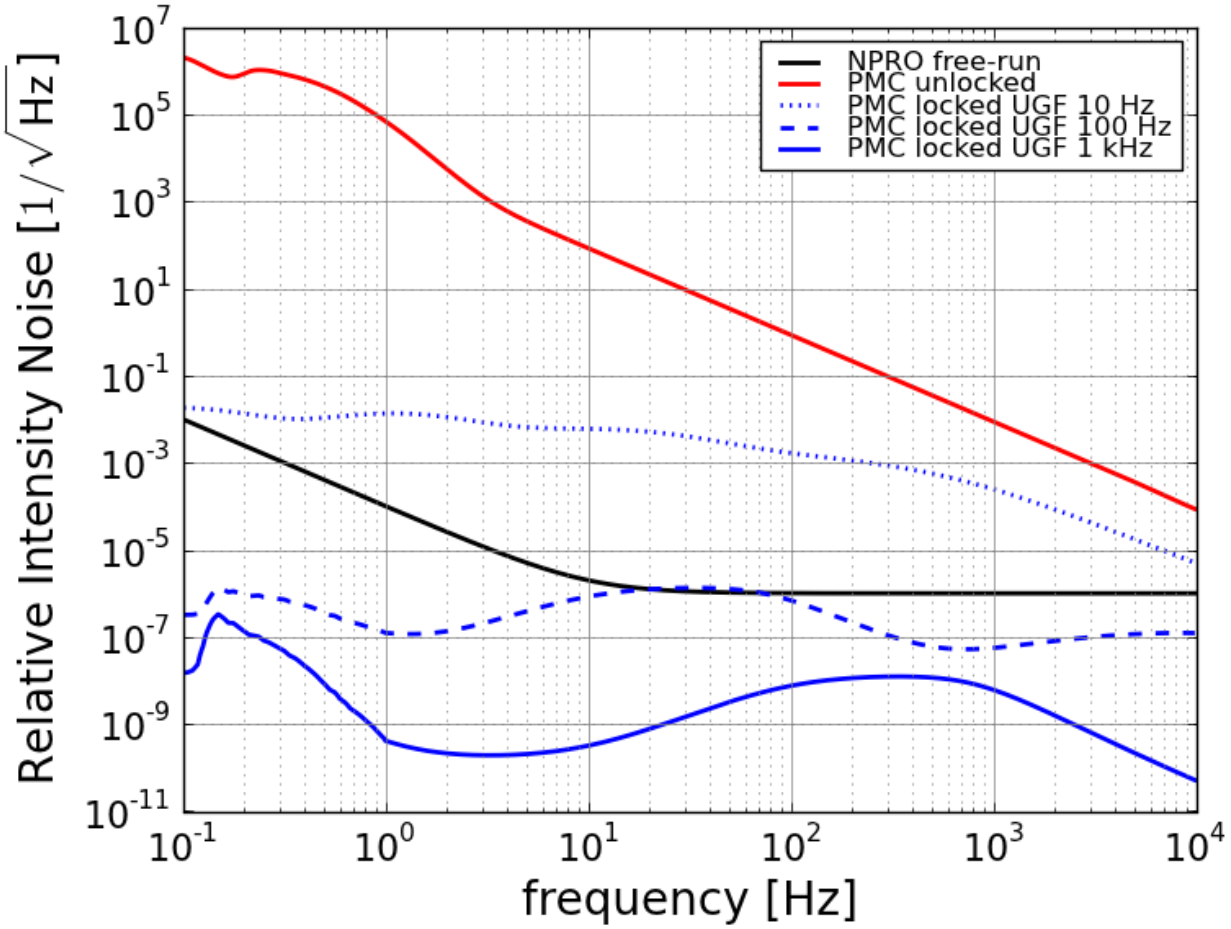
- since the effect is non-linear, we have to assume OLTF of PMC locking loop →
- calculation of spectrum from 2nd-order effect is shown in [my note](#) (in Japanese)

assumed PMC locking OLTF



UGF Requirement 2

- UGF 100 Hz is enough from intensity noise point of view
  (cavity detuning is assumed to be ~1e-12 m, which corresponds to ~1 kHz; this is roughly 1 mV assuming PDH signal peak-to-peak is ±1 V)



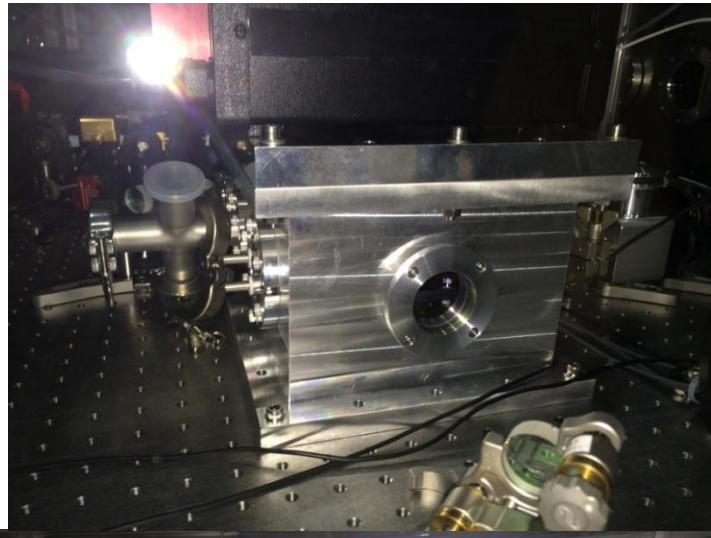
iKAGRA PMC Candidates

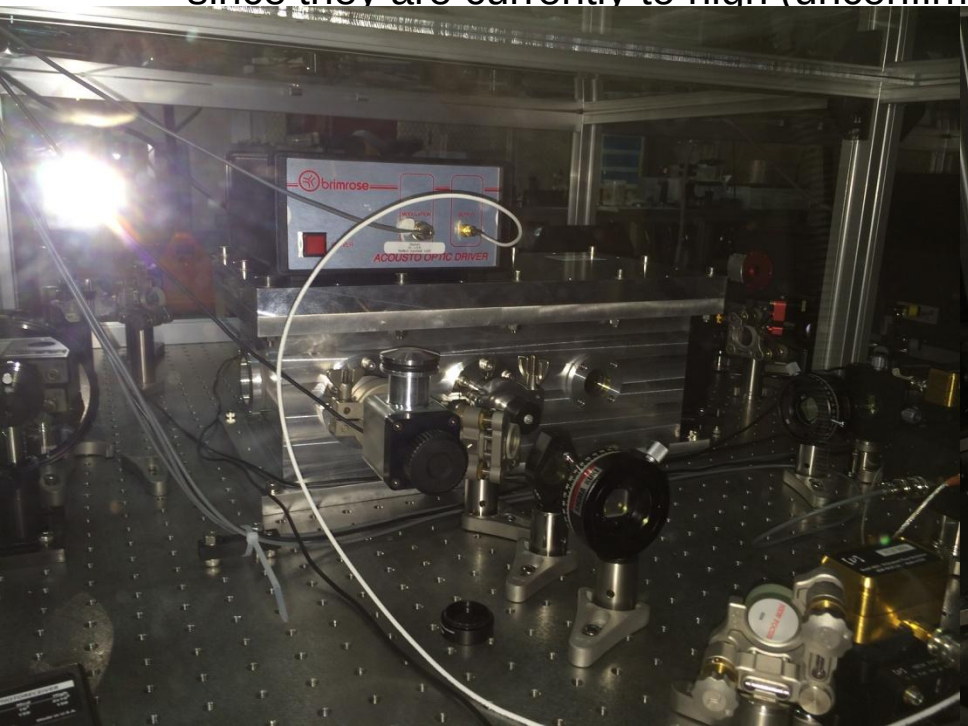
- Miyoki-san's seems like the strongest candidate

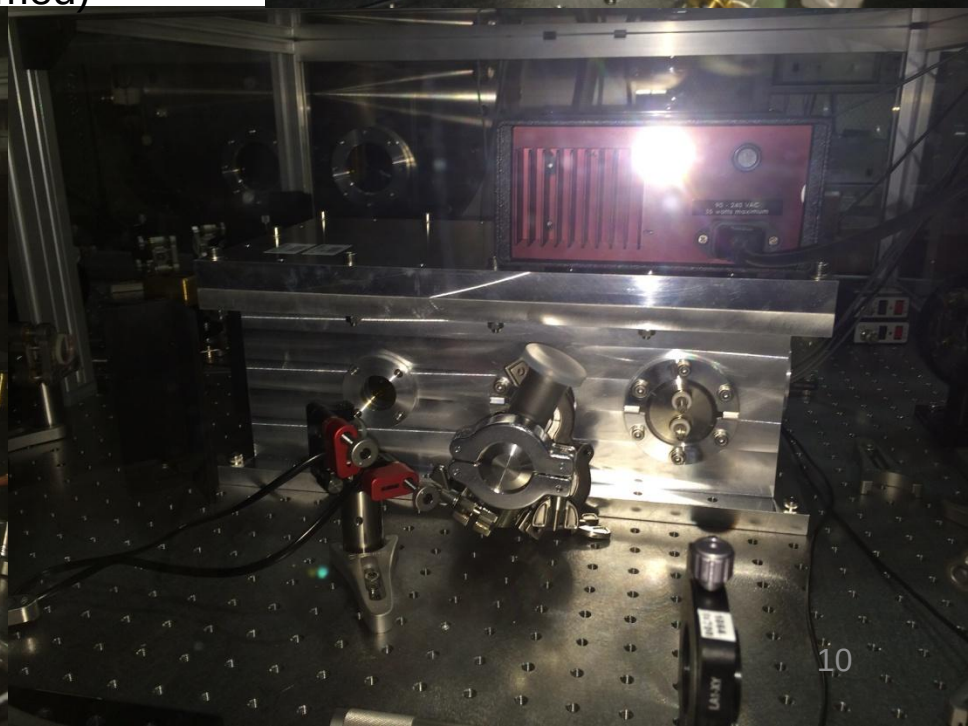
	Mio lab	Miyoki-san	eLIGO
Shape	triangular	triangular	triangular
Mirror RoCs	30 cm	30 cm	100 cm
Round-trip length	42 cm	40 cm	41 cm
FSR	714 MHz	750 MHz (calc)	713 MHz
Finesse	2900 (s), 220 (p)	measured mirror reflectivity was 99.97 %?	800
Transmissivity	77 % (s), 86 % (p)	~20 %? (s), ~13 %? (p)	?
Spacer	Invar	Invar	Fused Silica
Comment	Originally planned to be used for characterization of bKAGRA laser.	No PZT attached yet . Aluminum vacuum enclosure also available. (drawings: JGW-D1402348)	Rana offered spare one. Needs shipping fee.

Miyoki-san's PMC

- photos taken by Nakano-kun
- end mirror diameter is 30 mm, but smaller one is also available (according to Miyoki-san)
- PZT resonance will be ~few kHz with 30 mm mirror
- have to modify jigs to put smaller mirror if we need higher PZT resonance (1/2 inch mirror gives ~20 kHz)
- PZT is already bought, but viton O-ring is not
- we might also have to replace in/output mirrors since they are currently to high (unconfirmed)

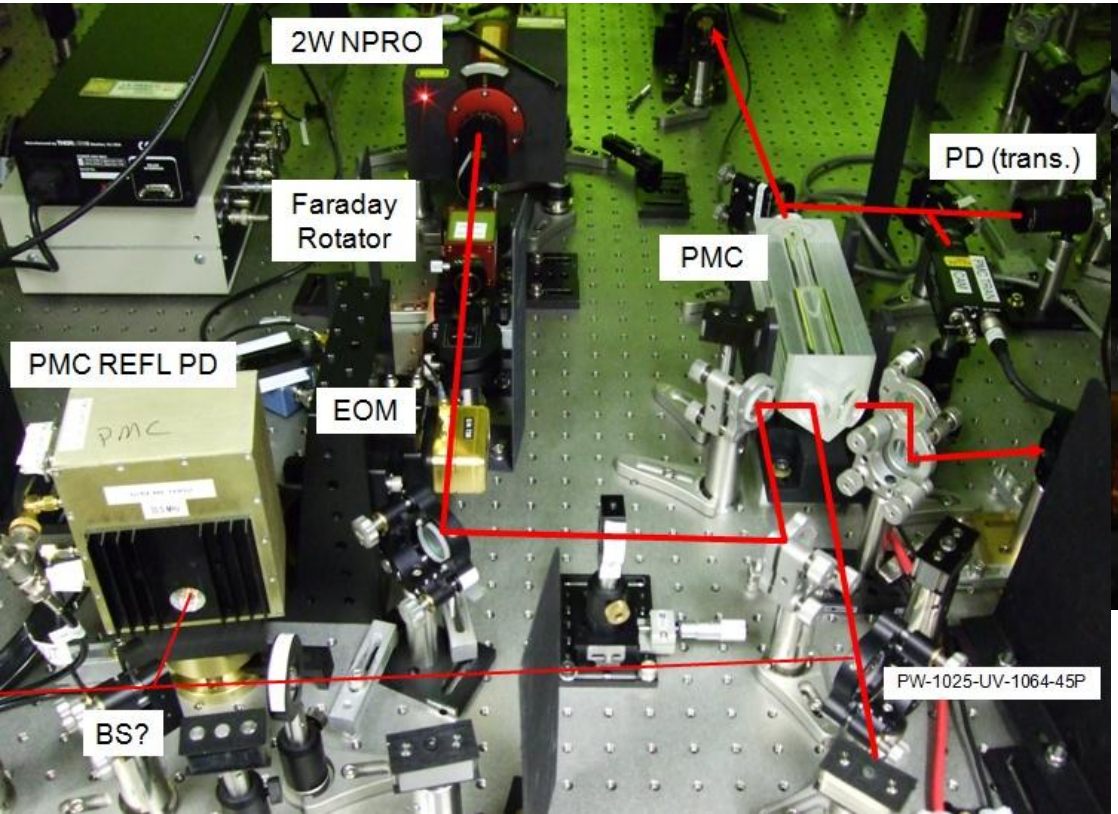


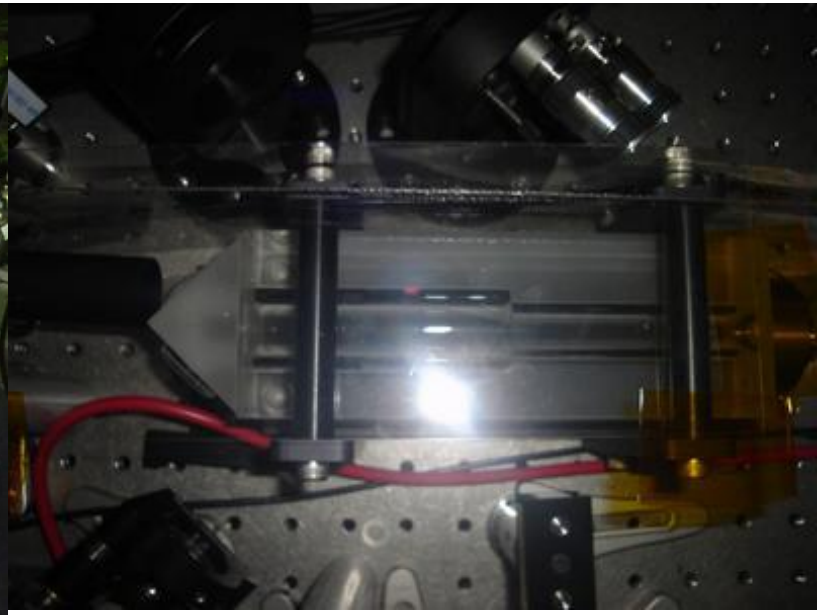




eLIGO PMC

- photos taken at Caltech 40m
- no modification is needed, but we have to ship it
- shipping fee is currently under estimation (23.5 kg mirror was 18万円 according to Kikuchi-san; PMC is ~3 kg)





Electronics, Electro-Optics

- high voltage amplifier for PZT
  - we need this also for periscope mirror
  - at least 4 channels in total for iKAGRA IOO
    (NPRO, PMC, periscope x 2)
  - Thorlabs MDT693B: 3ch, 25万円, ~1 week
  - MESS-TEK M-2629: 6ch, 63万円, ~1 week
  - if there's no money, we have to borrow from someone
- analog servo filters

  Effective delay of CDS including AA/AI is roughly 200 usec when sampling frequency is 16 KHz (see 40m elog #3961)

  - to achieve high UGF (above ~400 Hz), we need analog circuits (with switches using BO of CDS for DC boosts)

  binary output digital system
- EOM
  - if there's no money, we have to borrow from someone
  - modulation frequency must be set from MIF group
- RF PD (for PMC_REFL), DC PD (for PMC_TRANS)
  - broadband?

Test at ICRR, Kashiwa

- PMC test will be done at Kashiwa by Nakano and Michimura
- test includes;
  - PZT resonances
  - finesse, FSR, TMS
  - beam pointing stability
  - intensity noise of transmitted beam
  - servo filters (possibly with digital system)
- detailed schedule, plans will be fixed soon
  (~ 1 month between May to Sept 2014)
- iKAGRA PSL table will be shipped to ICRR soon
- students from Niigata U or Toyama U could help
  (maybe only during summer vacation)

Conclusions so far

- we will put PMC also for iKAGRA
- requirements are not so severe at all, but we should check pointing stability by measurement
- PZT range should be larger than ~4 um
- UGF should be higher than ~100 Hz from intensity noise point of view; this means PZT resonant frequency should be higher than ~1 kHz; but this could be achieved with 30 mm mirror; also, 100 Hz UGF servo is easily done with CDS
- we need PZT drivers (~50万円 or borrow), mirrors? (~10万円), EOM (borrow?), servo filters(AEL), RF PD(AEL), and DC PD (AEL)
- sideband frequency for PMC should be set soon (MIF)
- assembly and test will be done by Nakano and Michimura at ICRR, Kashiwa