DECIGO実験計画(仮)

KAGRA observatory,
Institute for cosmic ray research,
University of Tokyo

NAGANO Koji (長野 晃士)

Overture

Q. Who am I?

A. I'm NAGANO Koji, 2nd year of Ph.D. course, belonging to KAGRA observatory, ICRR, University of Tokyo.

Q. What did I do last fiscal year?

A. I studied on the optical levitation experiment in Hongo, and for KAGRA I worked for physics environmental monitor.

Q. Will I talk about them in this presentation?

A. No. I will talk about my future work for DECIGO!

Outline

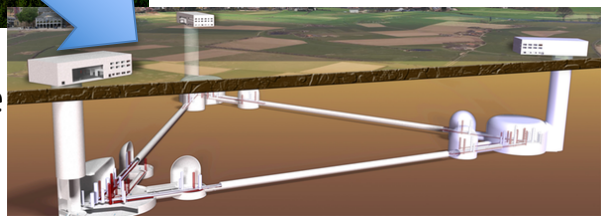
1. What is DECIGO?
2. What is B-DECIGO?
3. What are challenges for DECIGO and B-DECIGO operation?
4. What can be done in the lab experiment for DECIGO and B-DECIGO?

Introduction

- So far, 6 gravitational wave (GW) events have been detected by ground-based detectors.
- For further expansion of the GW physics and astronomy, we have two choices.

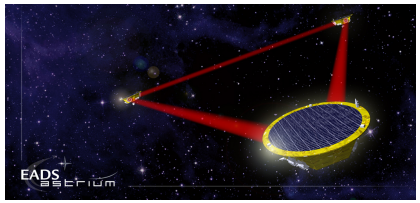
Improve ground-based detectors' sensitivity (10 Hz-1 kHz)

LIGO Livingston (Credit: Caltech/MIT/LIGO Lab)



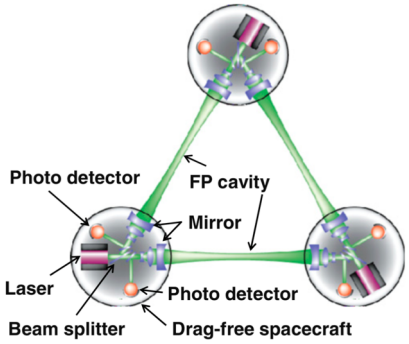
Einstein telescope (http://www.et-gw.eu)

Develop space detectors (0.1 mHz-10 Hz)



LISA (Credit: EADS Astrium)

DECIGO (S. Kawamura+, CQG, 2011)



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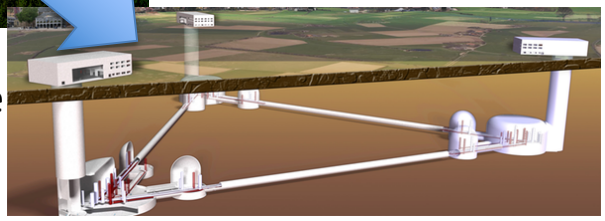

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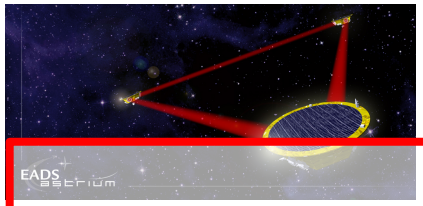

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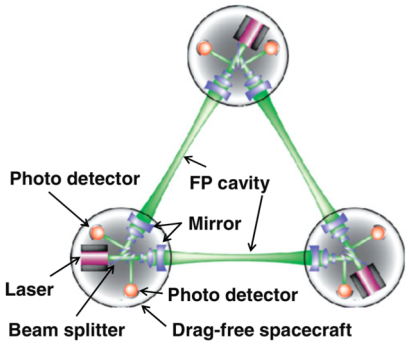


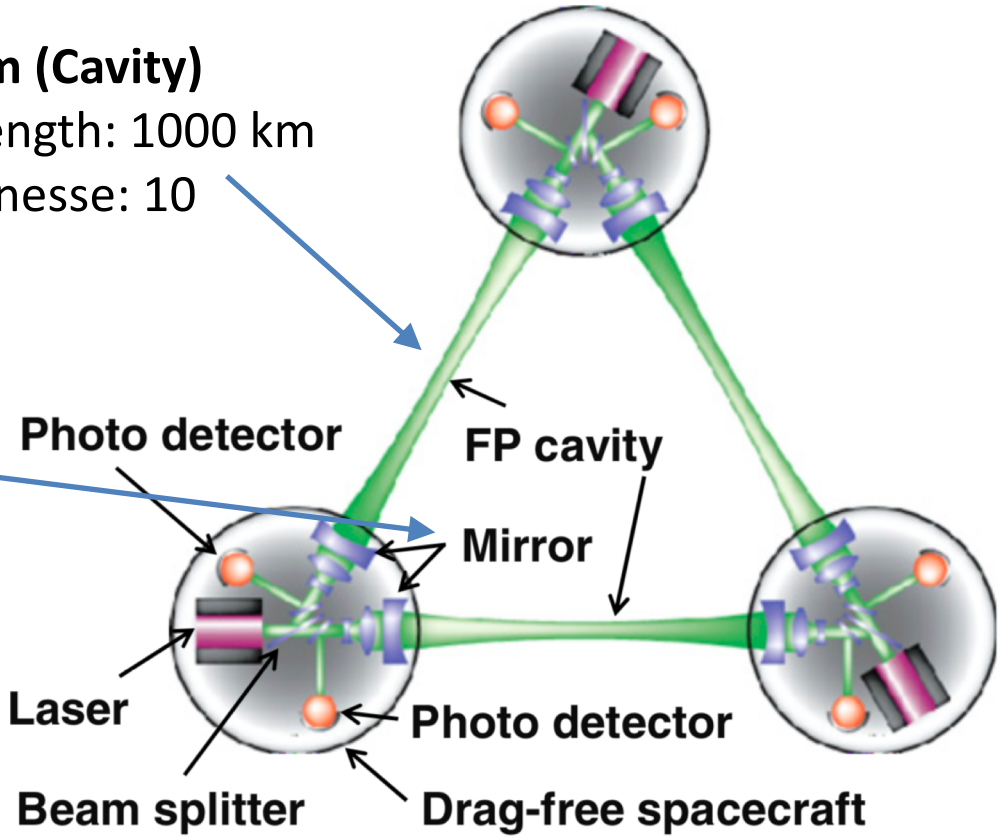
DECIGO

Decihertz interferometer
gravitational wave observatory

Arm (Cavity)
- Length: 1000 km
- Finesse: 10

Mirror
- Mass: 100 kg
- RoC: ????

Laser
- Wave length: 532 nm
- Input power: 10 W
- Freq. fluc.: <1 Hz/rtHz @1 Hz
- Power. fluc.: <1e-8 1/rtHz @1 Hz

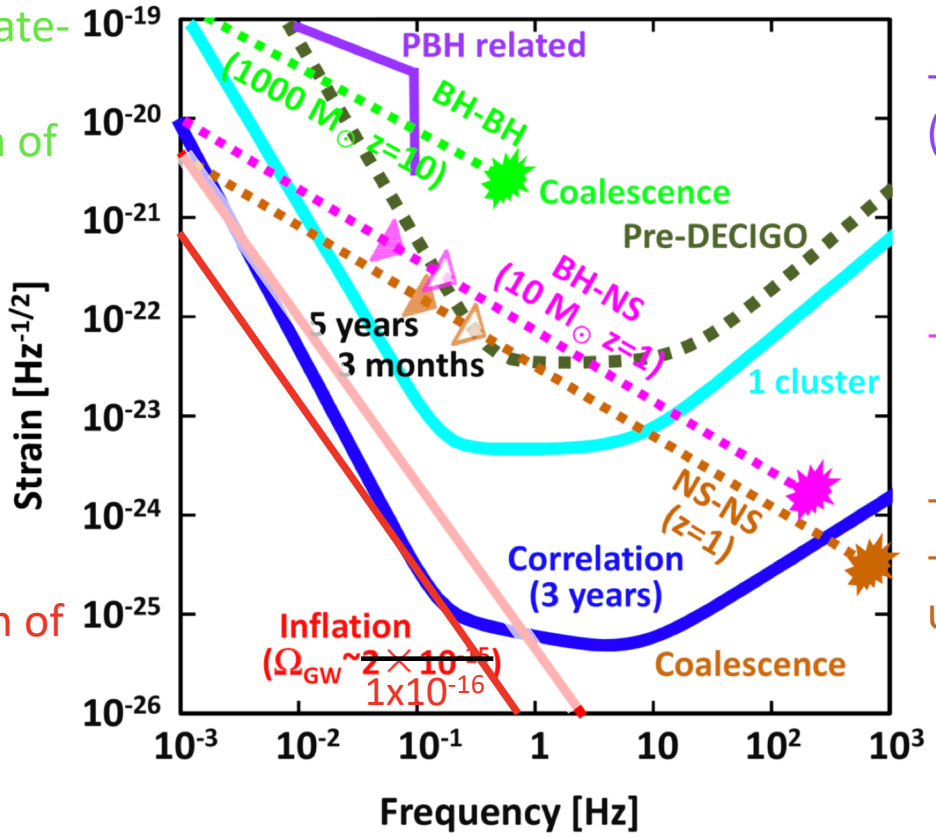


DECIGO schematics (S. Kawamura+, CQG, 2011)

DECIGO

- Observe intermediate-mass black holes
->Reveal mechanism of formulation of supermassive black holes

- Verify inflation
-> Direct observation of the beginning of the universe



DECIGO sensitivity (S. Kawamura+, CQG, 2011)

- Dark-matter (candidate) search

- Test gravity theories

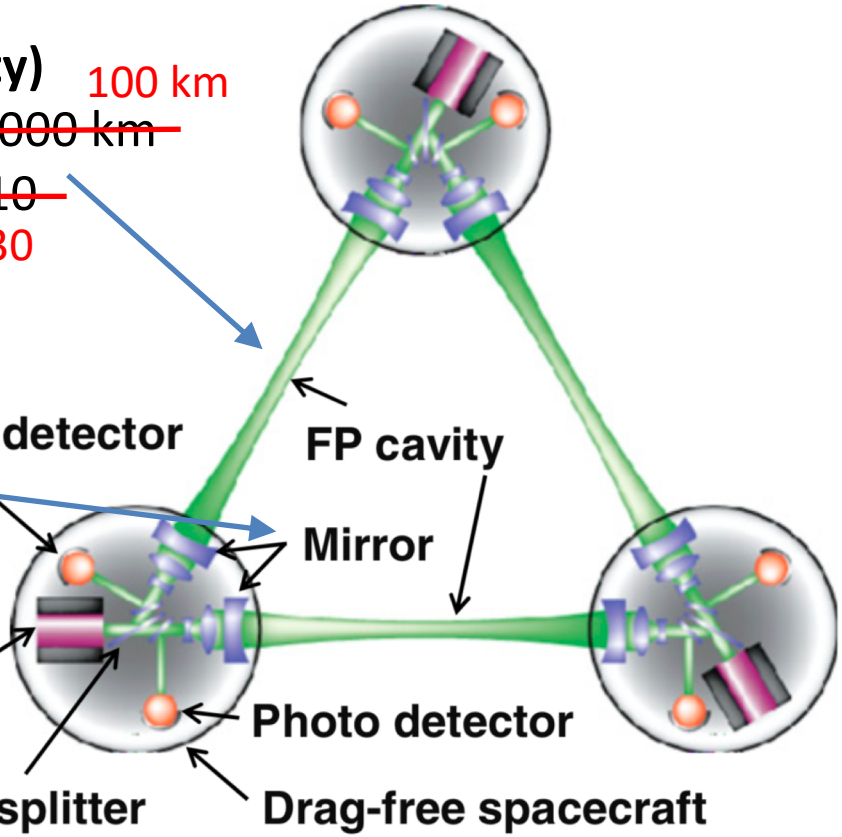
- Study neutron physics
- Measure accelerated universe directly
-> Dark-energy search

B-DECIGO

Arm (Cavity) 100 km
- Length: ~~1000 km~~
- Finesse: ~~10~~ 30

Mirror 30 kg
- Mass: ~~100 kg~~
- RoC: ????

Laser
- Wave length: 532 nm
- Input power: ~~10 W~~ 1 W
- Freq. fluc.: <1 Hz/rtHz @1 Hz
- Power. fluc.: <1e-8 1/rtHz @1 Hz



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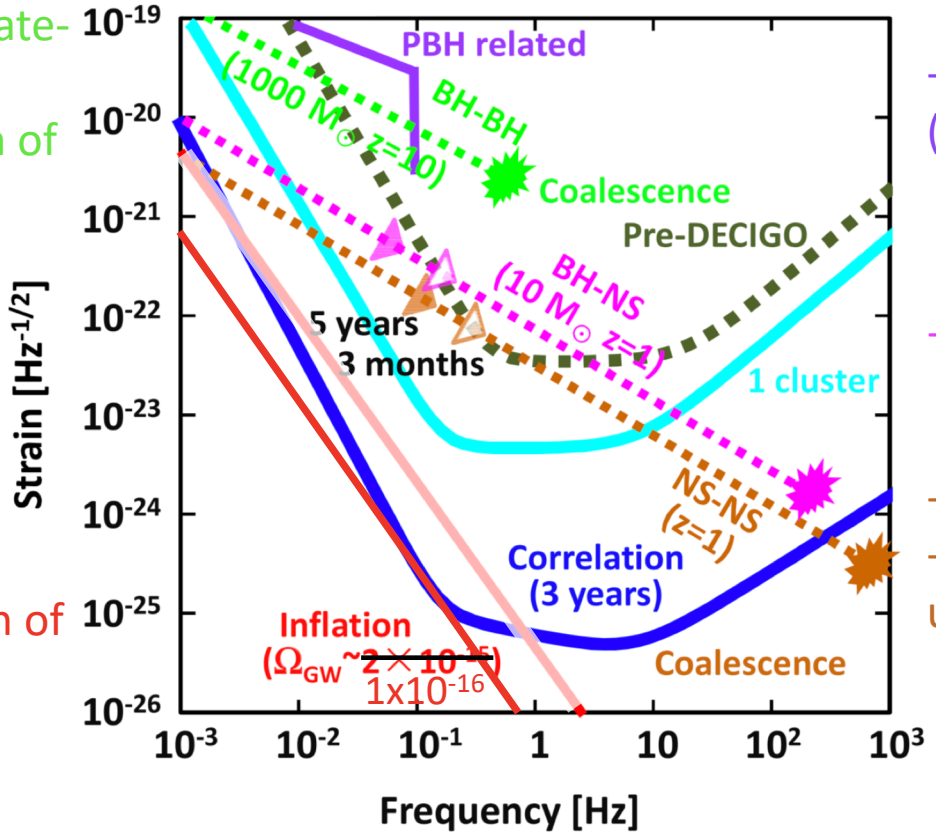

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- Dark-matter (candidate) search ○

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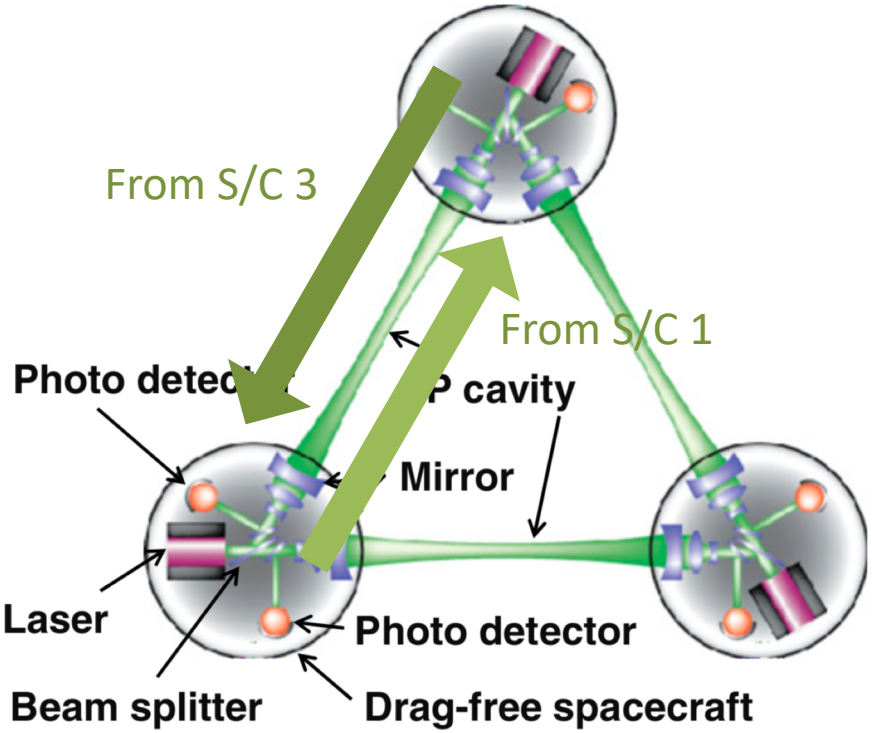
DECIGO/B-DECIGO

- Interferometer configuration
  - Dual-path Fabry-Perot cavity (not fixed)



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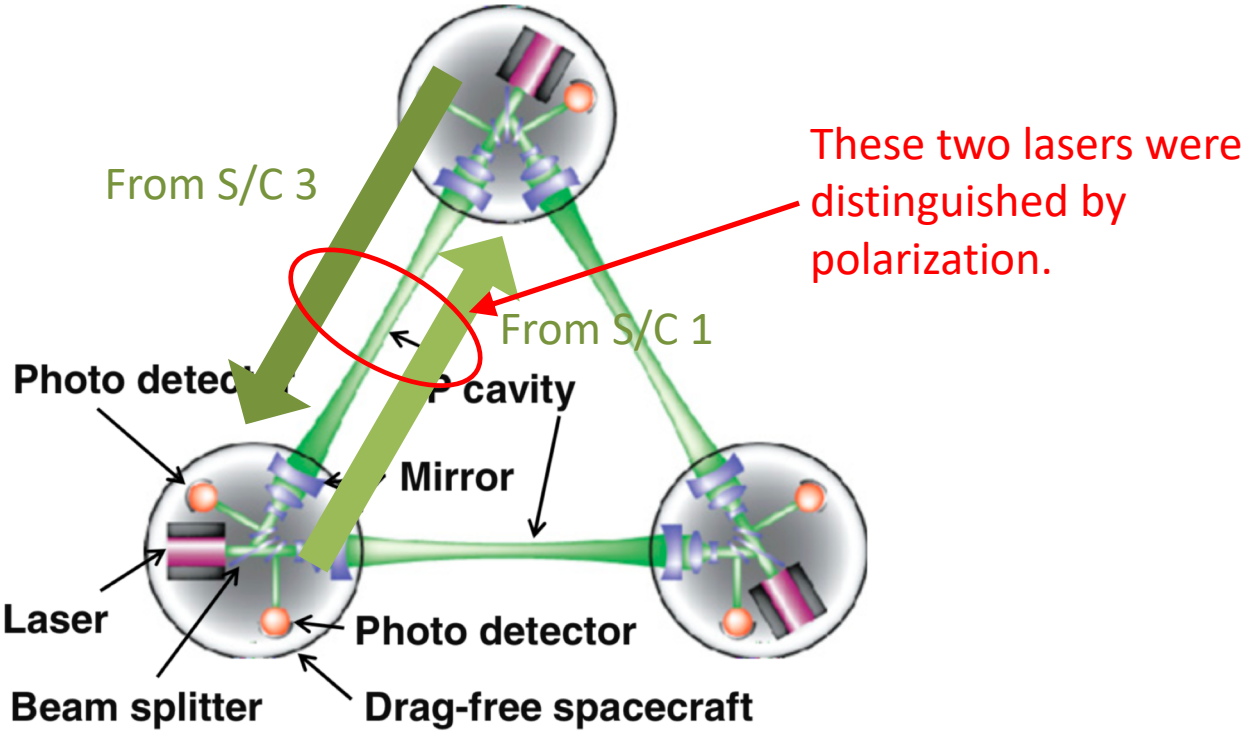


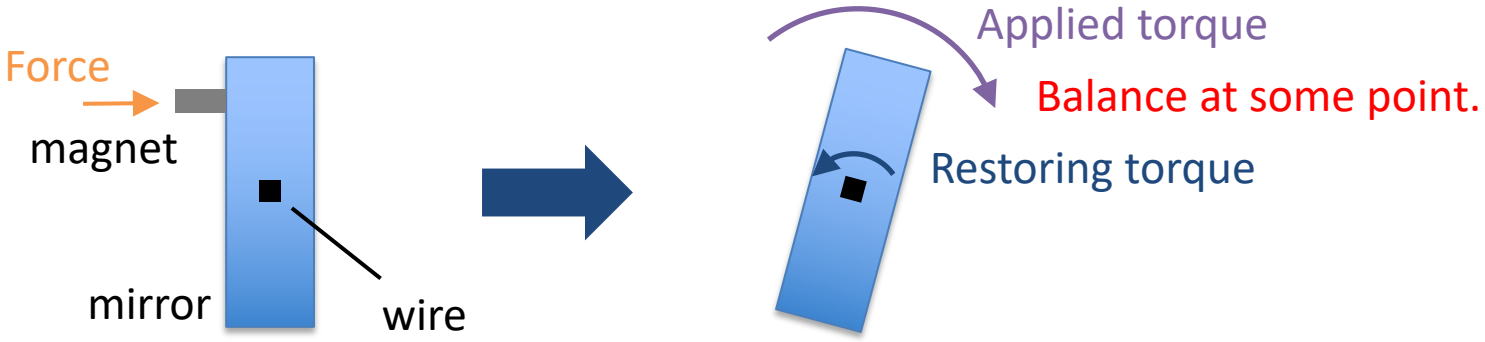
DECIGO schematics (S. Kawamura+, CQG, 2011)

Challenges for DECIGO/B-DECIGO

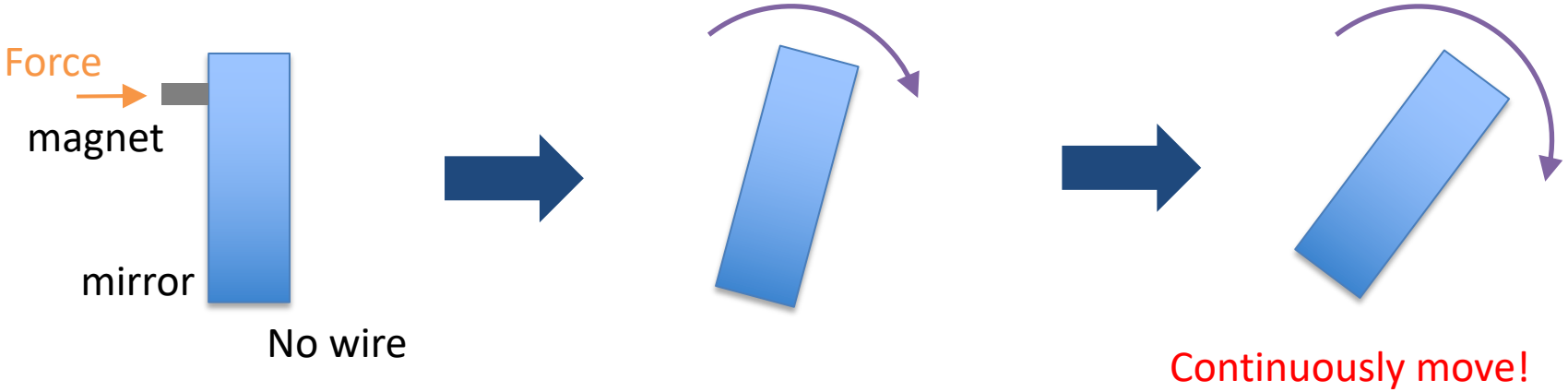
- Acceleration noise (Force noise) < 5×10^{-18} m/s^2/rtHz
  - LPF result @0.01 Hz: 2×10^{-15} m/s^2/rtHz (Armano+, PRL, 2018)
- How to do initial alignment of the cavity after S/C search.
  - Method.
  - All DoF of the mirror should be controlled.
    - However, during operation, the mirror should be be followed by S/C, i.e. control topology should be switched at some point.
  - If we align the mirrors from the Earth, signals are delayed.
    - If we choose geostationary orbit, the signal arrives at 0.1 s later.
- How to compensate radiation pressure applied to test masses.

Challenges for DECIGO/B-DECIGO

- Pendulum (which can be treated as free mass in observation frequency.)

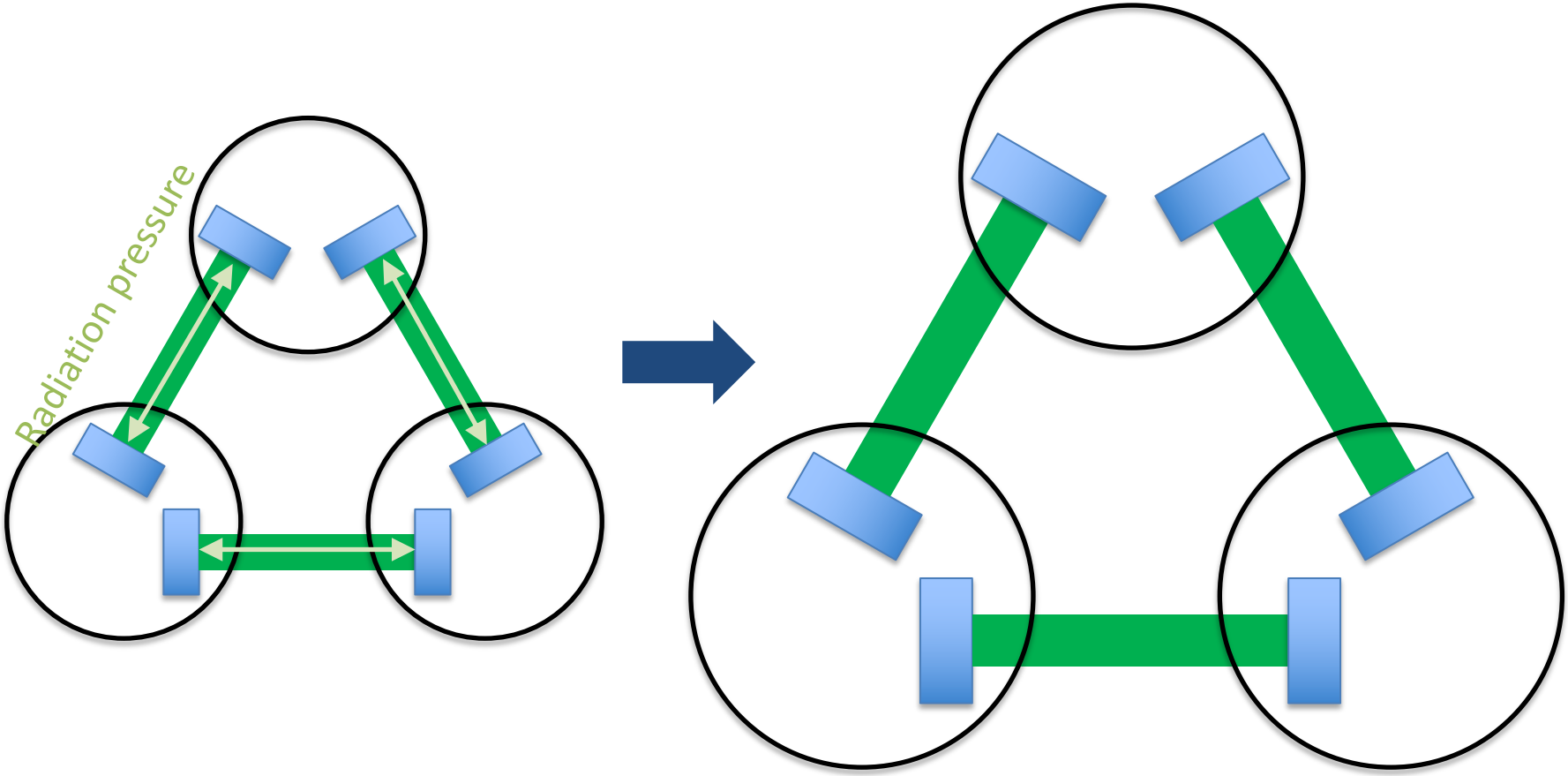


- Real free mass in space



Challenges for DECIGO/B-DECIGO

- Radiation pressure compensation

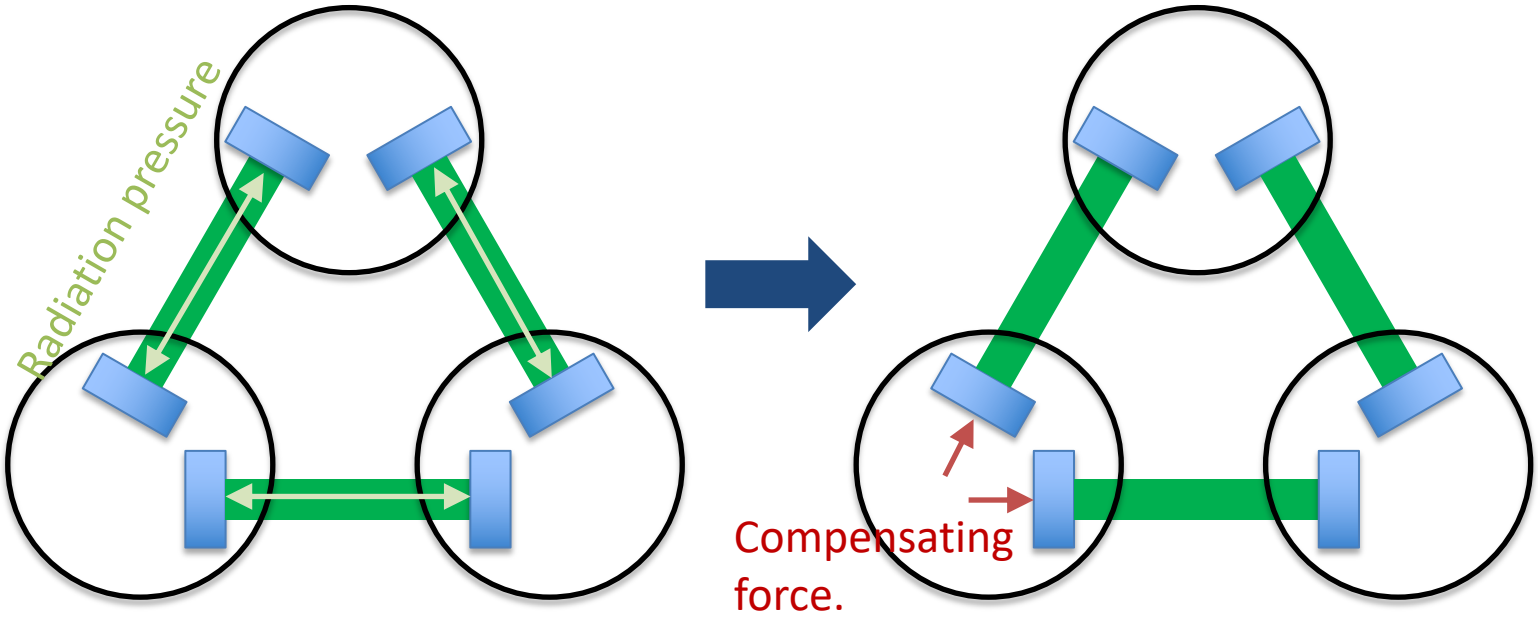


(If we use pendulums, radiation pressure and restoring force are balanced at some point.)

Challenges for DECIGO/B-DECIGO

- Radiation pressure compensation

(All forced applied to free mass should be compensated.)



Challenges
- Mirrors should be free,
- How to sense the force.

What will I do?

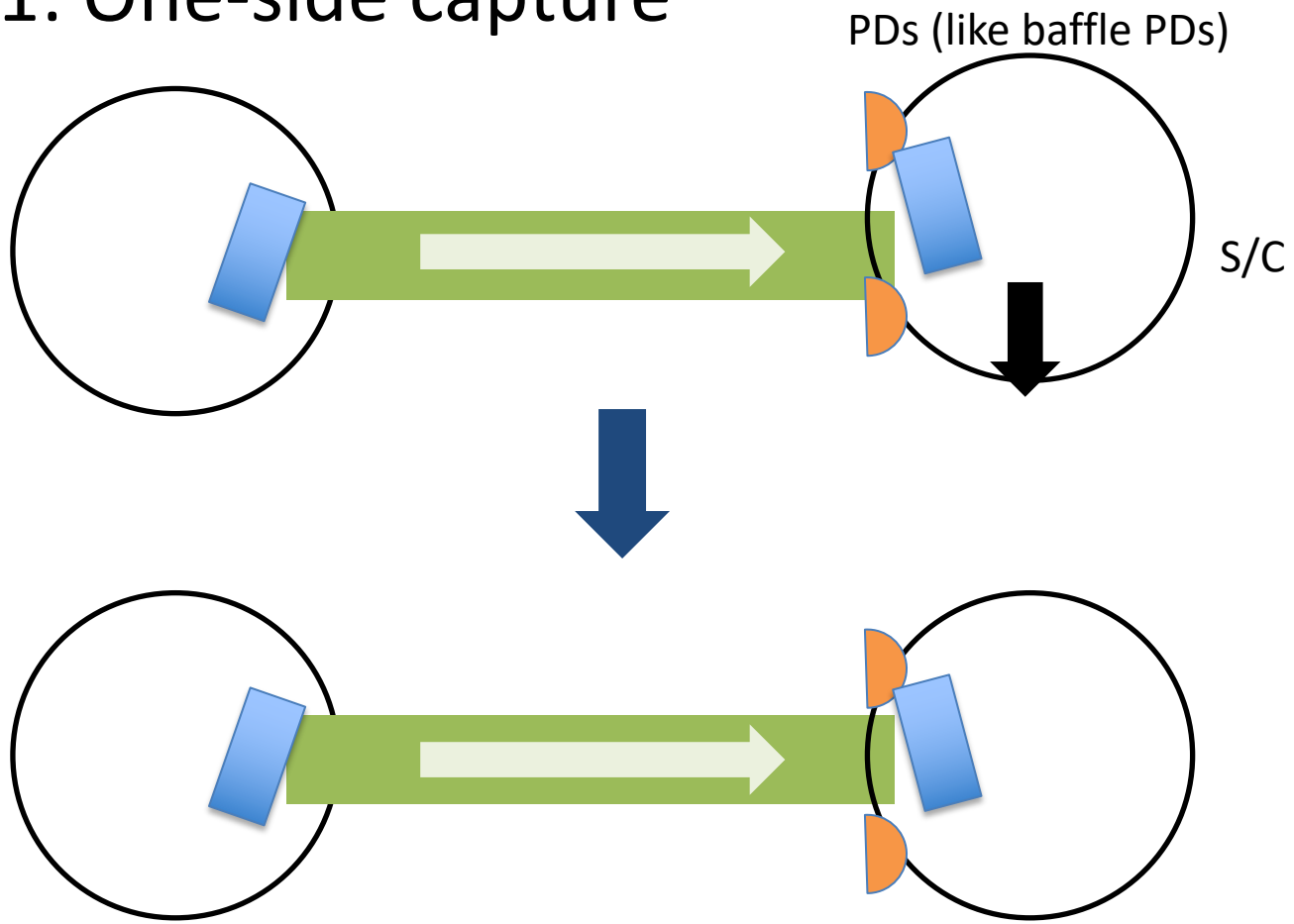
- Demonstration in lab of DECIGO/B-DECIGO observation operation after initial S/C searching.
  - I personally call this work “Mini-DECIGO.”
- Including,
  - Initial alignment of cavities in space,
  - Demonstration of dual-path FP cavity,
  - Demonstration of cavity operation with real free test mass (with pendulum)

Initial alignment

- Assumed initial status
  - All S/Cs founded each other roughly,
  - Distances between S/C were not locked.
  - All test masses were controlled to S/Cs.
- Requirement
  - Align all cavities (angle and distance)
  - (If possible) no communication between S/Cs.

Idea for initial alignment

STEP1: One-side capture



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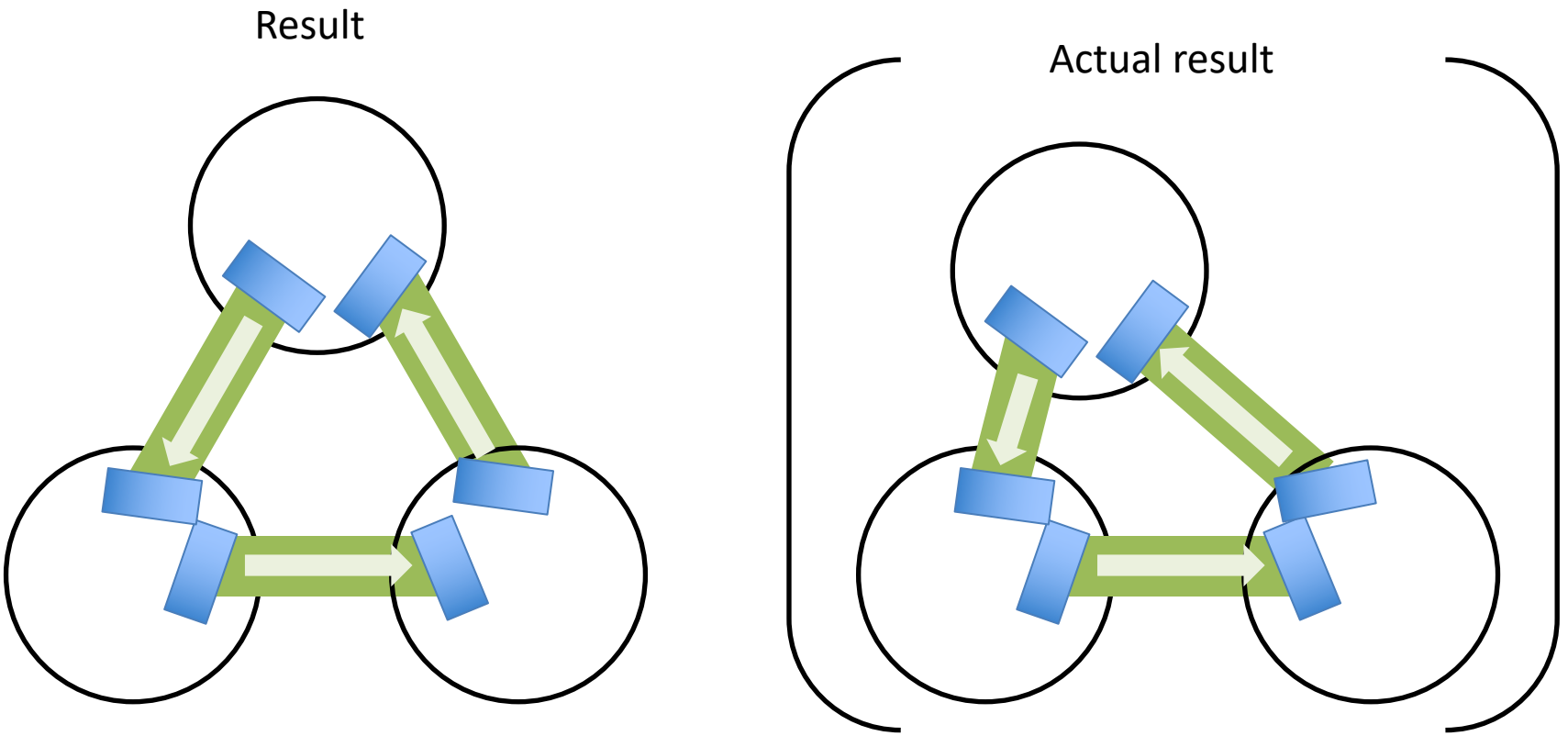
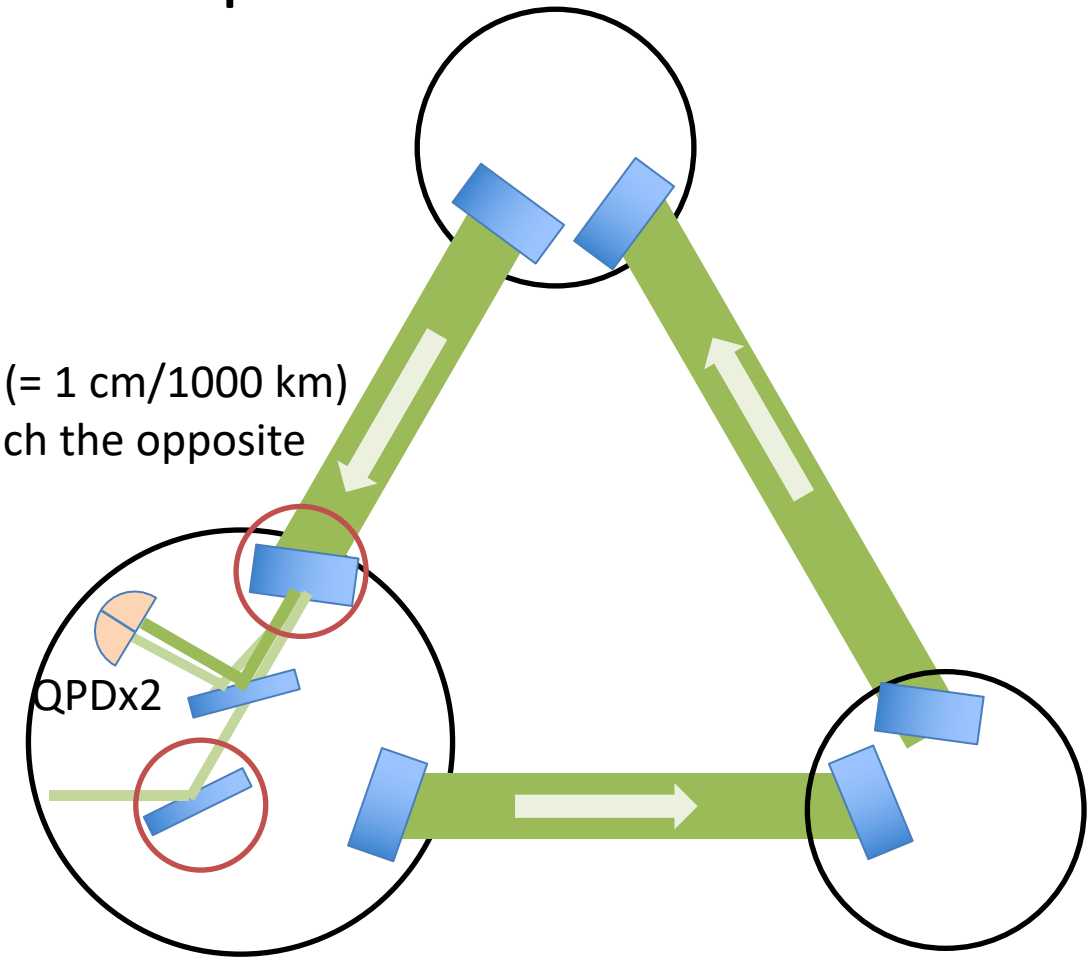


Idea for initial alignment

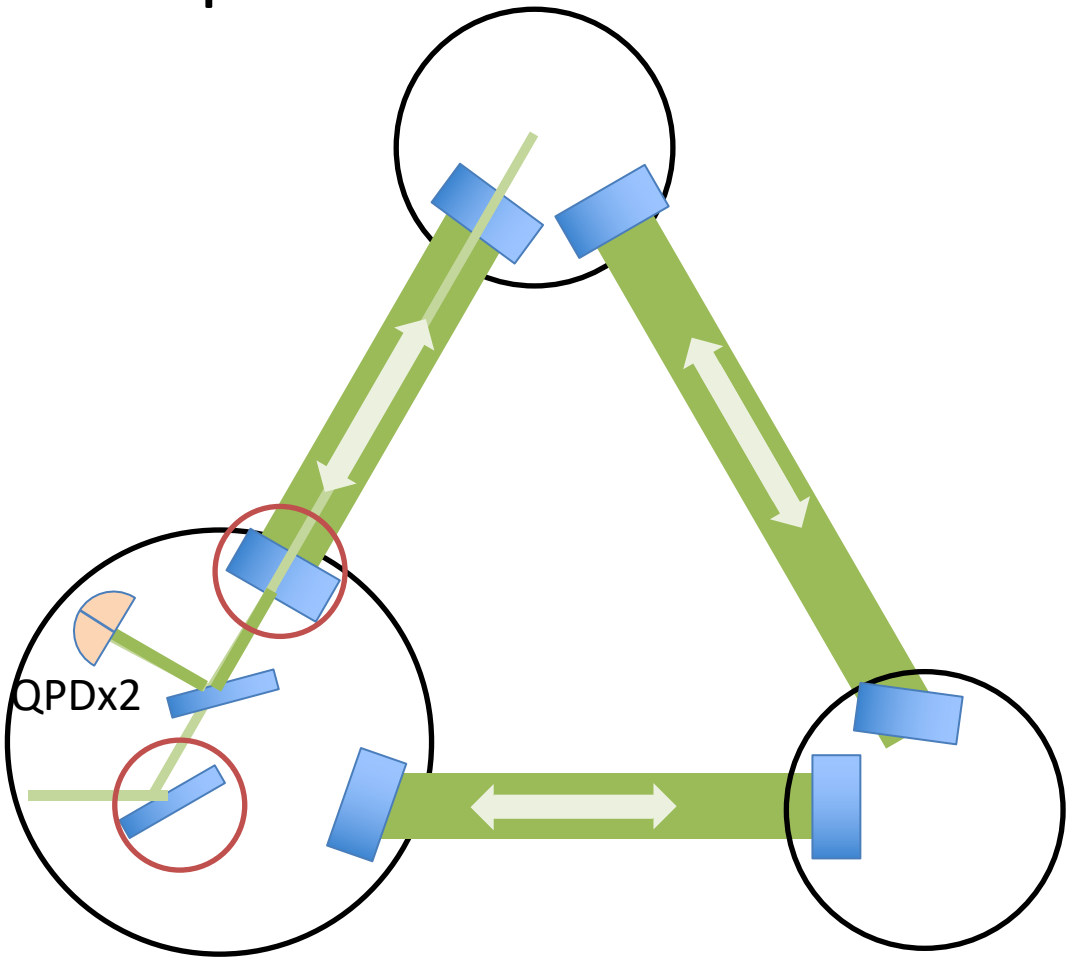
STEP2: Dual capture

Accuracy: 10^{-8} rad (= 1 cm/1000 km)
(Beam roughly reach the opposite S/C (~cm))



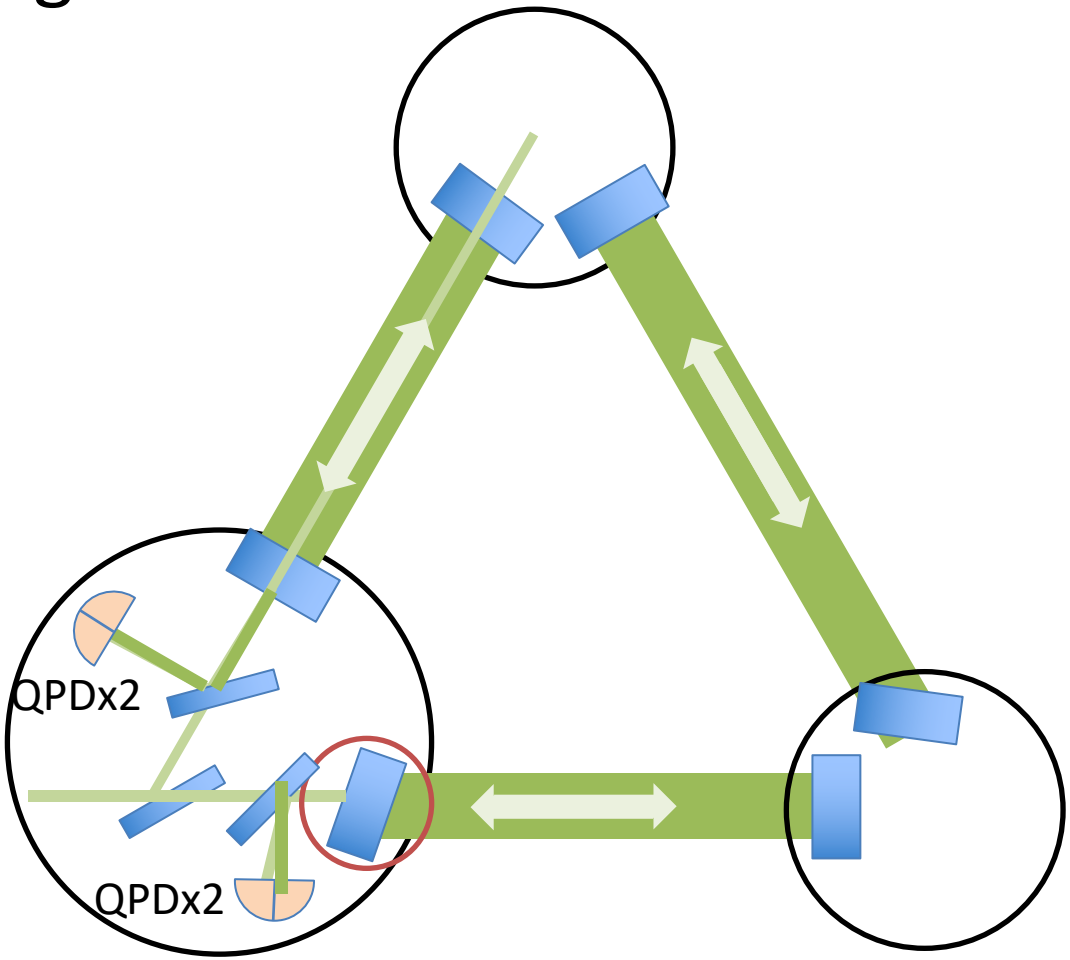
Idea for initial alignment

STEP2: Dual capture



Idea for initial alignment

STEP3: Align another mirror



Idea for initial alignment

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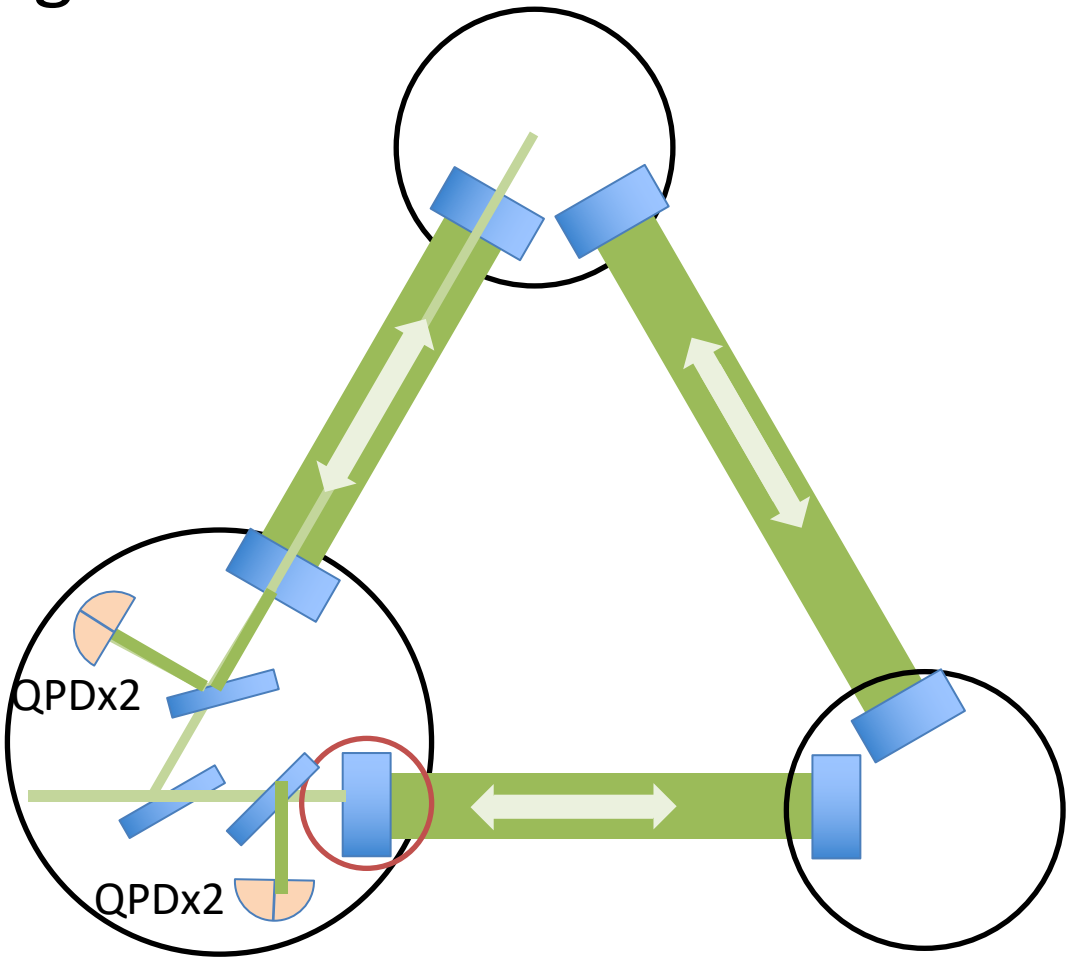
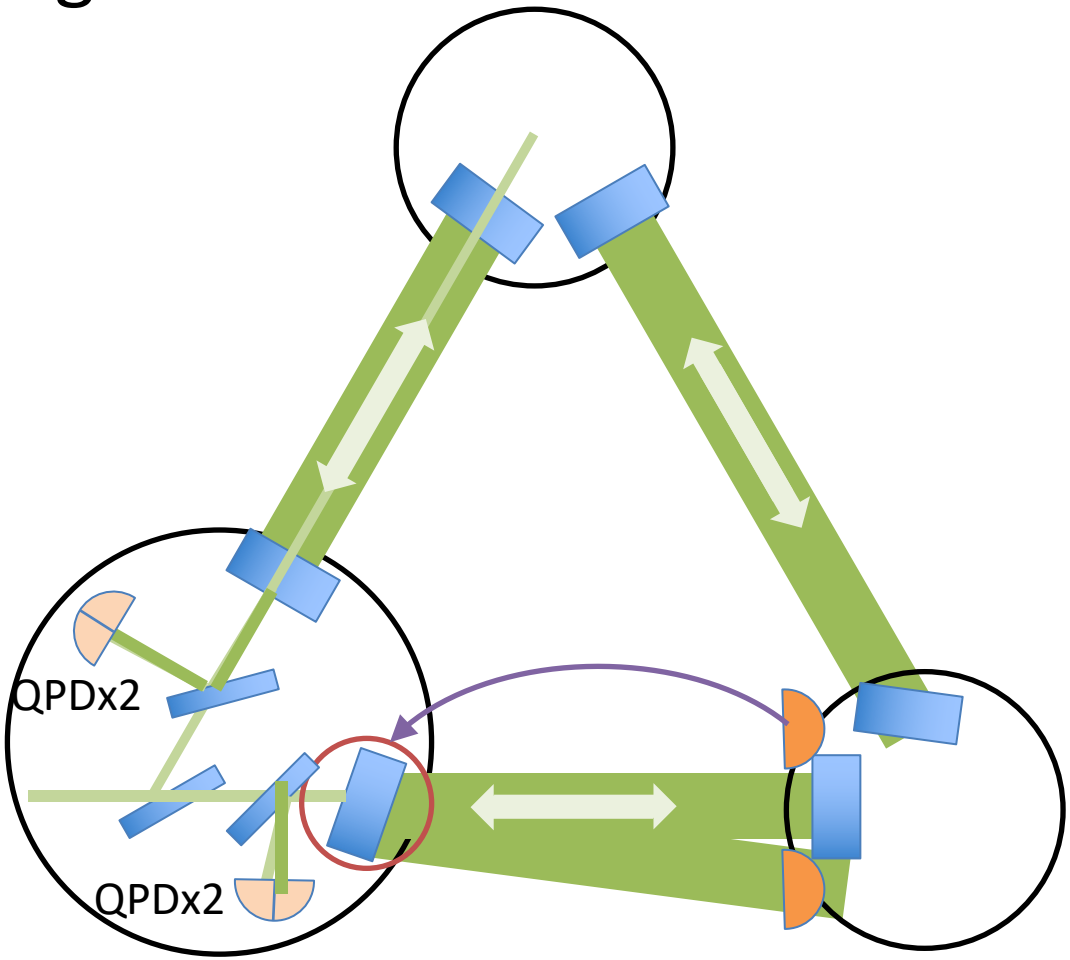


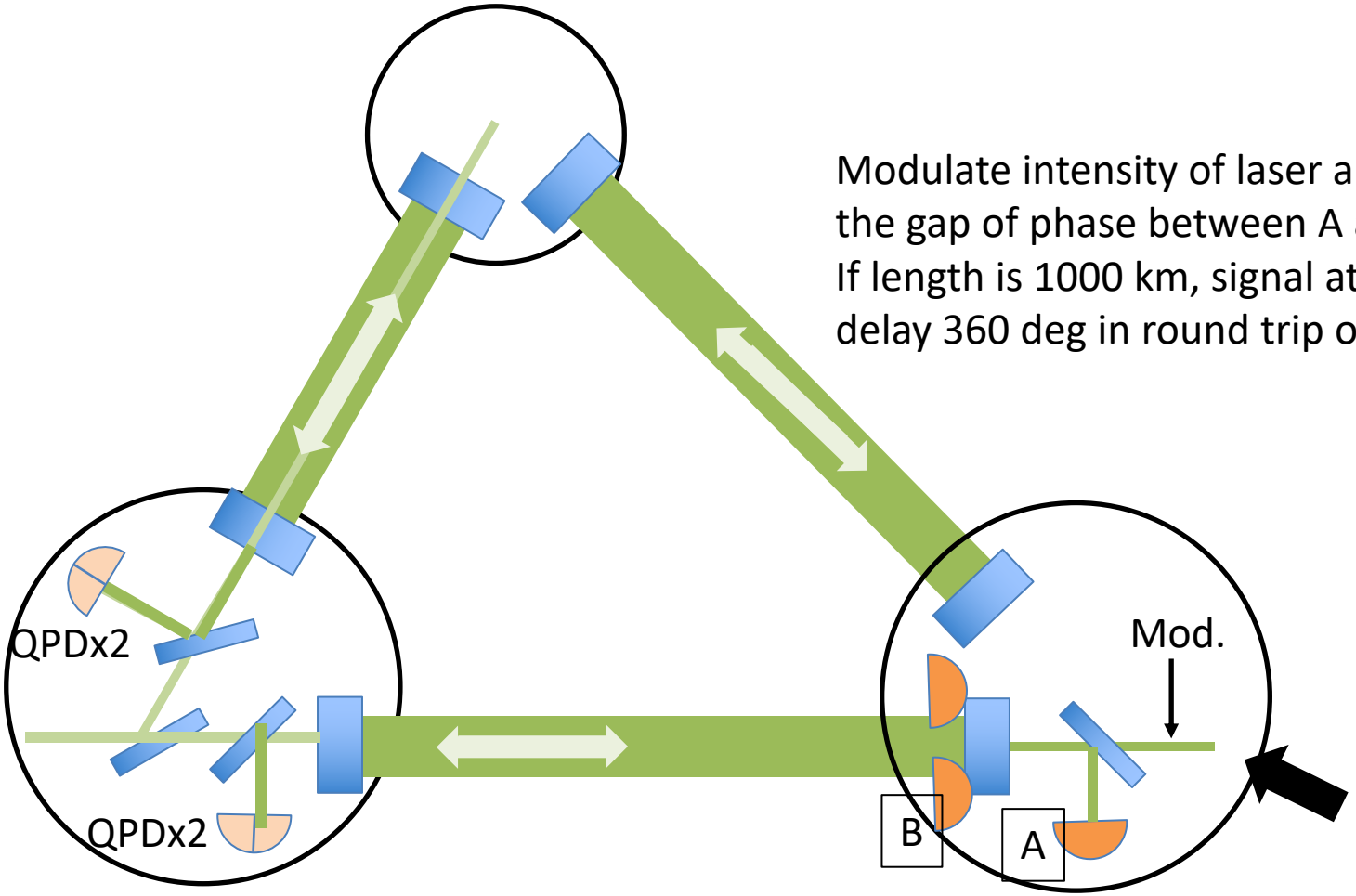
Idea for initial alignment

STEP3’: Align another mirror



Idea for initial alignment

STEP4: Adjust length

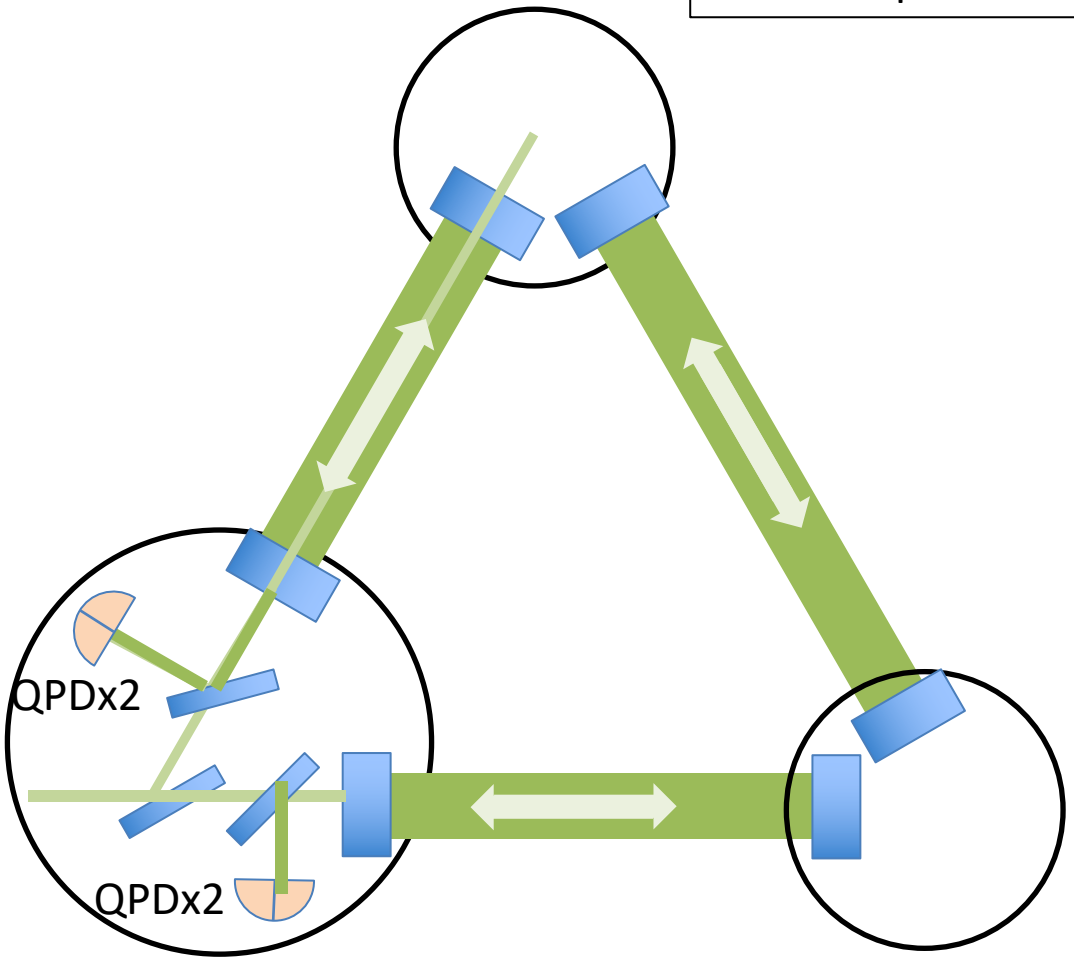


Modulate intensity of laser and measure the gap of phase between A and B.
If length is 1000 km, signal at 23.9 Hz will delay 360 deg in round trip of arm.

Idea for initial alignment

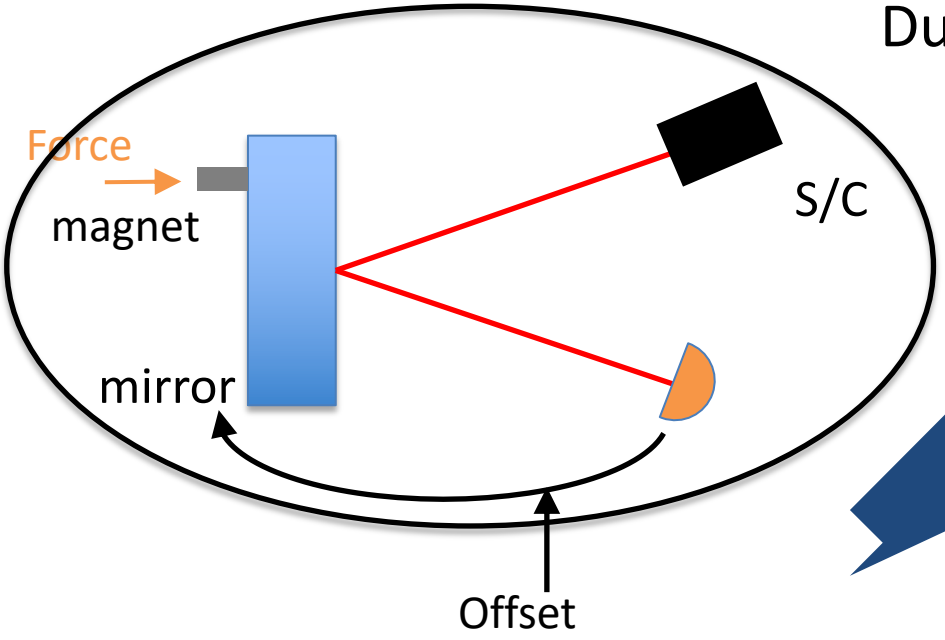
Result

I'd like to perform this automatically.

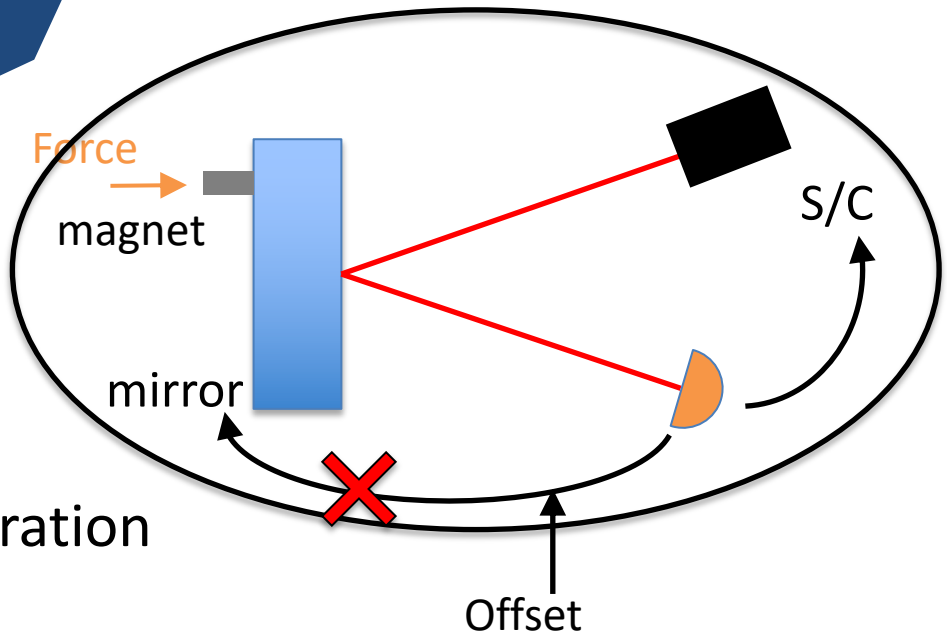


How to move free mirrors

During alignment



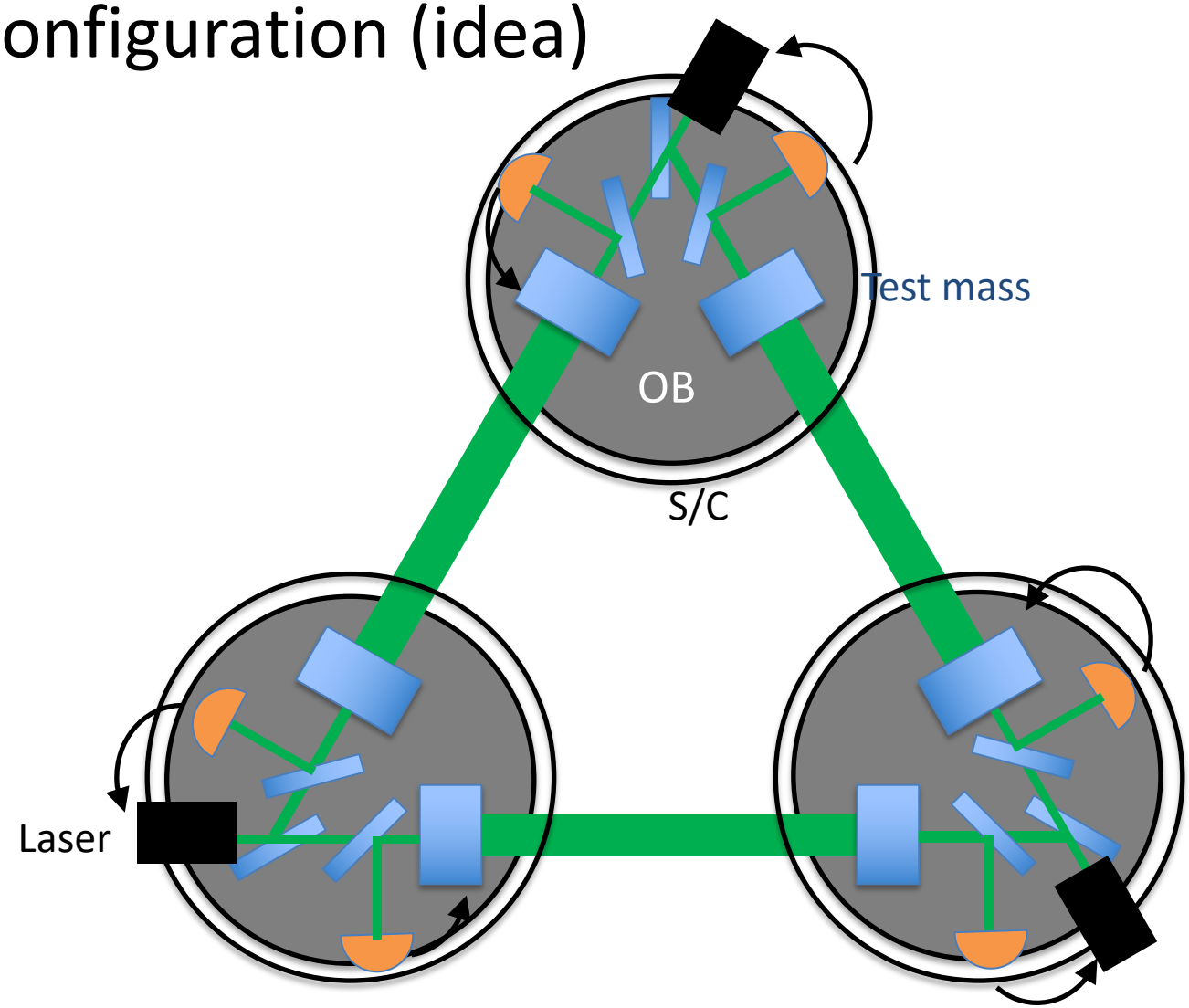
Control topology should
be changed at some point.



During operation

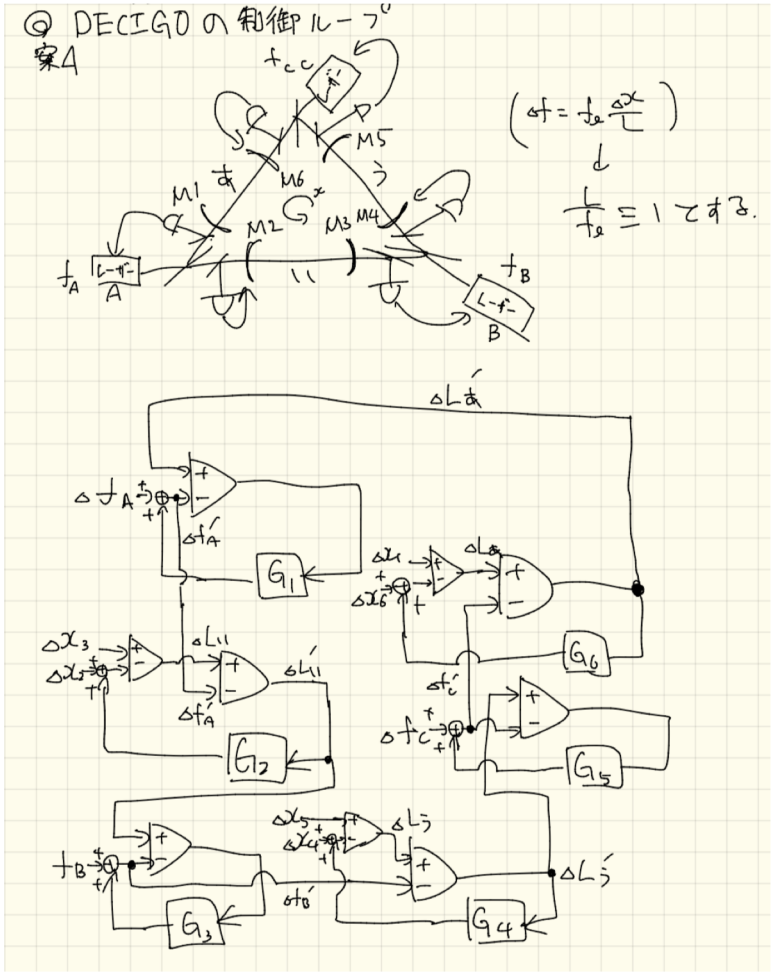
Operation of dual-path FP cavity

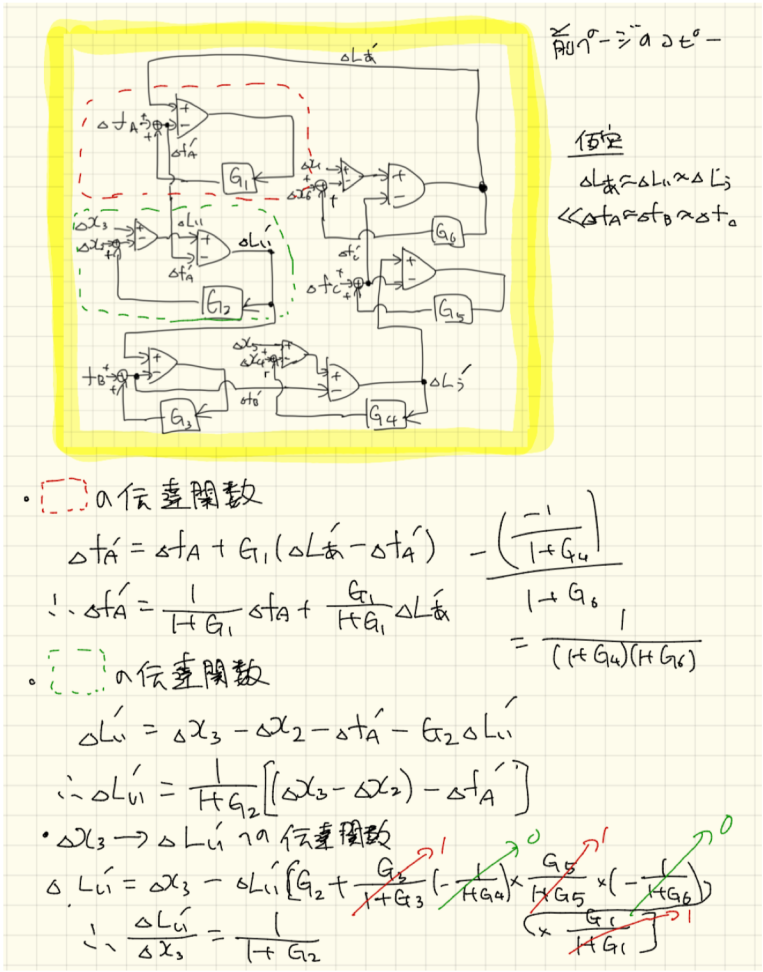
- Configuration (idea)



Operation of dual-path FP cavity

- Block diagram



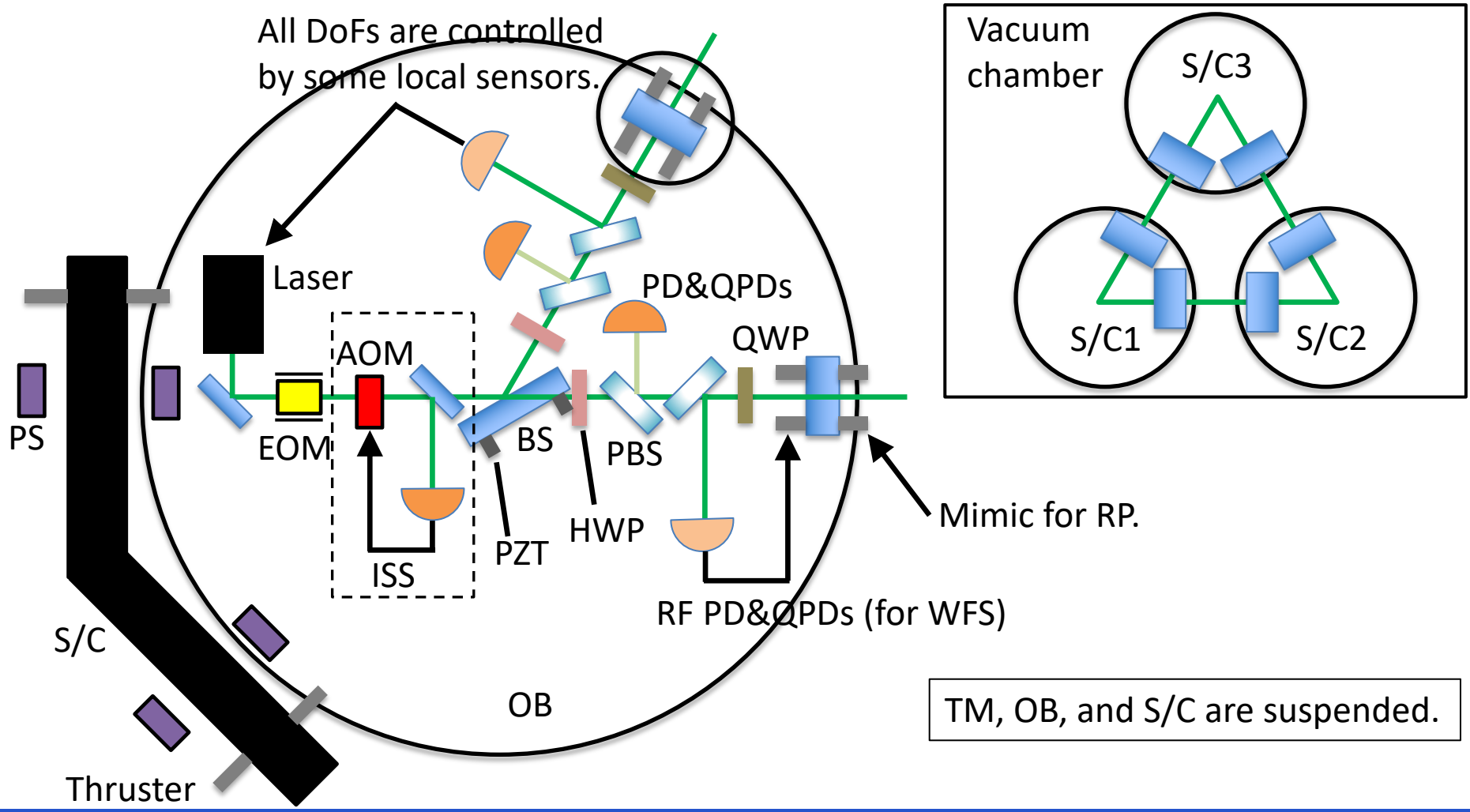


How to compensate RP

- There are several ideas
  - Monitor the laser power and apply force corresponding to it.
  - In DC, laser control path signal is fed back to the mirror.
  - Measure the distance between S/Cs and control it.
  - Change control topology to feed all signal back to mirrors.
  - Use additional free mass for reference of DC position.

Experimental plan

- My goal is operation of mini-DECIGO in lab.



TM, OB, and S/C are suspended.

Road to goal

- Phase 0.5 (half a year)
  - 1 OB, 1 cavity, 1 laser, in air (2 susps.)
  - Aim: Test switchable control method (and auto alignment).
- Phase 1 (in this fiscal year)
  - 1(->2) OBs, 2 cavities, 2 lasers, in vac (4->6 susps.)
  - Aim: Test alignment method and dual-path FP cavity.
- Phase 2 (a few months)
  - 3 OBs, 3 cavities, 3 lasers, in vac (12 susps.)
  - Aim: Demonstrate full operation.
    - Full alignment, RP compensation.
- Phase 3
  - Extra stage

Extra success

- Integrate other components
  - AOD alignment method (Musha-lab)
  - Freq. stabilization (Musha-lab)
  - Thruster (Sato-lab)
- Quantum things
  - Optical spring to reduce actuator noise.
- Obtain common mode signal.
- Data analysis
  - Making data analysis method.

Remaining problems

- How to make this work be worth as Ph.D. thesis.
  - Although DECIGO is space detector, Mini-DECIGO is in lab.
  - Although DECIGO is large (1000 km), Mini-DECIGO is short (~10 cm).
  - Although DECIGO's one of the main problems is acceleration noise, Mini-DECIGO does not provide any information about it.
  - How to defend from the statement like "This is classical dynamics and must be able."
- Join DECIGO WG.

Alternative ideas

- Contribute the other project for DECIGO.
  - Free flyer
  - …

Summary

- I made a brief introduction of DECIGO.
- Some challenges which I conceived were listed.
- I showed my plan about Mini-DECIGO
- However, there are many things to be considered/done.
- Anyway, I should decide and go.

Mini-DECIGO sensitivity