Measuring the birefringence of the sapphire mirrors installed in the KAGRA detector

Research Results Presentation Meeting
of the Inter-University Research Program
for Fiscal Year 2022

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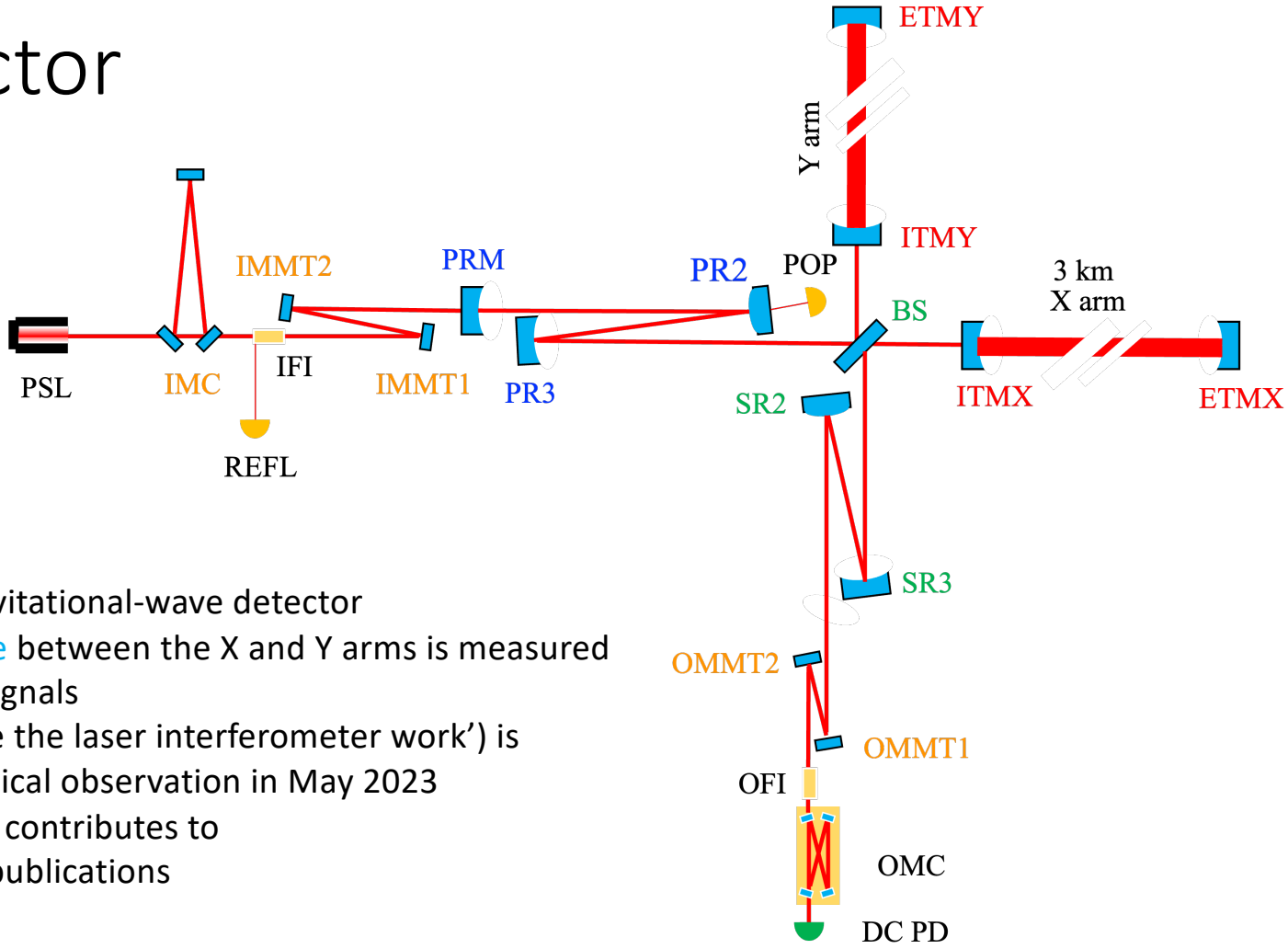
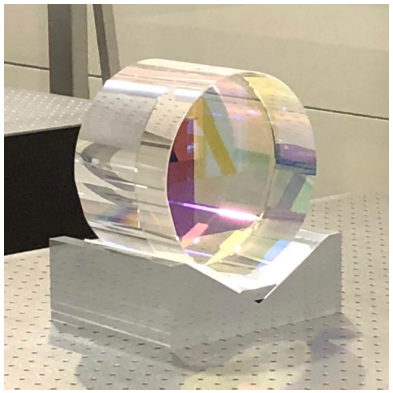
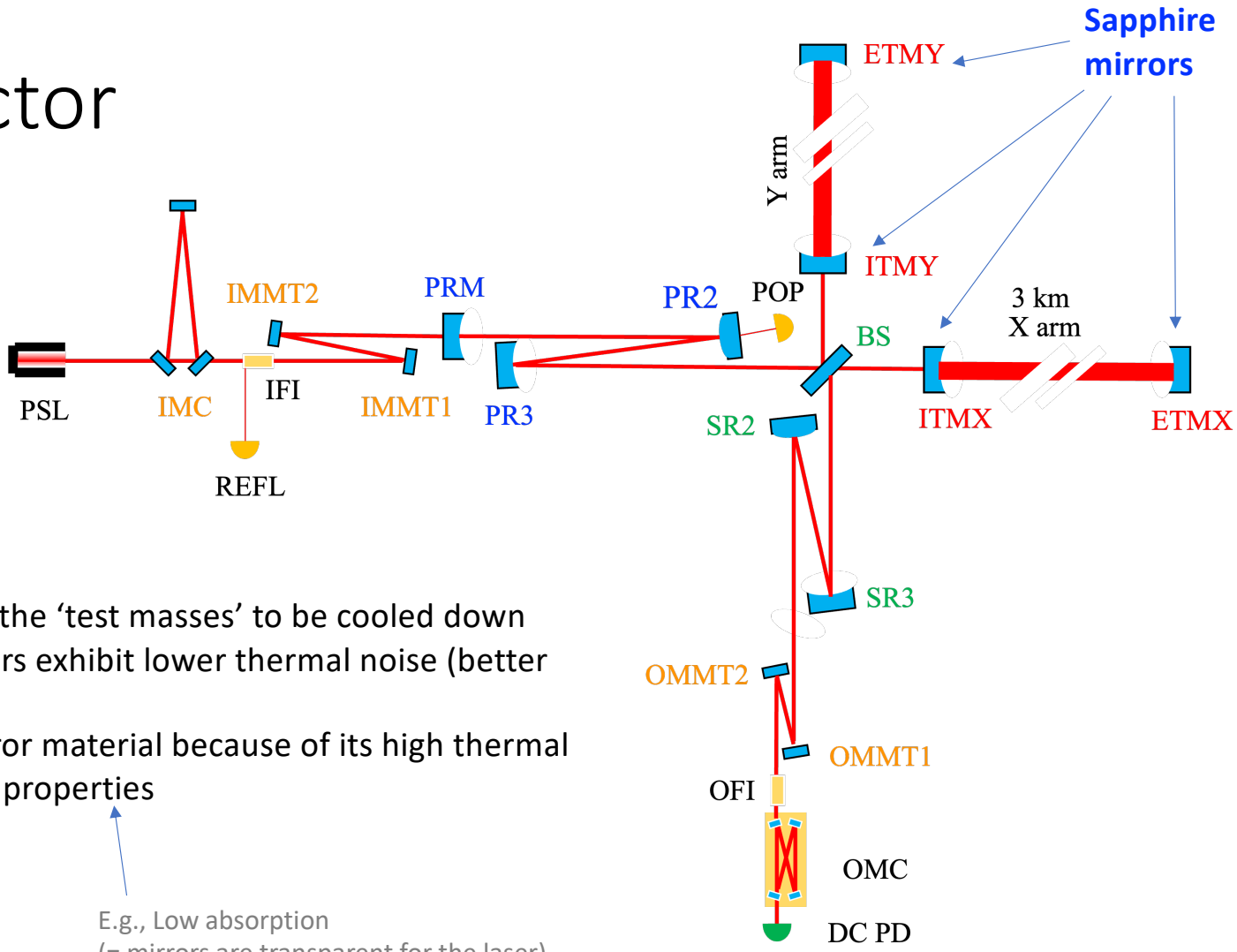
KAGRA Detector



- Large-scale and cryogenic gravitational-wave detector
- Differential arm length change between the X and Y arms is measured to detect gravitational wave signals
- Intense commissioning (‘make the laser interferometer work’) is ongoing to start the astronomical observation in May 2023
- Cardiff University significantly contributes to detector commissioning and publications

KAGRA Detector



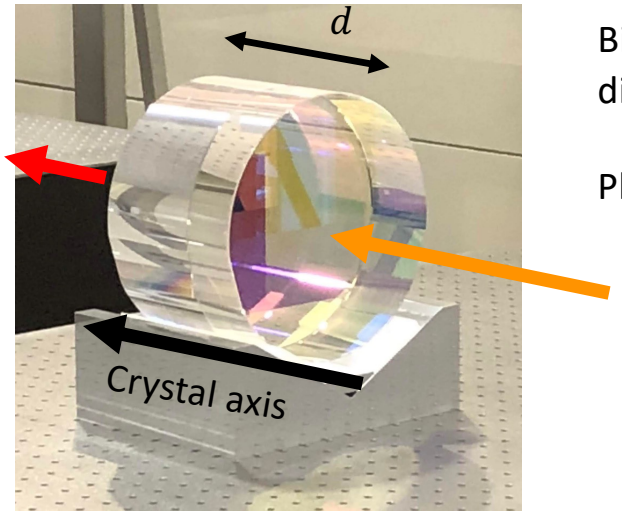


- Sapphire mirrors are used for the 'test masses' to be cooled down
- Lower the temperature, mirrors exhibit lower thermal noise (better sensitivity)
- Sapphire is chosen as the mirror material because of its high thermal conductivity and good optical properties

Heat induced by laser must be removed

E.g., Low absorption
(= mirrors are transparent for the laser)

Sapphire and Birefringence

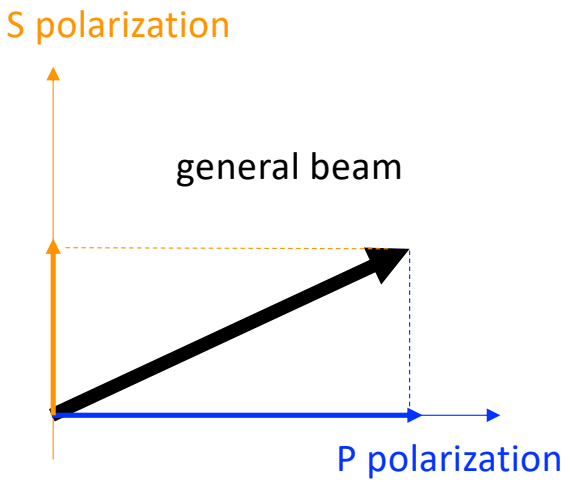


Birefringence materials have different refractive indexes for different light polarization.

Phase difference R between the blue- and orange-polarized beams:

$$R = \frac{2\pi d(n_o - n'_e)}{\lambda}$$

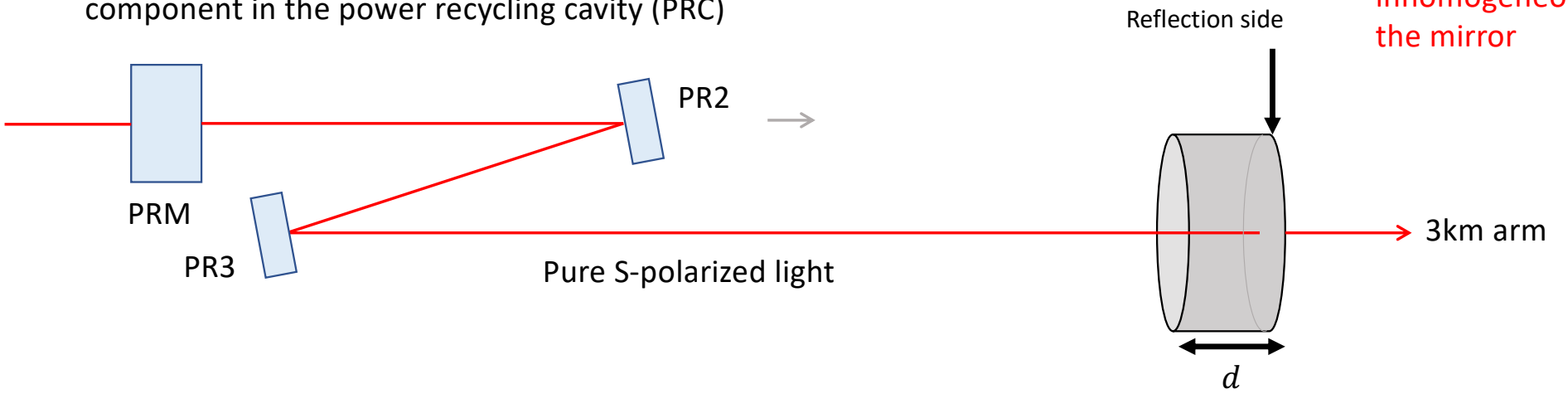
Because any general linear polarized beam is a combination of the orthogonal blue- and orange-polarized beam, the transmitting beam's polarization state is changed if the crystal z-axis and the beam propagation axis don't match, or the crystal axis is inhomogeneous over the crystal



Birefringence Problems in KAGRA

Birefringent input test masses (ITMs) generate unwanted polarization component in the power recycling cavity (PRC)

The crystal axis was found to be inhomogeneous over the mirror



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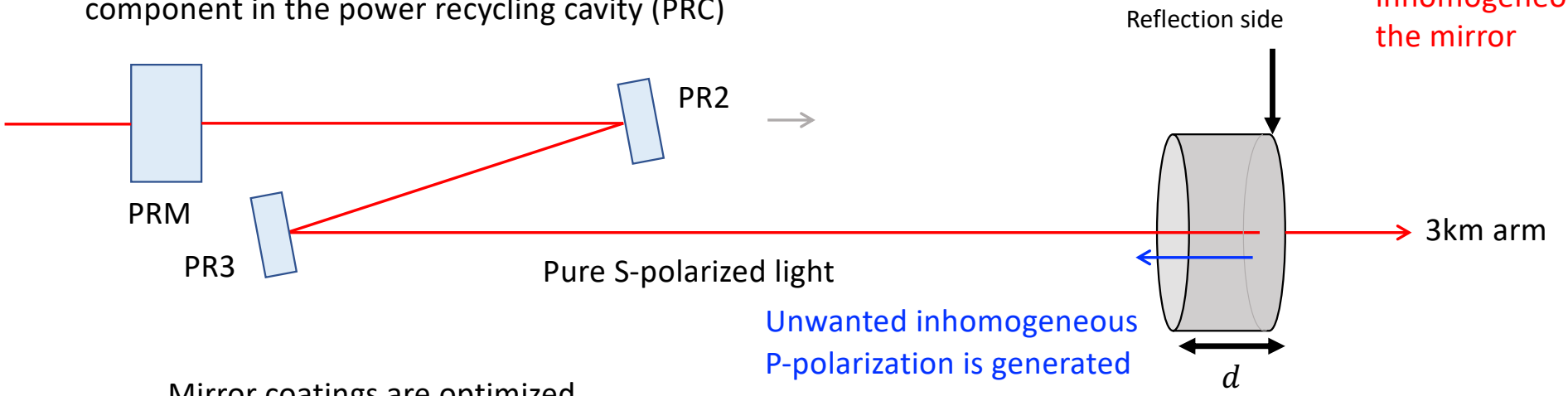

Mirror coatings are optimized only for S-polarization

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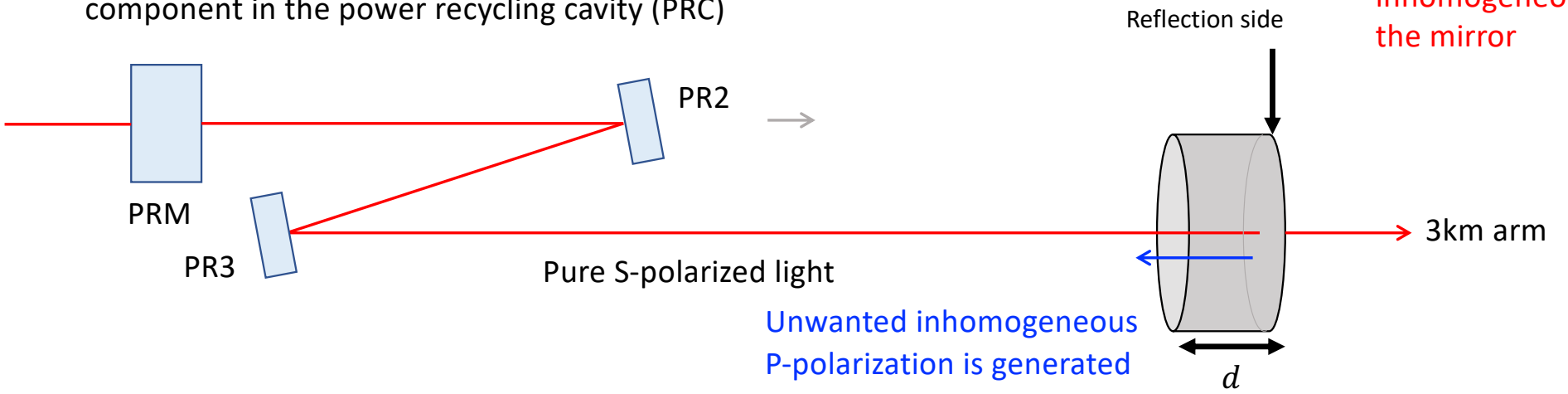
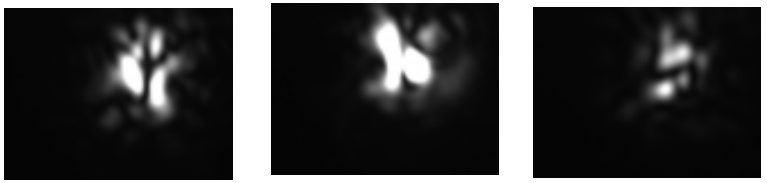


Resulted in

- Laser power loss
- Unstable error signals for the cavity length and angular controls

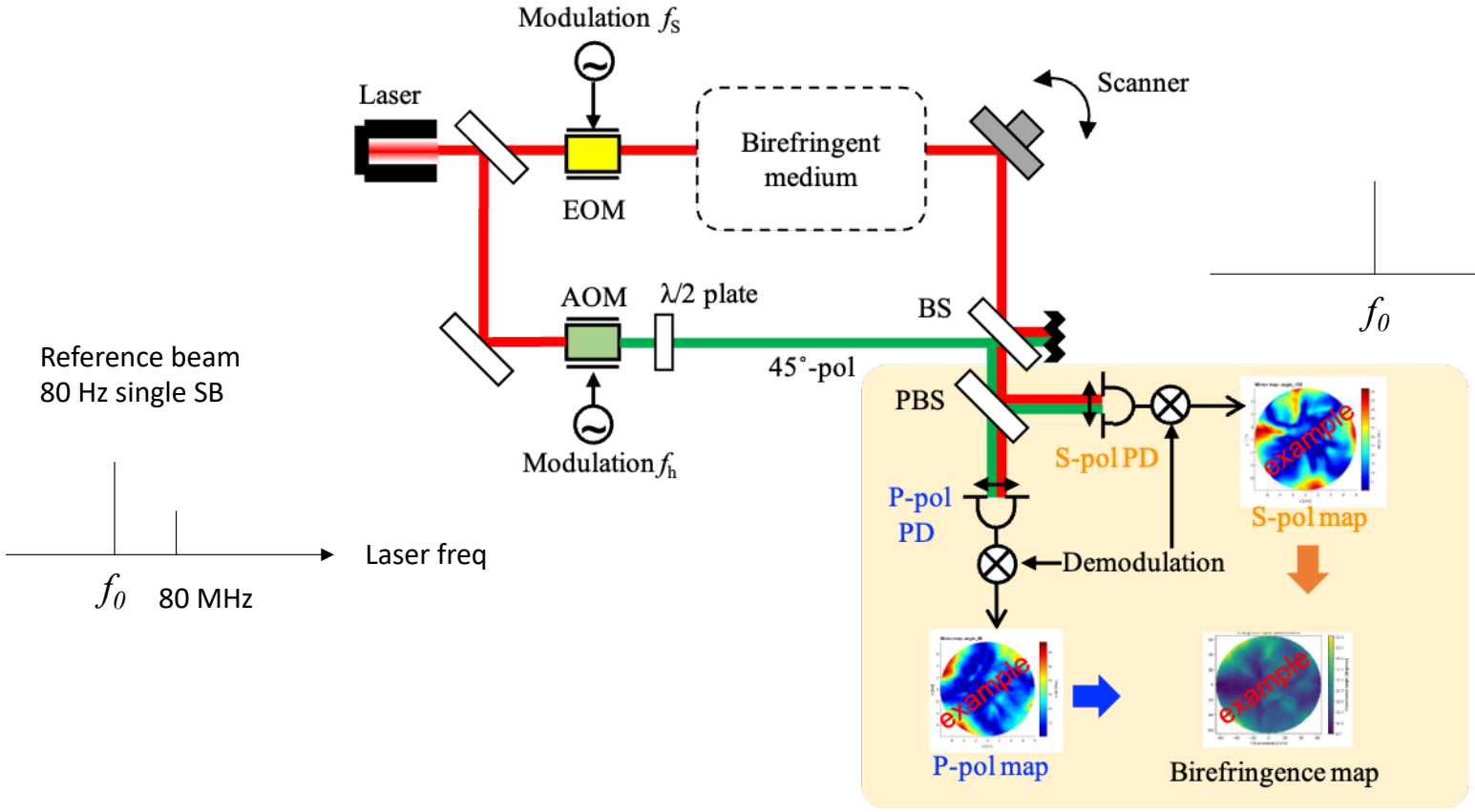
  → Lower duty factor of the observation

https://klog.icrr.u-tokyo.ac.jp/osl/?print&r=9495



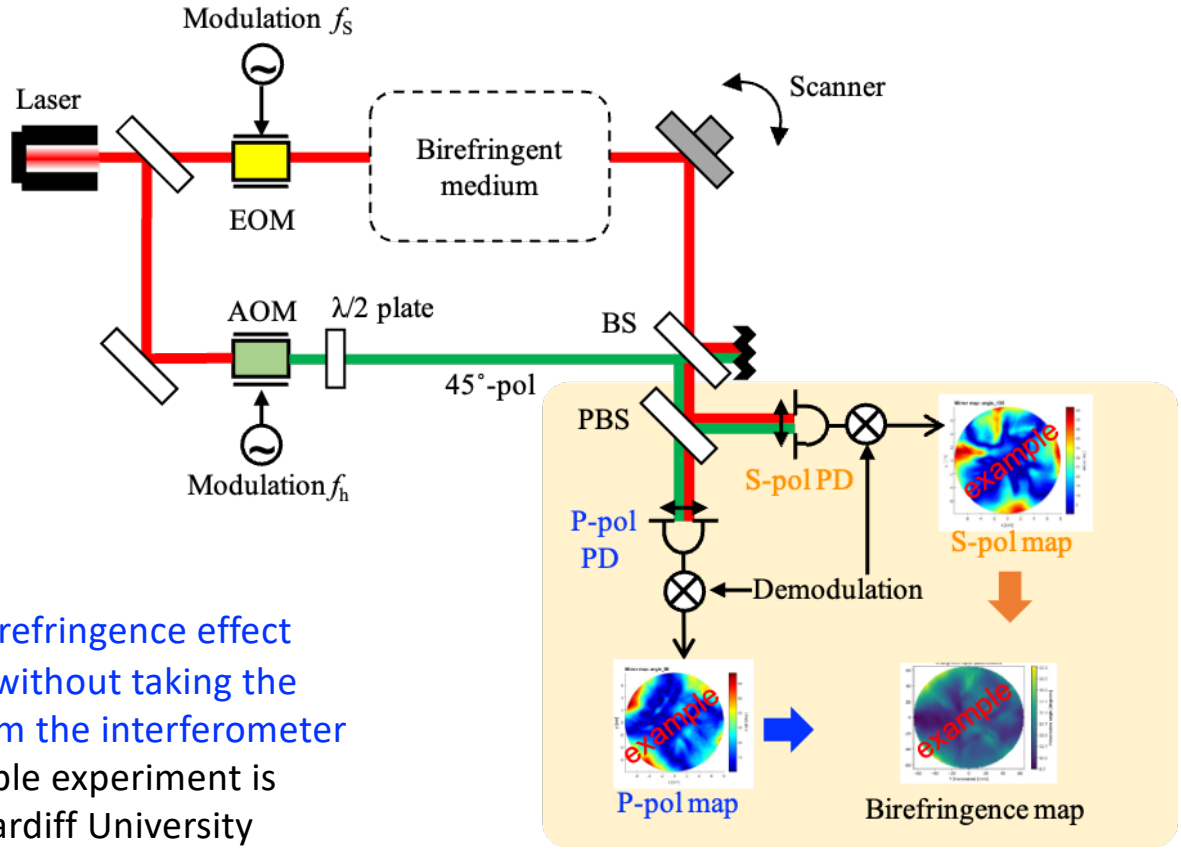
→ Transmitted beam of PR2 in the unwanted polarization

Principle of the polarized phase camera



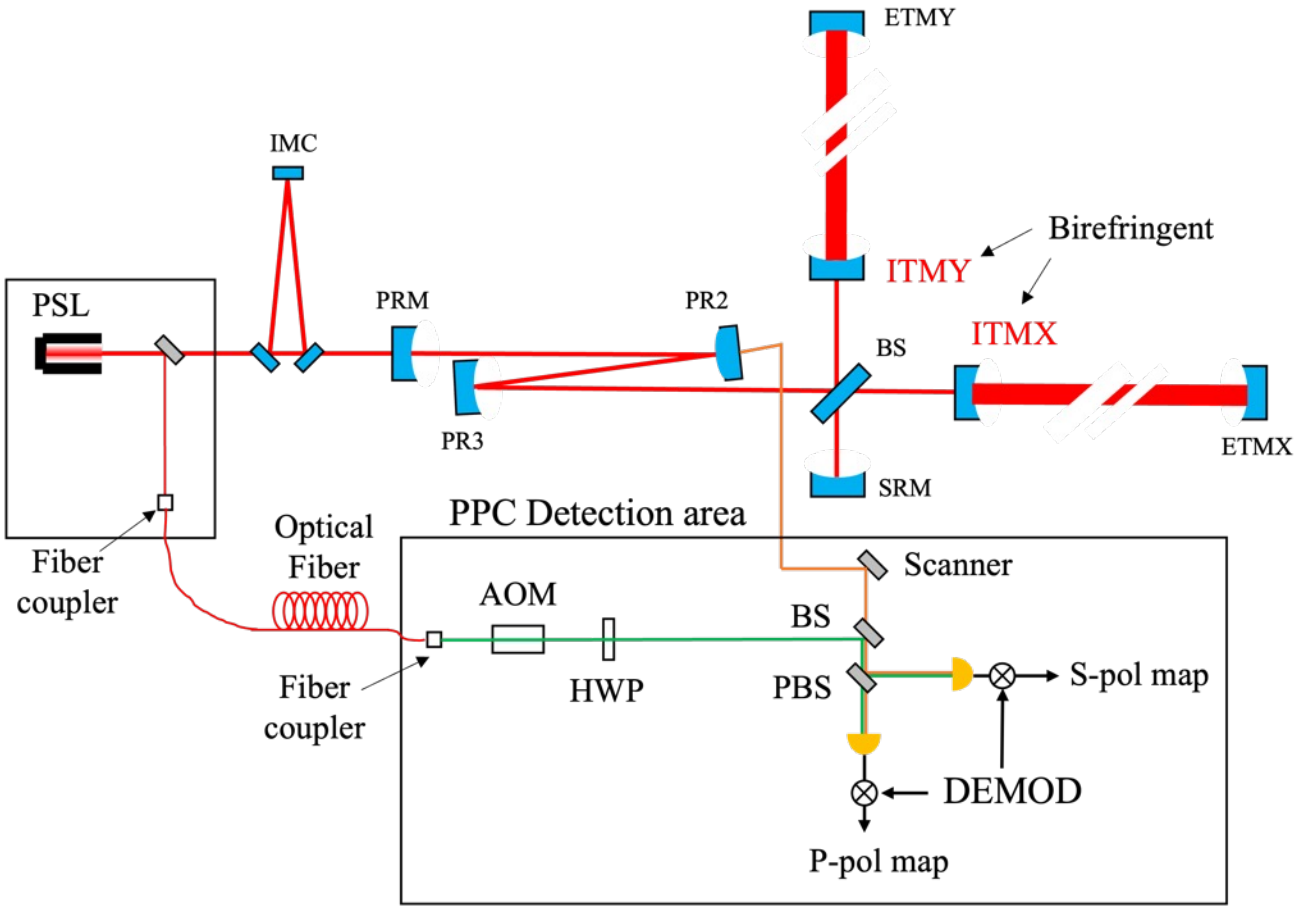
f_0 and 80 MHz are mixed (demodulated) and detected at each pixel scan over the beam

Principle of the polarized phase camera



- Enabling the birefringence effect measurement without taking the mirrors out from the interferometer
- Proof-of-principle experiment is underway at Cardiff University

FSY 2022: Application Design



Procurement of FSY2022

- Approved: JPY 300,000
- Used: JPY 144,188
  - Half wave plate
  - Fiber checker to align the fiber-coupled AOM

Plans for FSY2023

- Prepare the reference beam
  - Consider how to pick off from the pre-stabilized laser room (upstream of the interferometer)
  - Select the optical fiber and paths to send the beam to the PPC detection area (near PR2) by optical fiber
  - Purchase the AOM