Polarization issue in PRC

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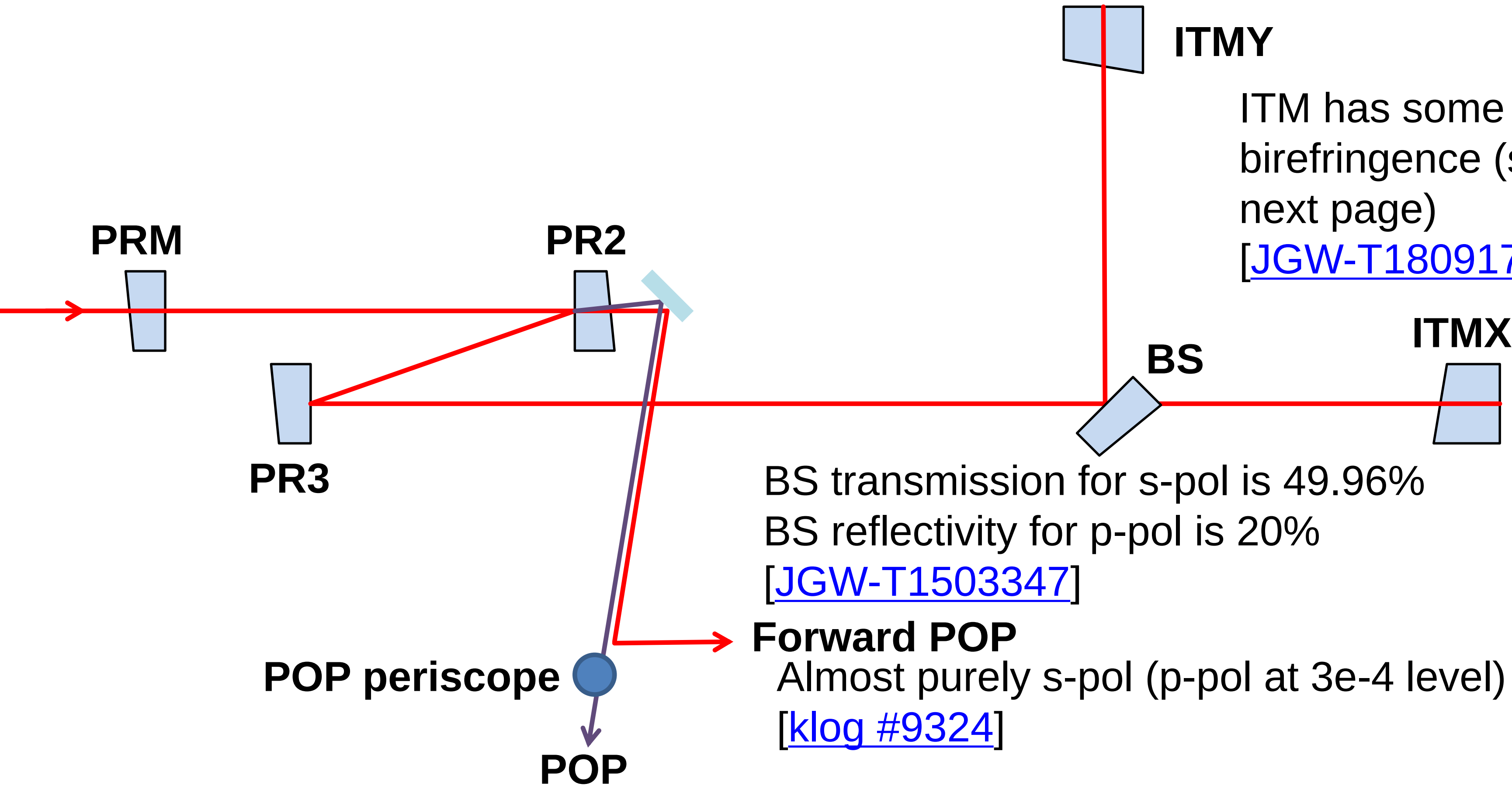
The Situation

- ITM reflection has some p-pol, while forward beam is almost purely s-pol



9.4 % p-pol from ITMX single bounce
4.6 % p-pol from ITMY single bounce [klog #9314]

ITM Birefringence

- Vendor measured transmission wavefront error (TWE) with circular polarization, but TWE measured with s-pol was different

JGW-T1809173

	specification	vendor report	measured
ITMX	< 6nm	3.47	25.9nm
ITMY	< 6nm	4.07	30.1nm

Table 6. figure error of TWE at 140mm aperture

- This suggests that ITM has some birefringence
- Optical path length difference between two polarizations $\Delta l_{\rm b}$ gives polarization rotation of

$$\phi = \pi \Delta l_{\rm b} / \lambda$$

ITM Birefringence

- If we treat RMS linearly, Δl_{b} can be written as
  $$\Delta l_{\mathrm{b}} = l_{\mathrm{p}} - l_{\mathrm{s}} = 2l_{\mathrm{u}} - 2l_{\mathrm{s}}$$
  where $l_{\mathrm{u/s/p}}$ are the optical path length measured with circular polarization and s/p polarization
- The power loss due to s-pol turning into p-pol is therefore written as
  $$\rho = 1 - \cos^2 2\phi$$ (2 for double pass inside ITM substrate)
- The power loss will be 6.8% for X and 9.2% for Y
- This corresponds to the power ratio at POP (p/(s+p)) of 9.3 % for X and 5.7 % for Y (note that BS reflectivity is different between polarizations)
- This seems to (amazingly) agree with the measurement (9.4% for X and 4.8% for Y)

Implications

- We need both uniform $l_{\rm s}$ and small $\Delta l_{\rm b}$ but this cannot be achieved by surface corrections
- Using ordinary and extraordinary refractive indices, $\Delta l_{\rm b}$ can be written as

$$\Delta l_{\rm b} = dn_o(n_o^2 - n_e^2)\theta^2/n_e^2$$

where θ is angle between c-axis and beam axis, JGW-T0400030 and d is ITM thickness (15cm)

For sapphire @ 1064 nm

$$n_e = 1.747$$

$$n_o = 1.754$$

Note that they are different in cryogenic temperatures and there might be additional birefringence due to stress or something

- If we require loss to be smaller than a threshold,

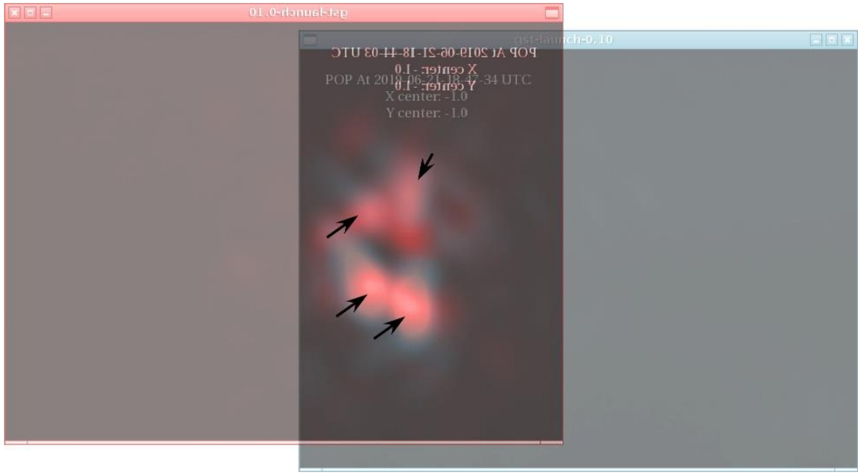
$$\Delta l_{\rm b} < \sqrt{\lambda^2 \rho_{\rm th}/(2\pi)^2}$$

$$\theta < \sqrt{\frac{n_e^2\sqrt{\lambda^2 \rho_{\rm th}/(2\pi)^2}}{dn_o(n_o^2 - n_e^2)}}$$

For 100ppm loss, these will be 5 nm and 0.09 deg

Other Possibilities

- The shape of p-pol beams from ITMX and ITMY seems similar which implies common p-pol generation? [klog #9329]



- Beam height changes could create p-pol beam? (we have 1/300 inclination)