Astronomical Polarimetry

Practice session:
Data analysis of the SQUIDPOL's data

2025 Oct 22, 14:00~15:50

Lecturer: Jooyeon GEEM (김주연),
Postdoc in Lulea university of technology, Sweden

Hello, I am Jooyeon GEEM!!

- PhD thesis = “‘Polarimetric Study of Small Solar System Bodies with Water and Hydrated Minerals"
- PostDoc=“What happens on asteroids near very close to Sun (<0.12au)”

Business trip
to Japan
(2024 June 25)

@ My kitchen

What you will learn

1) Theory

1. Theory of polarimetry

<- will be given by Ishiguro next week

2) Instrument

2. Design of Polarimeter (SQUIDPOL)
3. Calibration of polarimetric data

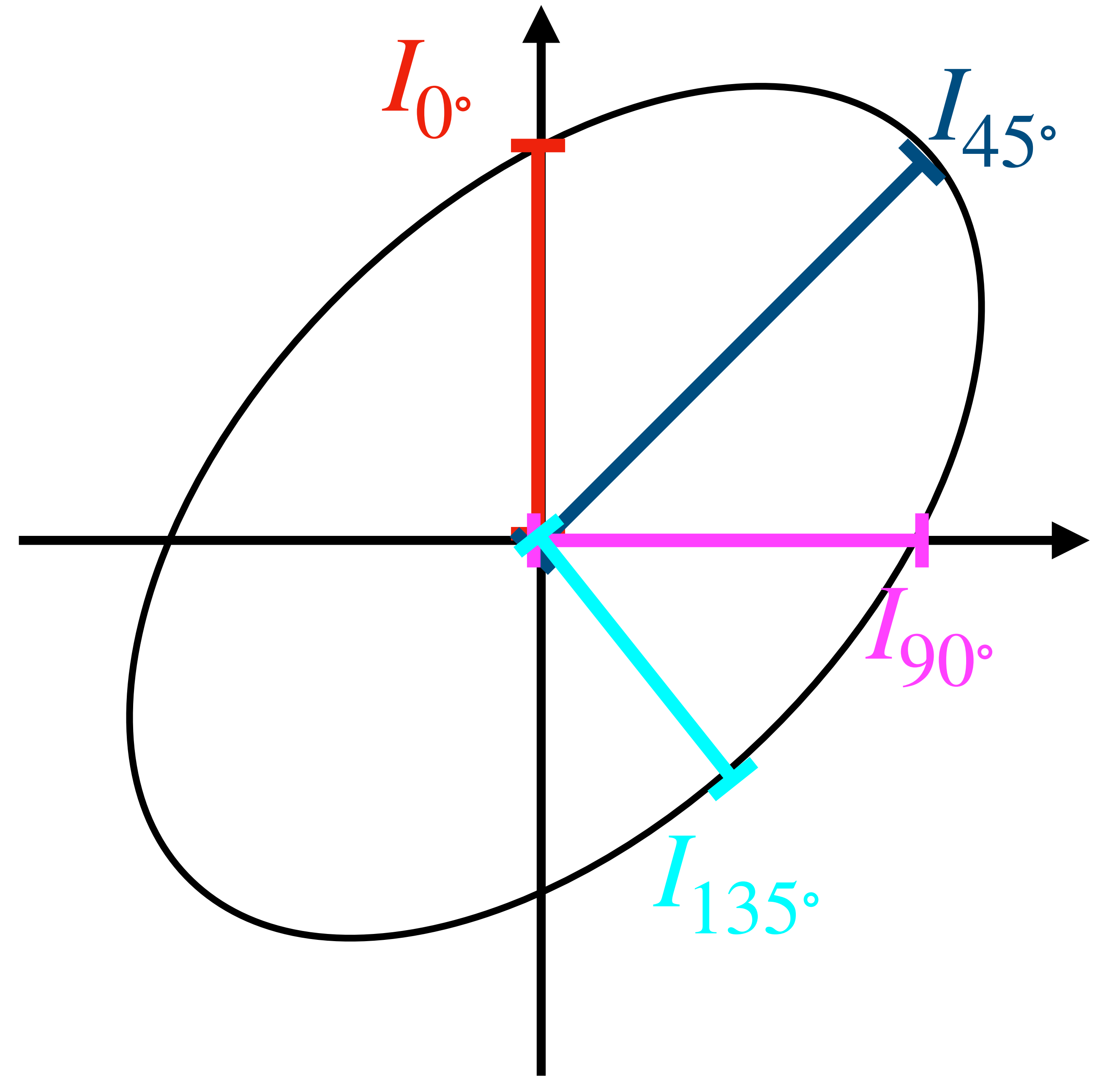
3) Practice

4. Deriving the linear polarization (Q/I and U/I) by using the SQUIDPOL images

will be given by me today

To derive polarization, we need the Stokes parameters…To derive the Stokes parameters, we need the intensity at four different angles.

Measuring Intensity



Stokes parameters

$$\frac{Q}{I} = \frac{I_0 - I_{90}}{I_0 + I_{90}}$$

$$\frac{U}{I} = \frac{I_{45} - I_{135}}{I_{45} + I_{135}}$$

Polarization

$$P = \sqrt{\frac{Q^2}{I^2} + \frac{U^2}{I^2}}$$

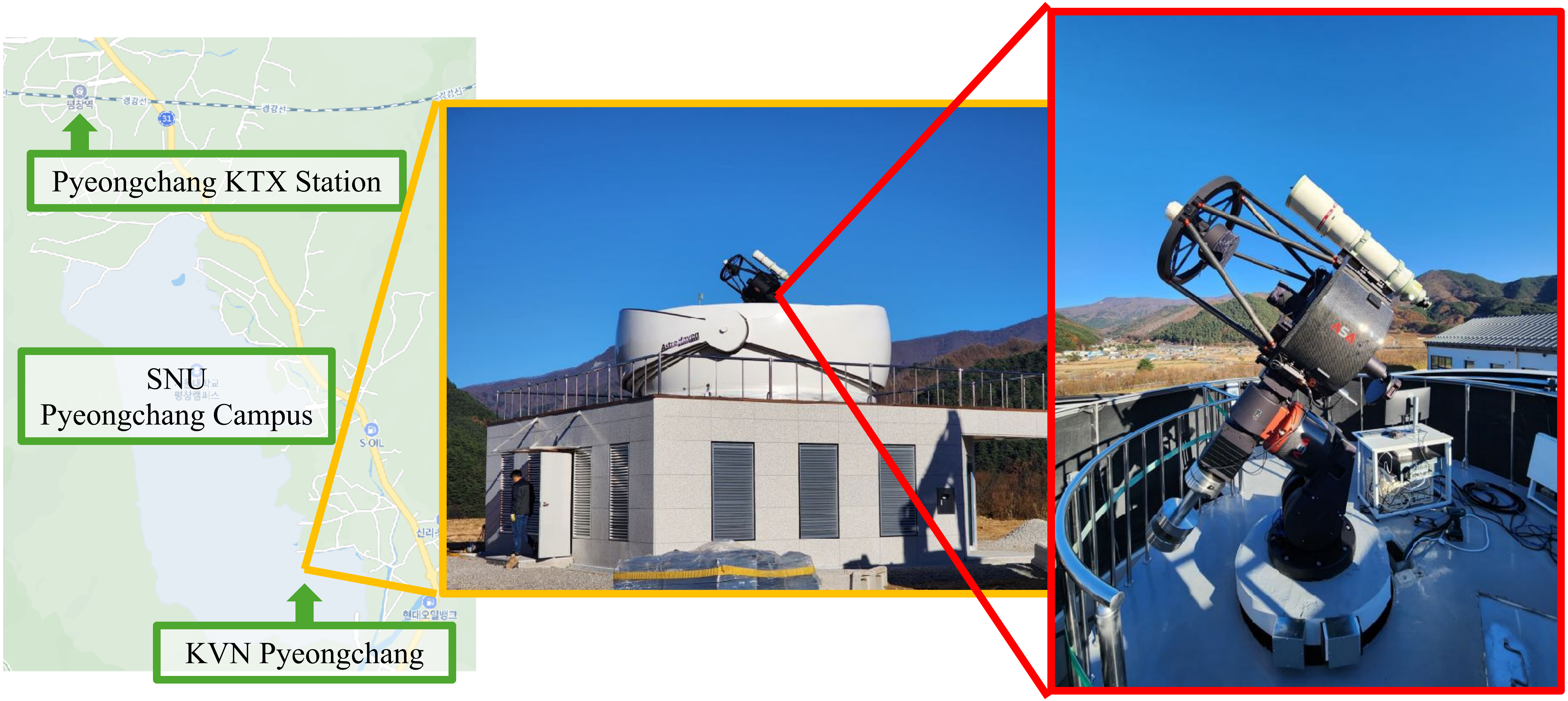
$$\theta_P = \frac{1}{2}\tan^{-1}\left(\frac{U}{Q}\right)$$

Polarimeter: *"Okay, I'll let you measure the intensity of light polarized at a certain angle."*
Us: *"Okay, then we'll do photometry four times."*

Design of SQUIDPOL (SNU QUadruple Imager for POLarimetry) for the SNU Pyeongchang 60-cm Telescope

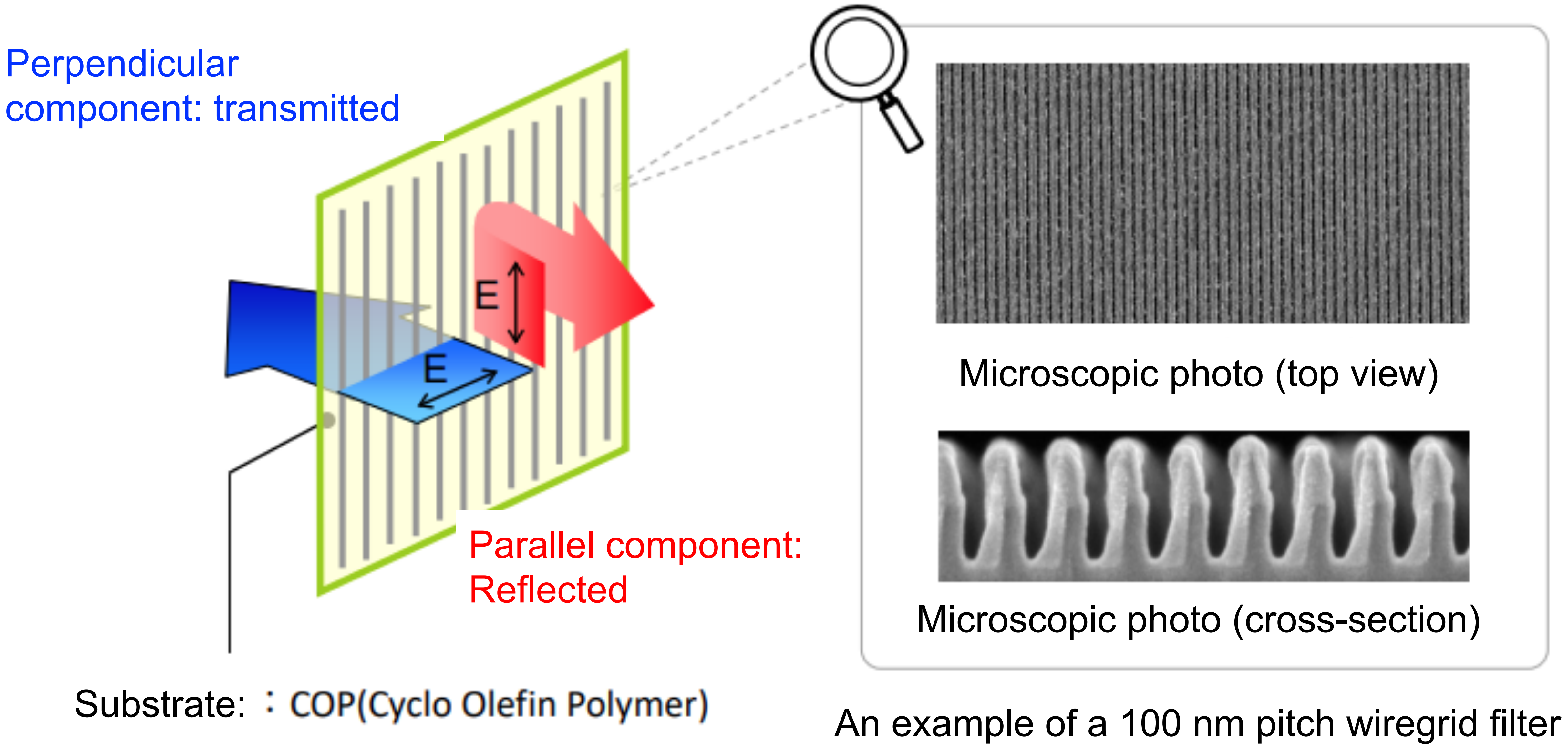
From the 2024 추계 천문학회 presentation made by Sun Jin

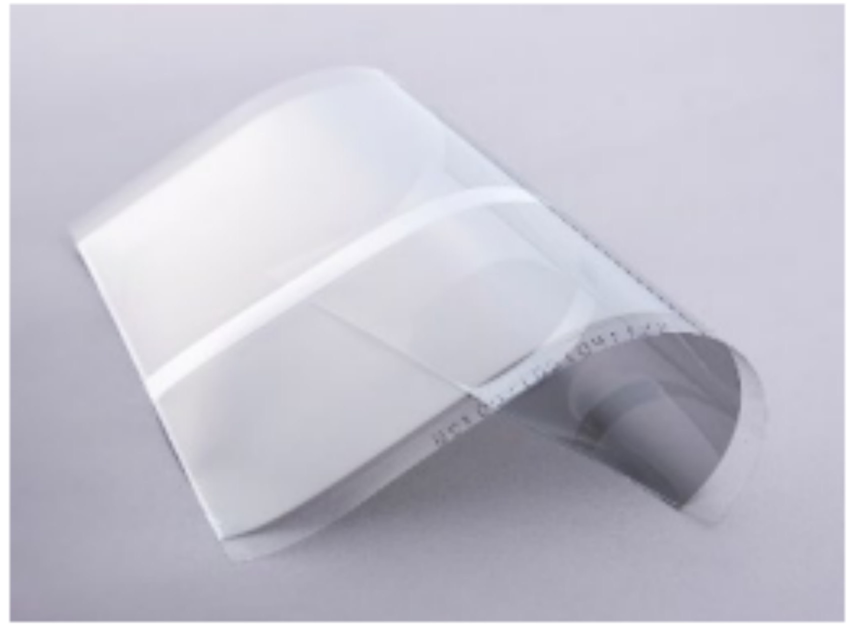
SNU Pyeongchang 60-cm telescope



3. Polarimetric device (2) Polarizing filter

- Wiregrid filter
  - This type of polarizing filter consists of ‘an array of parallel metallic wires’.
  - It is sandwiched between glass substrates.
  - Wire grid polarizers transmit light with an electric field perpendicular to the wire and reflect light with the electric field parallel to the wire (see the figure below) because





An example of a 100 nm pitch wiregrid filter

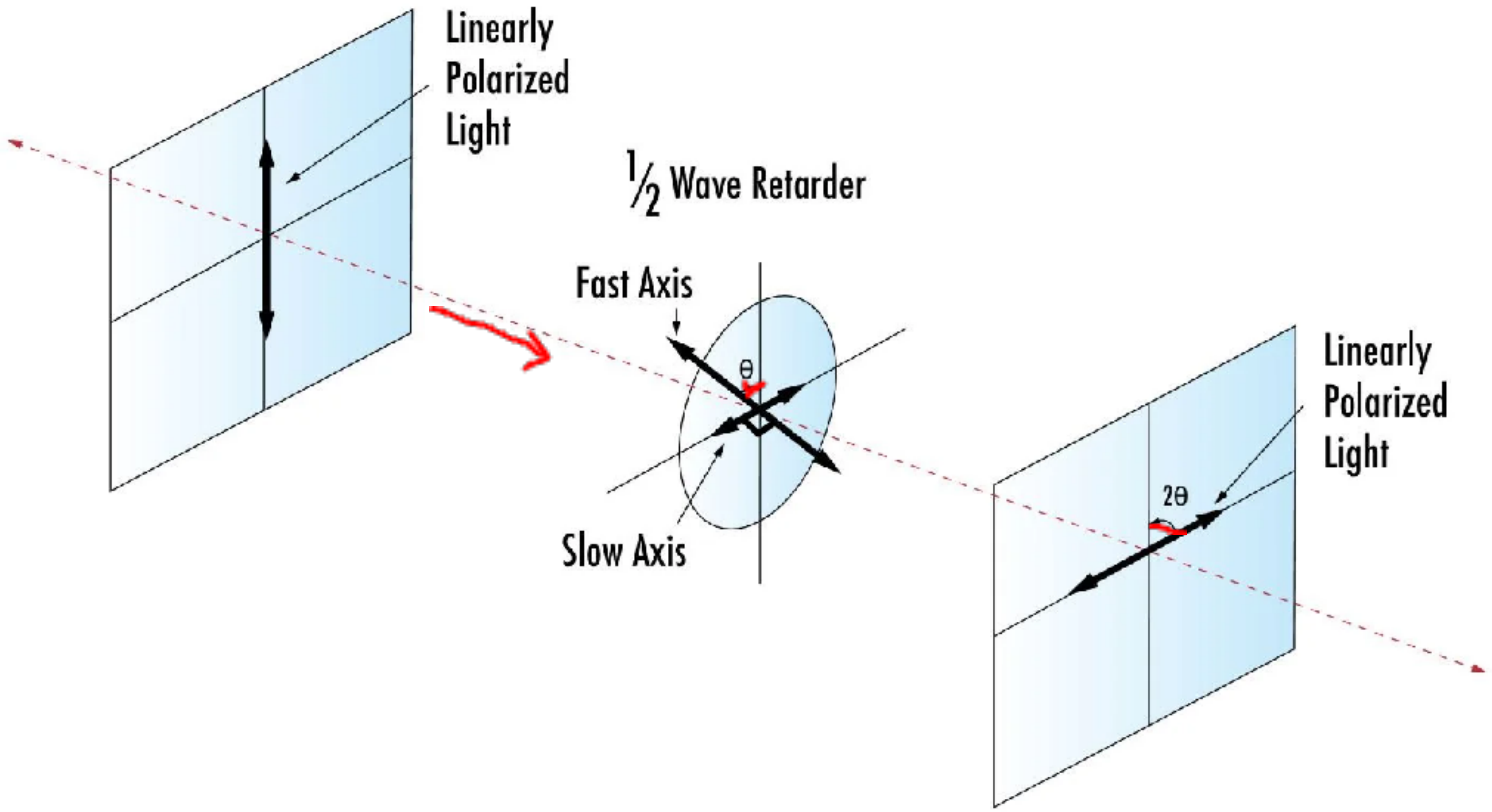
Modified: (Original https://www.osc-japan.com/mirror-corp/film/)

3. Polarimetric device (4) λ/2 Waveplates [2]

- λ/2 waveplates:

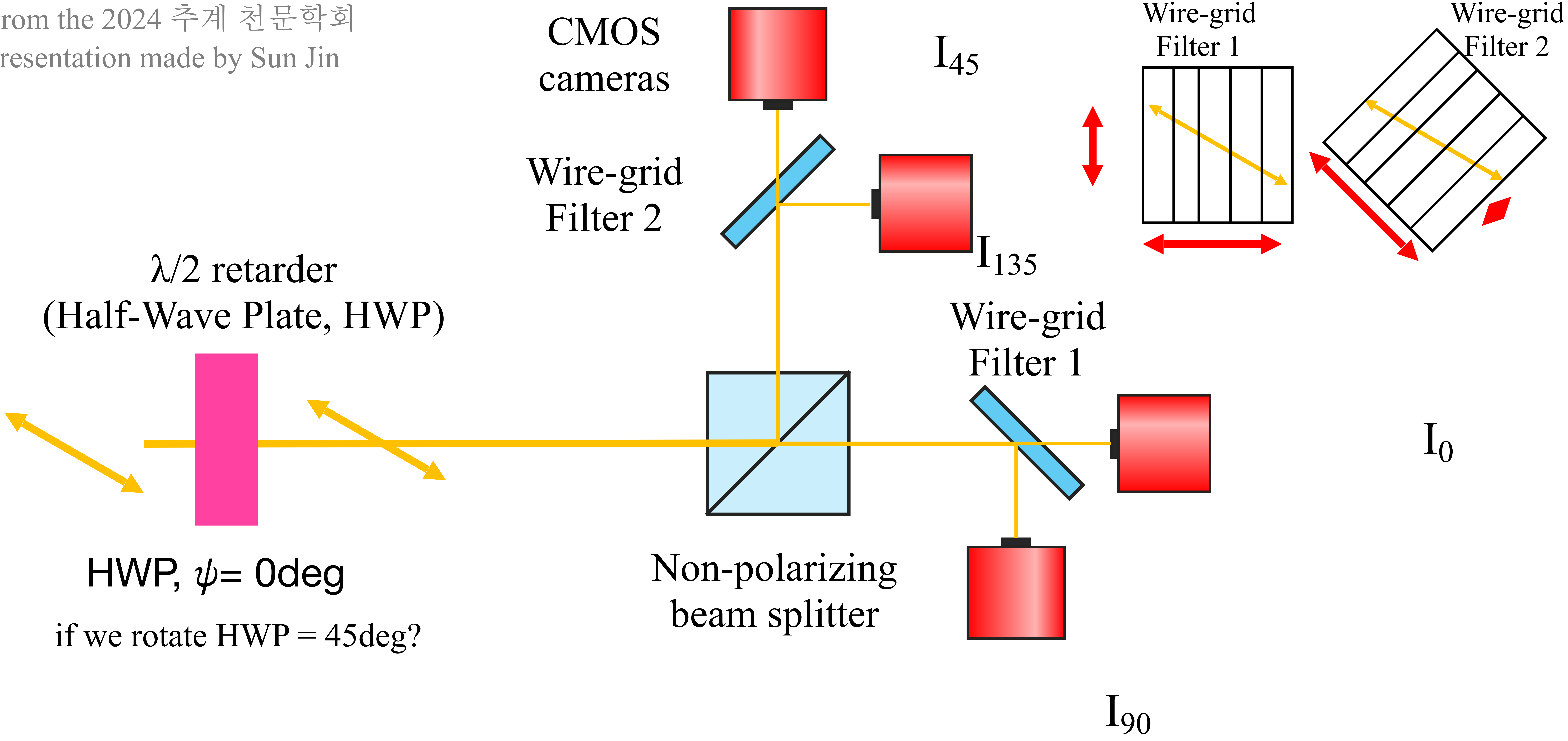
- It converts linearly polarized light in the direction of angle θ into linearly polarized light with angle 2θ.

- It also acts to reverse the direction of rotation of circularly polarized light.



https://www.edmundoptics.com/knowledge-center/application-notes/optics/understanding-waveplates/

From the 2024 추계 천문학회
presentation made by Sun Jin



if we rotate HWP = 45deg?

Concept

From the 2024 추계 천문학회
presentation made by Sun Jin

if we rotate HWP = 45deg?

Concept

$$\frac{Q}{I} = \frac{I_0 - I_{90}}{I_0 + I_{90}} = \frac{1 - a_1}{1 + a_1} \qquad \frac{U}{I} = \frac{I_{45} - I_{135}}{I_{45} + I_{135}} = \frac{1 - a_2}{1 + a_2}$$

$$a_1 = \sqrt{\frac{I_{90}}{I_0} / \frac{I_0}{I_{90}}} = \sqrt{\frac{O_{cam2}(\psi = 0^\circ)}{O_{cam1}(\psi = 0^\circ)} / \frac{O_{cam2}(\psi = 45^\circ)}{O_{cam1}(\psi = 45^\circ)}}$$

$$a_2 = \sqrt{\frac{I_{135}}{I_{45}} / \frac{I_{45}}{I_{135}}} = \sqrt{\frac{O_{cam4}(\psi = 0^\circ)}{O_{cam3}(\psi = 0^\circ)} / \frac{O_{cam4}(\psi = 45^\circ)}{O_{cam3}(\psi = 45^\circ)}}$$

In this way, we can **<u>cancel out the weather effects</u>** and instrumental throughput differences among the cameras.

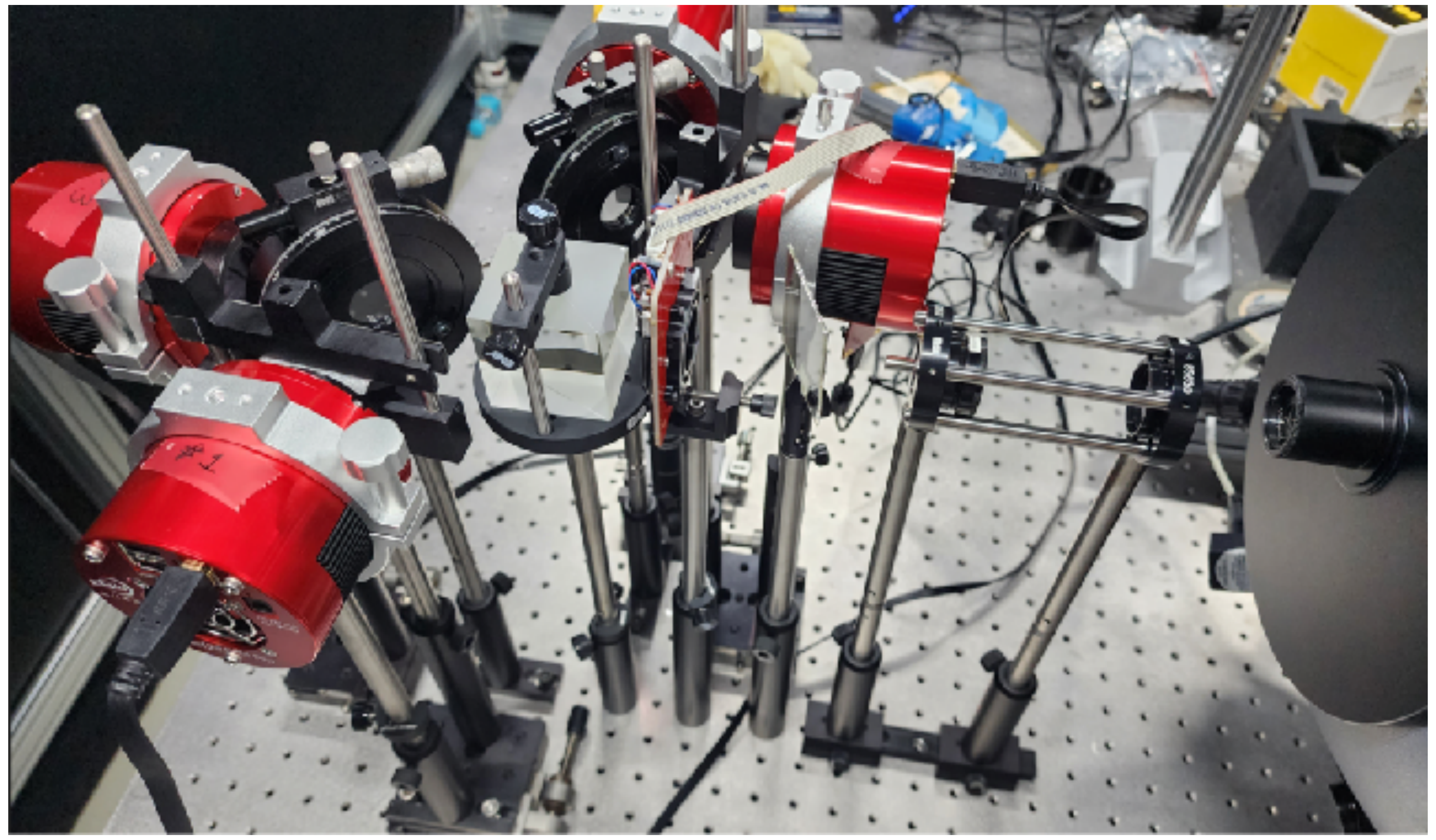
$$O_{cam1}(\psi = 0^\circ) = I_0 * W_1 * T_{\mathrm{cam1}}$$
$$O_{cam2}(\psi = 0^\circ) = I_{90} * W_1 * T_{\mathrm{cam2}}$$
$$O_{cam1}(\psi = 45^\circ) = I_{90} * W_2 * T_{\mathrm{cam1}}$$
$$O_{cam2}(\psi = 45^\circ) = I_0 * W_2 * T_{\mathrm{cam2}}$$

$O_{\mathrm{cam\,N}}(\psi = \theta^\circ)$ = Observed intensity measured by the Nth camera at HWP angle of θ°

W_1, W_2 = weather effect during the first and second exposures

$T_{\mathrm{cam1}}, T_{\mathrm{cam2}}$ = instrumental throughput for the optical paths of camera 1 and 2

Developing SQUIDPOL

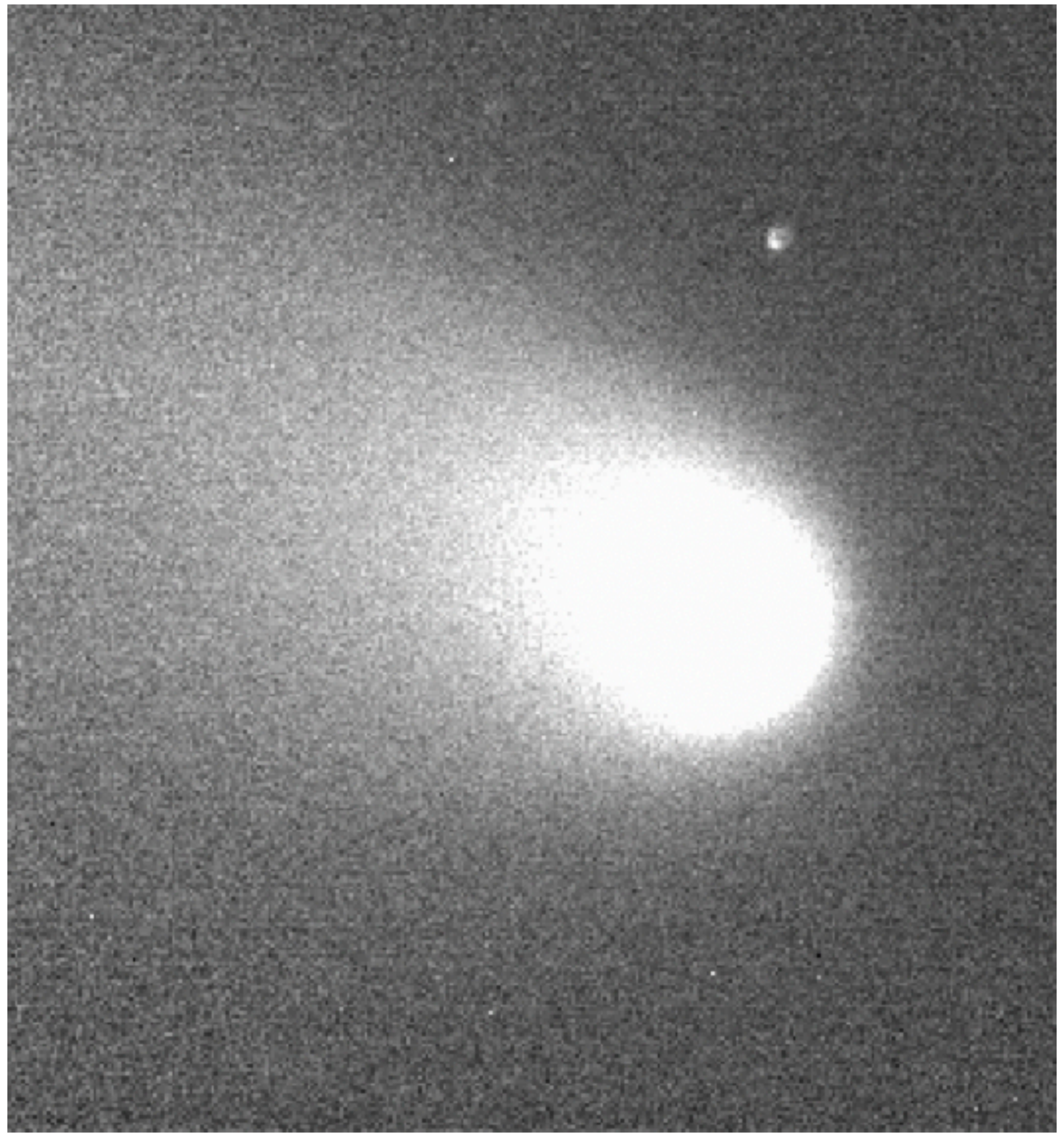


@Laboratory

@ Pyeongchang Campus

What we will do: Deriving Q/I and U/I values of the C/2023 A3

2024 Oct 16, @ Pyeonchang Campus
Exp=3s, taken by Prof.Ishiguro, iPhone



Example image of C2023A3
Exp=30s, taken by Lim & Geem,
SQUIDPOL, R-band

Method

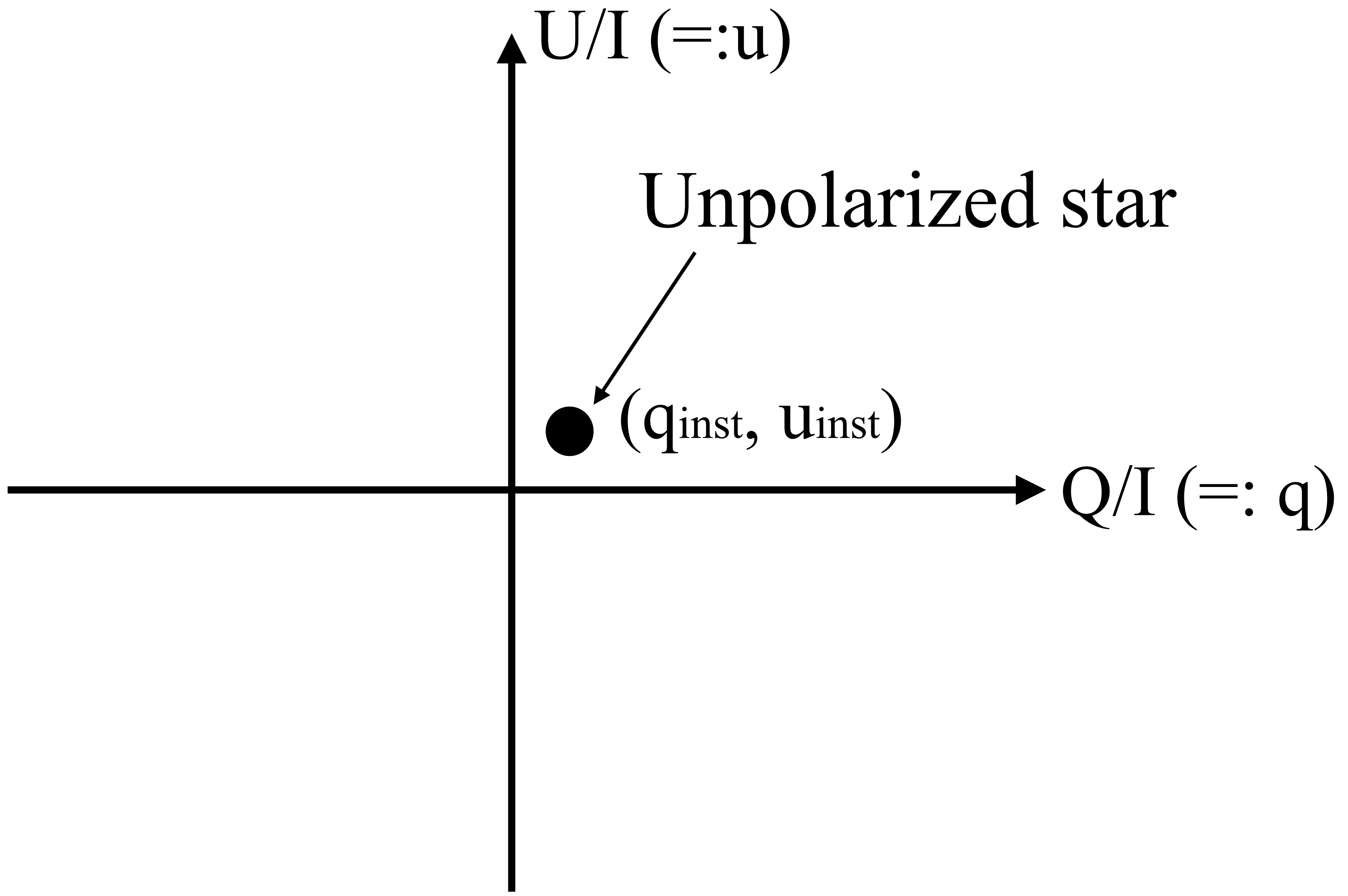
1. Aperture photometry to derive I_0, I_{45}, I_{90}, and I_{135}
   -I will distribute the python code

2. Deriving Q/I and U/I
   (What you have to do)

3. Polarimetric Calibration
   - Instrumental polarization
   - Position angle offset
   (What you have to do)

Polarimetric Calibration

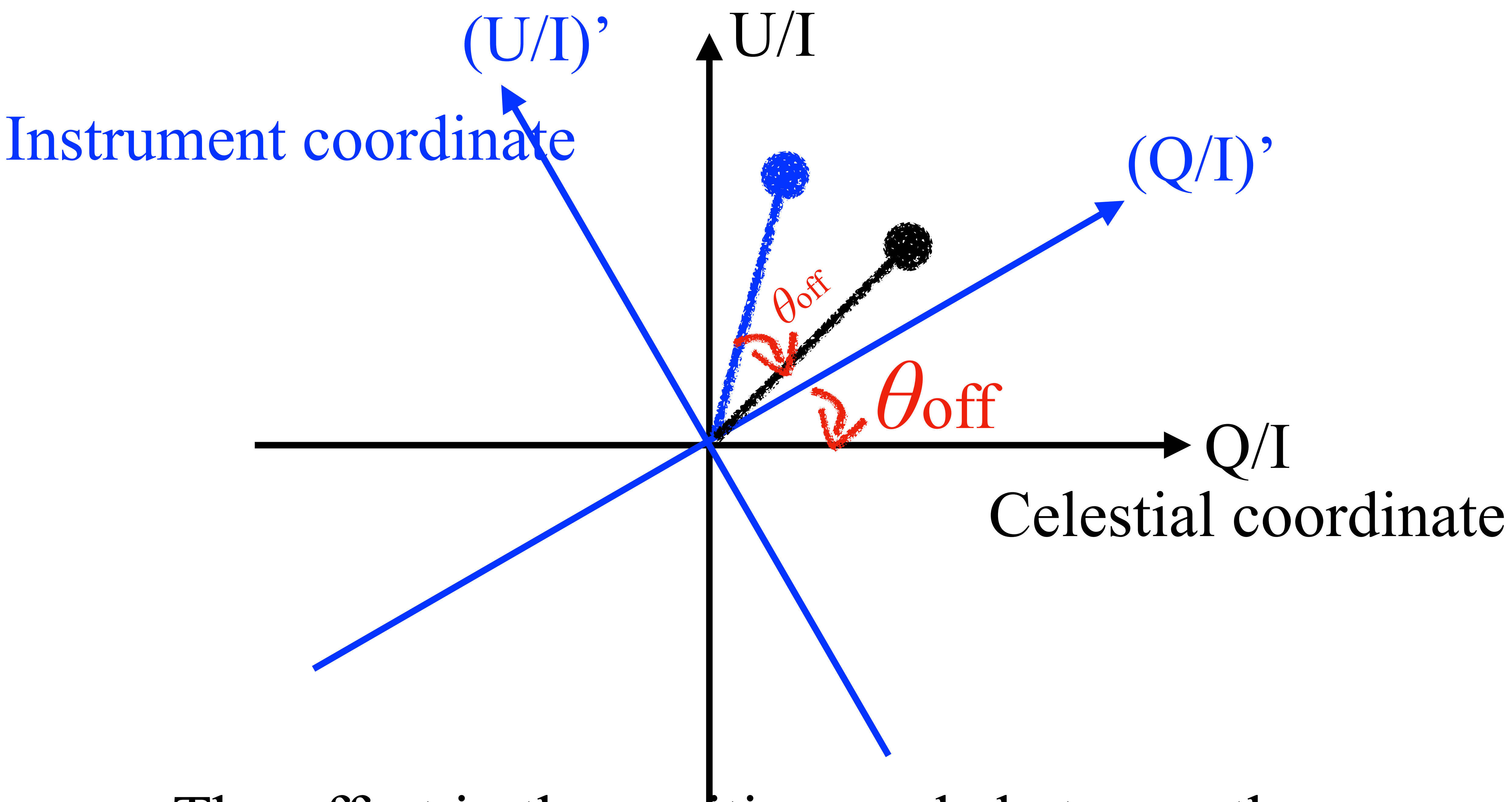
- **Instrumental polarization**



It is mainly produced by Fresnel reflection and refraction at the surfaces of telescope mirrors and lens elements located in front of HWP.
(Ikeda et al. 2007)

$$q' = q - q_{inst}, \quad u' = u - u_{inst}$$

- **Position angle offset**



The offset in the position angle between the celestial and instrumental coordinates should be corrected.

$$q'' = q' \cos(2\theta_{off}) + u' \sin(2\theta_{off})$$
$$u'' = - q' \sin(2\theta_{off}) + u' \cos(2\theta_{off})$$

Information you may need

1. Data (https://github.com/Geemjy/TA)
   - 2024 Oct 16, R-band, C2023 A3
   - After the preprocessing (Result P = 21.8%)

Component	Camera ID
O_{cam1}	Cam4
O_{cam2}	Cam3
O_{cam3}	Cam1
O_{cam4}	Cam2

3. Calibration parameters in R-band

Calibration parameters	Values
q_{inst}	-0.28 ± 0.16 %
u_{inst}	-0.45 ± 0.26 %
θ_{off}	-8.85 ± 0.2°

filename	Object	DATE	UT	EXPTIME	Cam	HWPANG	FIL
pSQ20241016_000036_Cam1.fits	C2023A3_r	2024-10-16	09:38:54.69	30.0	1	0.0	R
pSQ20241016_000036_Cam2.fits	C2023A3_r	2024-10-16	09:38:54.69	30.0	2	0.0	R
pSQ20241016_000036_Cam3.fits	C2023A3_r	2024-10-16	09:38:54.69	30.0	3	0.0	R
pSQ20241016_000036_Cam4.fits	C2023A3_r	2024-10-16	09:38:54.69	30.0	4	0.0	R
pSQ20241016_000037_Cam1.fits	C2023A3_r	2024-10-16	09:39:38.57	30.0	1	45.0	R
pSQ20241016_000037_Cam2.fits	C2023A3_r	2024-10-16	09:39:38.57	30.0	2	45.0	R
pSQ20241016_000037_Cam3.fits	C2023A3_r	2024-10-16	09:39:38.57	30.0	3	45.0	R
pSQ20241016_000037_Cam4.fits	C2023A3_r	2024-10-16	09:39:38.57	30.0	4	45.0	R
pSQ20241016_000038_Cam1.fits	C2023A3_r	2024-10-16	09:40:21.22	30.0	1	0.0	R
pSQ20241016_000038_Cam2.fits	C2023A3_r	2024-10-16	09:40:21.22	30.0	2	0.0	R
pSQ20241016_000038_Cam3.fits	C2023A3_r	2024-10-16	09:40:21.22	30.0	3	0.0	R
pSQ20241016_000038_Cam4.fits	C2023A3_r	2024-10-16	09:40:21.22	30.0	4	0.0	R
pSQ20241016_000039_Cam1.fits	C2023A3_r	2024-10-16	09:41:03.84	30.0	1	45.0	R
pSQ20241016_000039_Cam2.fits	C2023A3_r	2024-10-16	09:41:03.84	30.0	2	45.0	R
pSQ20241016_000039_Cam3.fits	C2023A3_r	2024-10-16	09:41:03.84	30.0	3	45.0	R
pSQ20241016_000039_Cam4.fits	C2023A3_r	2024-10-16	09:41:03.84	30.0	4	45.0	R