SIGGRAPH ASIA 2024 TOKYO 東京

Polarimetric BSSRDF Acquisition of Dynamic Faces

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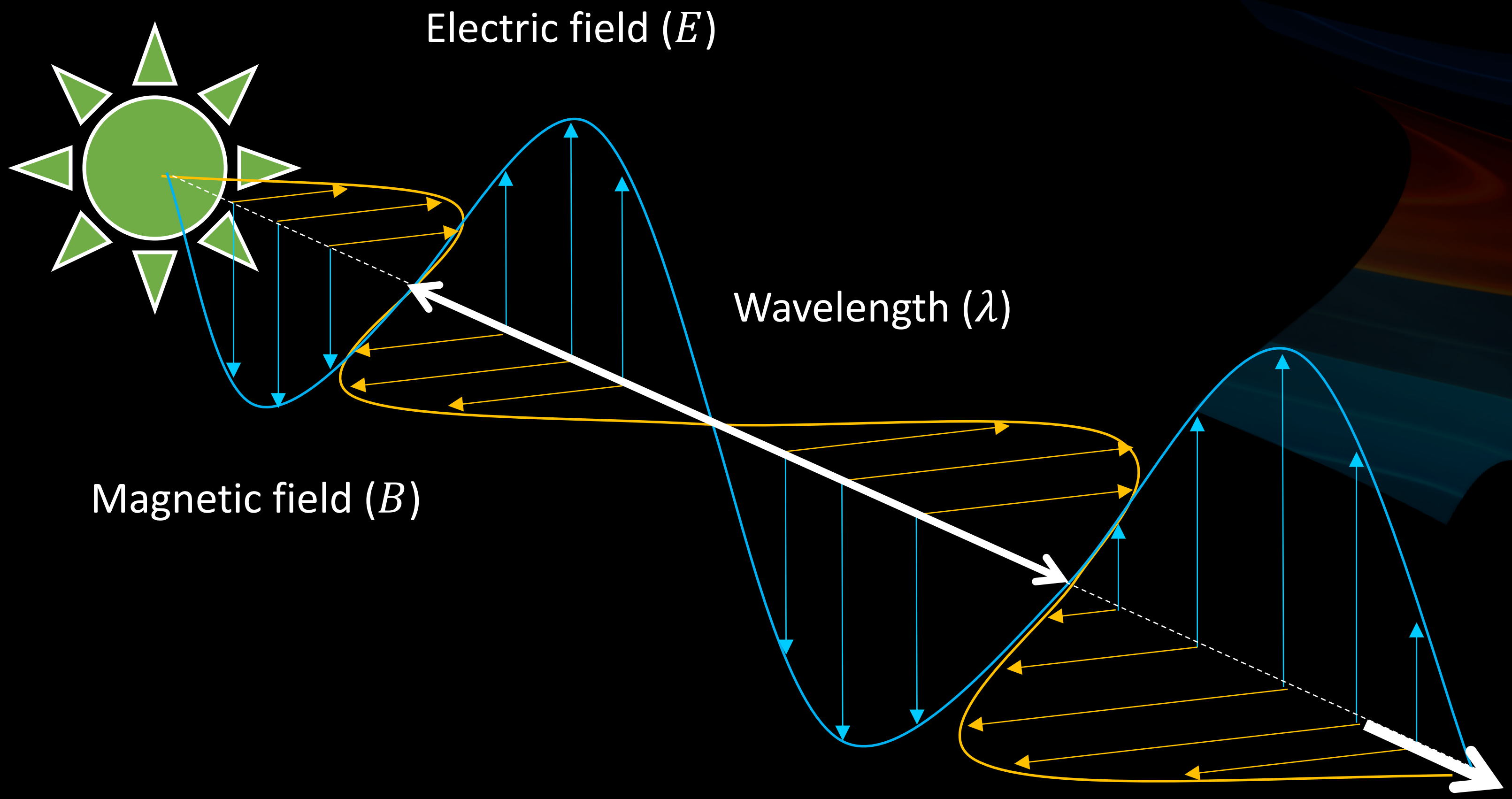
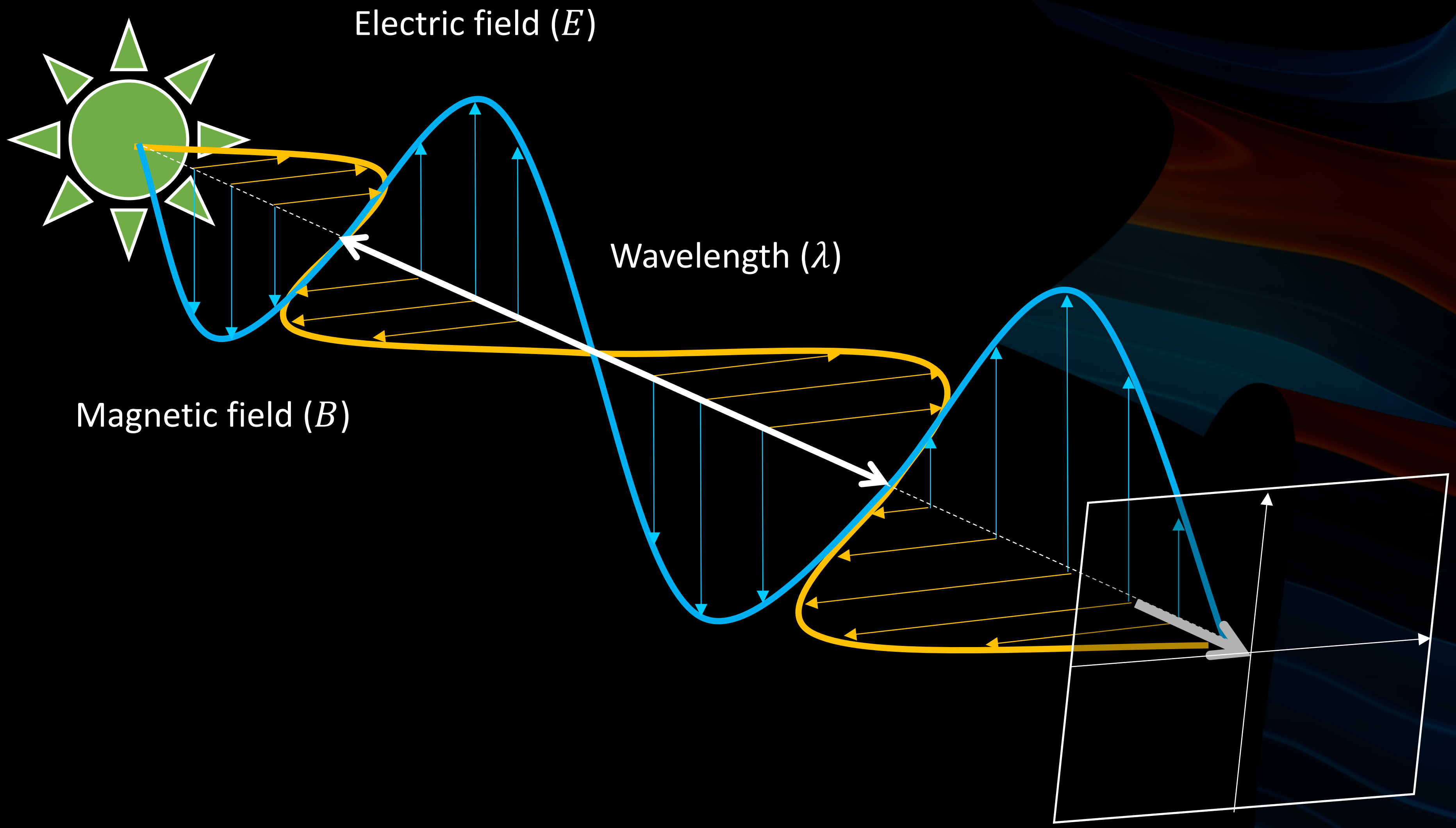
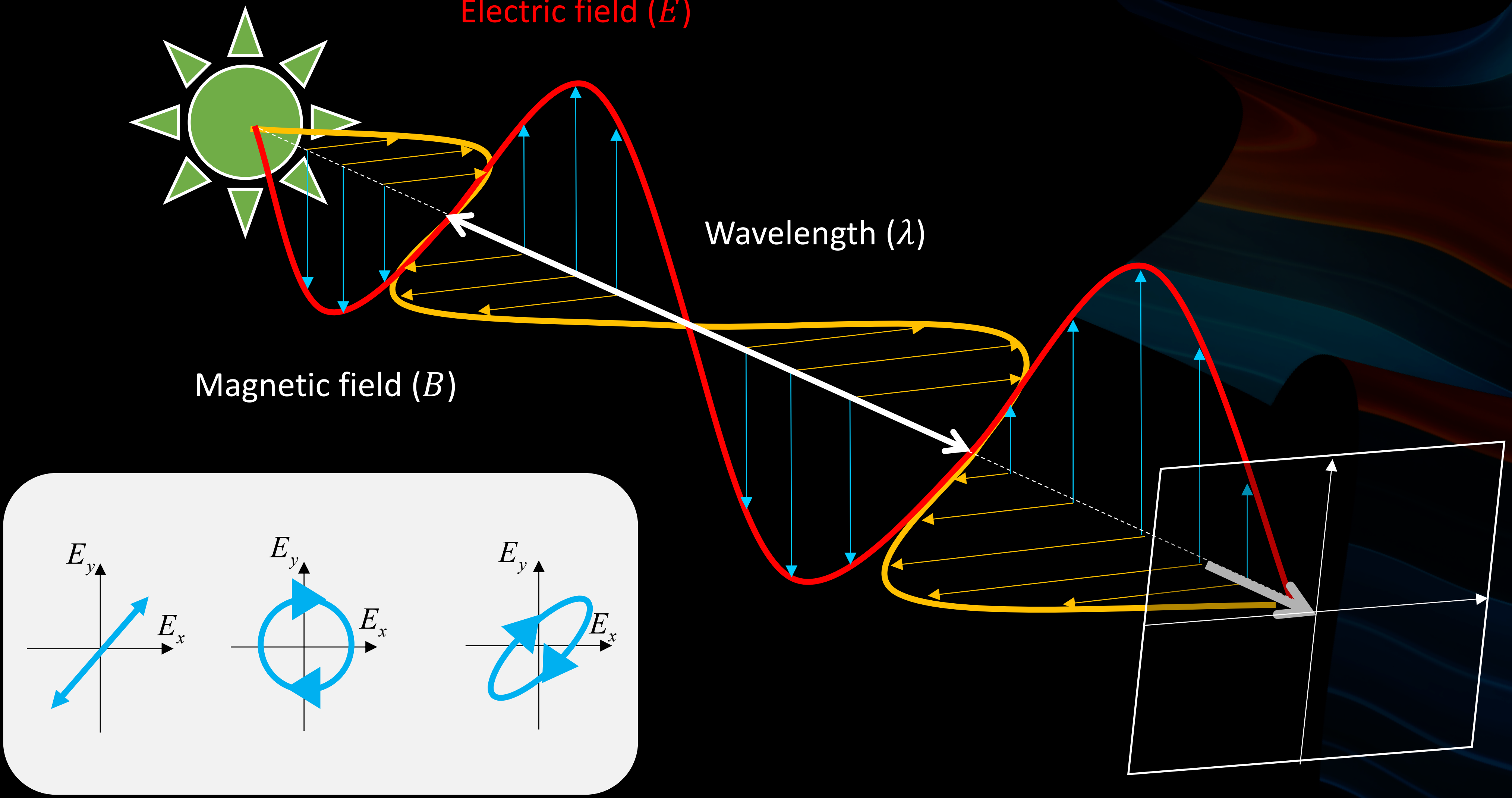
Polarization



Polarization



Polarization



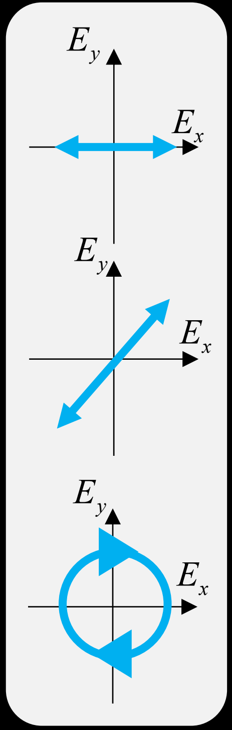
Stokes Vector and Mueller Matrix

$$\mathbf{s}_o = \mathbf{M} \quad \mathbf{s}_i$$

Stokes vector

$$\mathbf{s} = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix}$$

- S_0: Intensity
- S_1: Horizontal/vertical
- S_2: Diagonal/antidiagonal
- S_3: Circular



Mueller matrix

$$\mathbf{M} = \begin{bmatrix} M_{00} & M_{01} & M_{02} & M_{03} \\ M_{10} & M_{11} & M_{12} & M_{13} \\ M_{20} & M_{21} & M_{22} & M_{23} \\ M_{30} & M_{31} & M_{32} & M_{33} \end{bmatrix}$$

Face Model

- Oiliness
  - Main specular reflection
- Outer layer
  - Epidermis + upper part of the dermis

$C_{\mathrm{h,out}}$ Fraction of hemoglobin

C_{m} Fraction of melanin

β_m Fraction of eumelanin in melanin

- Inner layer
  - Lower part of the dermis

$C_{\mathrm{h,in}}$ Fraction of hemoglobin in inner layer

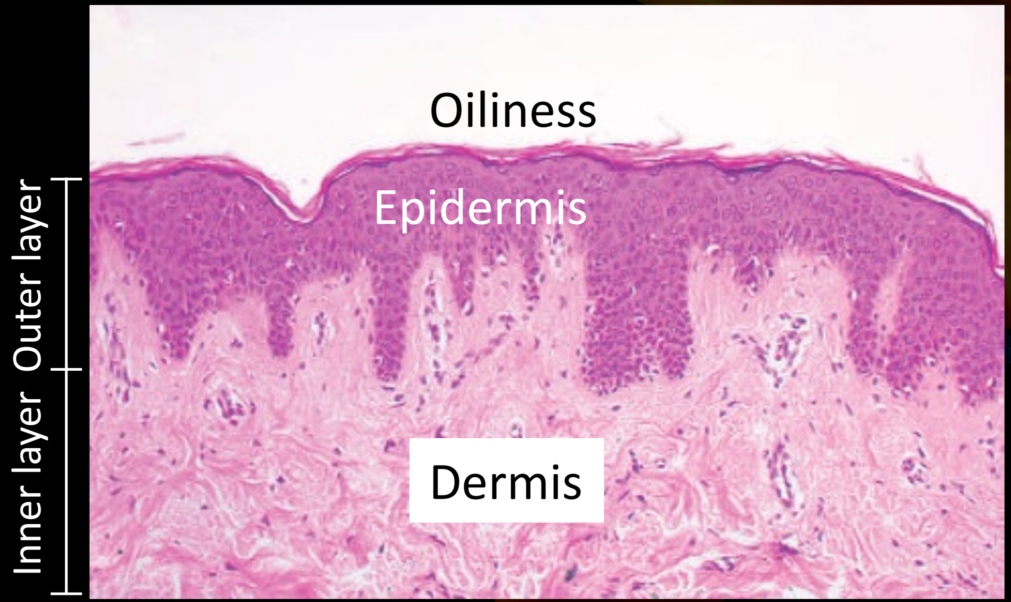
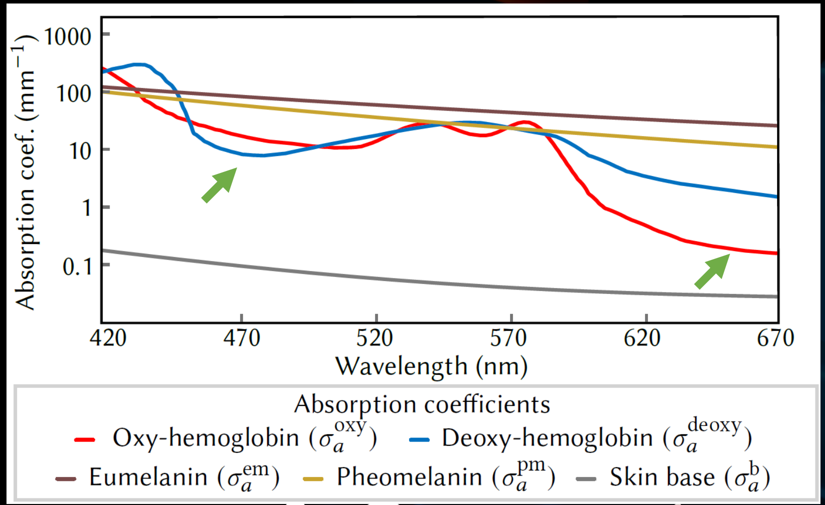


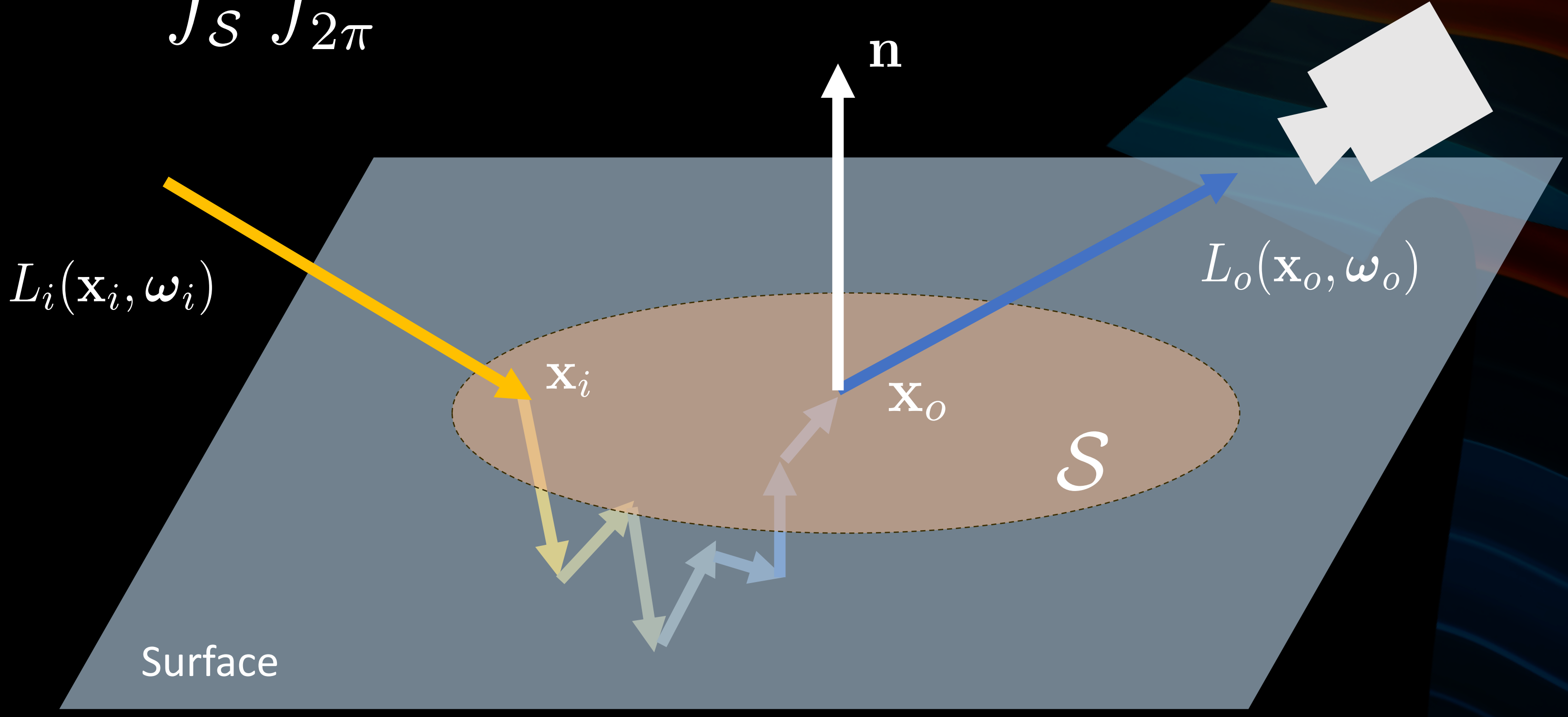
Figure from *Dermatology Lecture Notes*, Eleventh Edition.



Human Skin: Subsurface Scattering

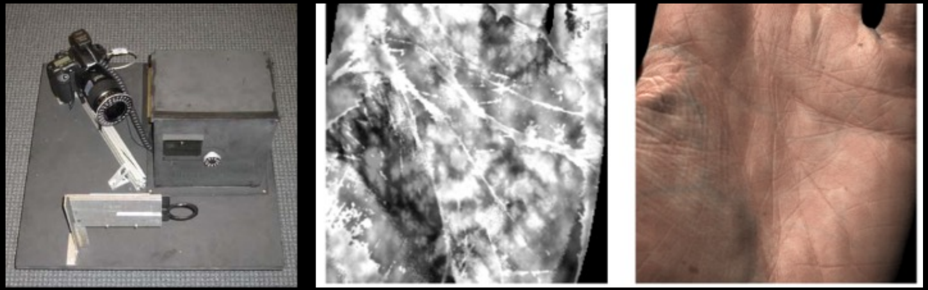
- Bidirectional Subsurface Scattering Reflectance Distribution Function Ψ

$$L_o(\mathbf{x}_o, \boldsymbol{\omega}_o) = \int_{\mathcal{S}} \int_{2\pi} \Psi(\mathbf{x}_i, \boldsymbol{\omega}_i; \mathbf{x}_o, \boldsymbol{\omega}_o) L_i(\mathbf{x}_i, \boldsymbol{\omega}_i)(\mathbf{n} \cdot \boldsymbol{\omega}_i) d\boldsymbol{\omega}_i d\mathcal{S}(\mathbf{x}_i)$$

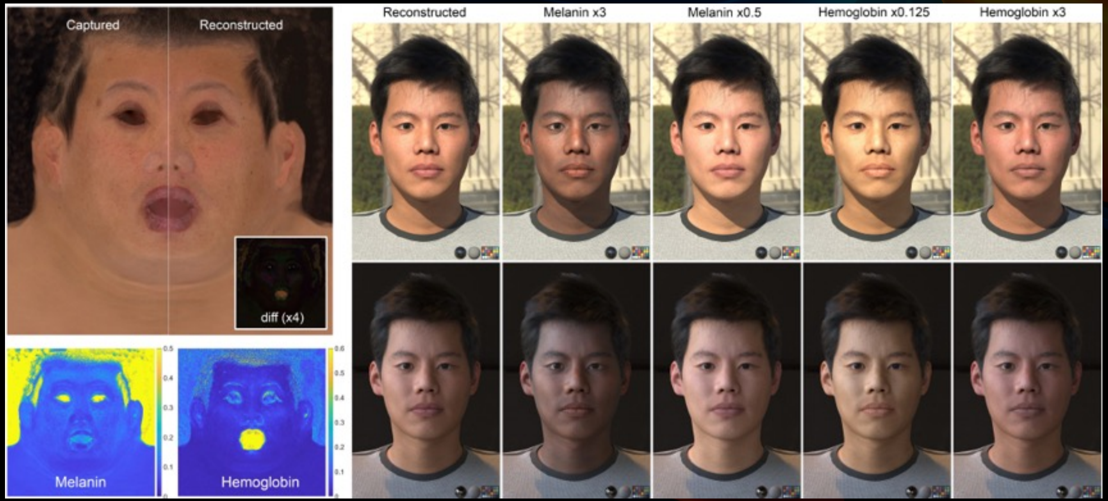


Related Work

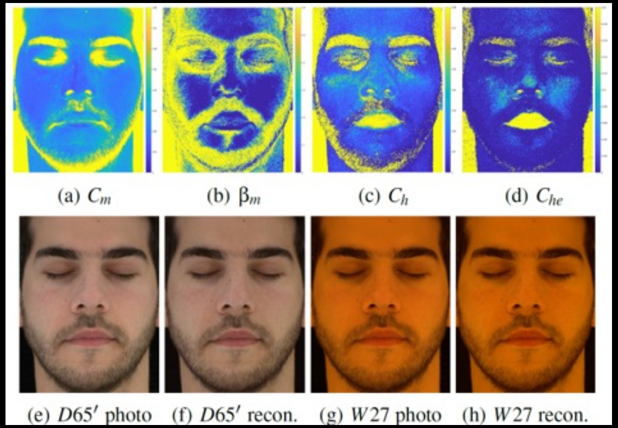
- Human face: beneath skin



Donner et al. 2008

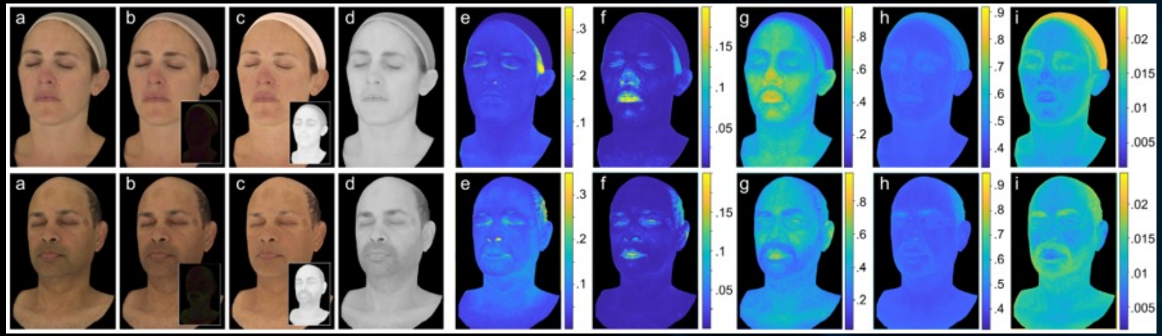


Aliaga et al. 2022



Gitlina et al. 2010

Jimenez et al. 2010



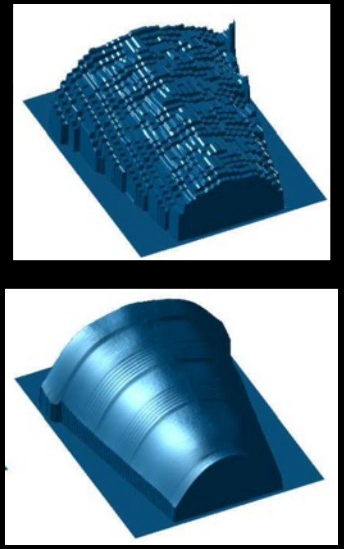
Aliaga et al. 2023

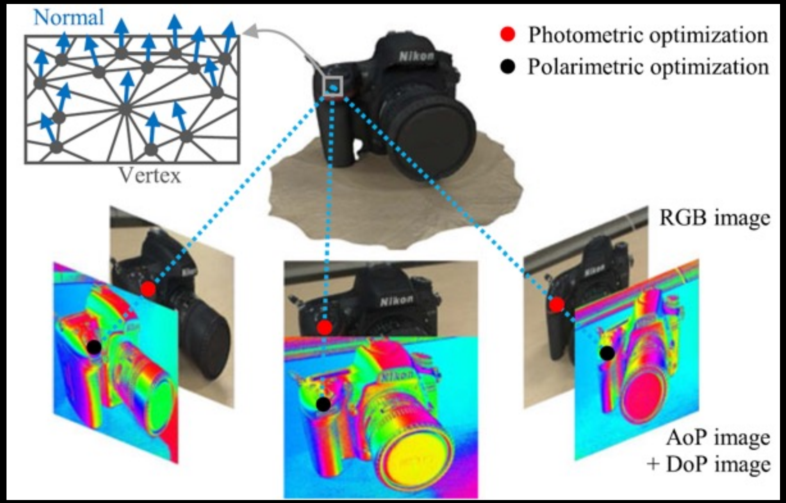
Related Work

- Polarimetry

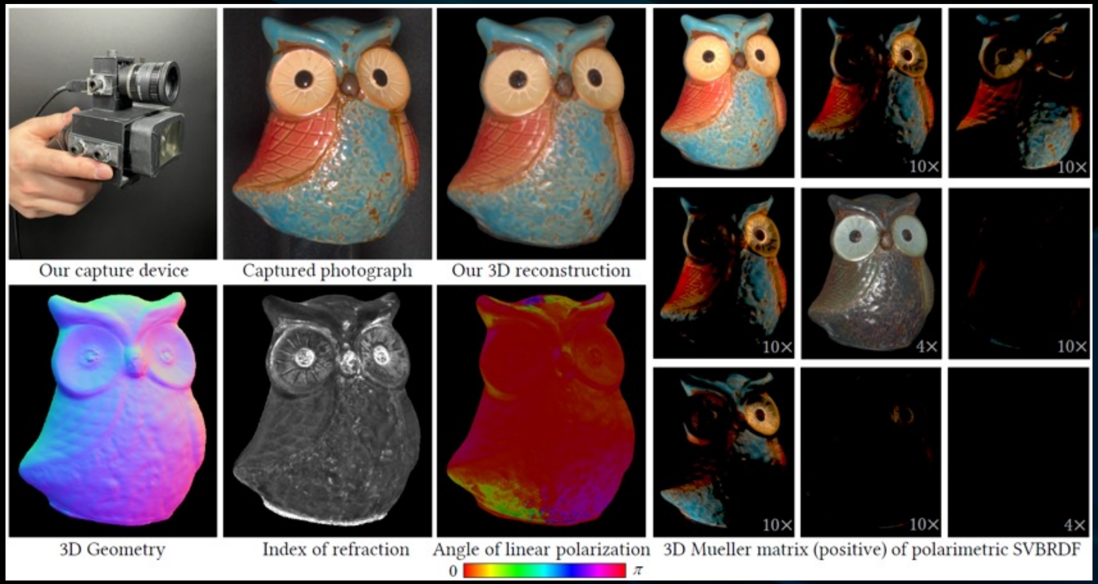
Ghosh et al. 2010


Baek et al. 2018


Kadambi et al. 2010



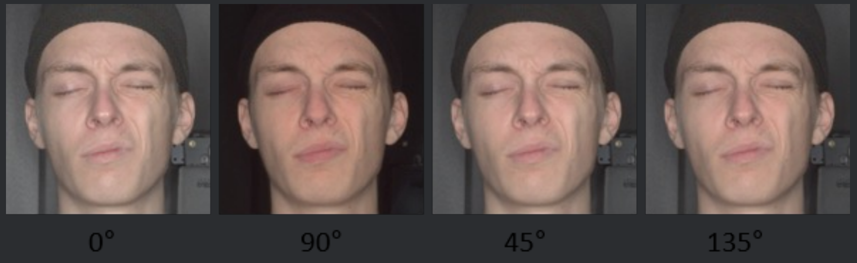
Zhao et al. 2020



Hwang et al. 2022

Goals

Specular appearance



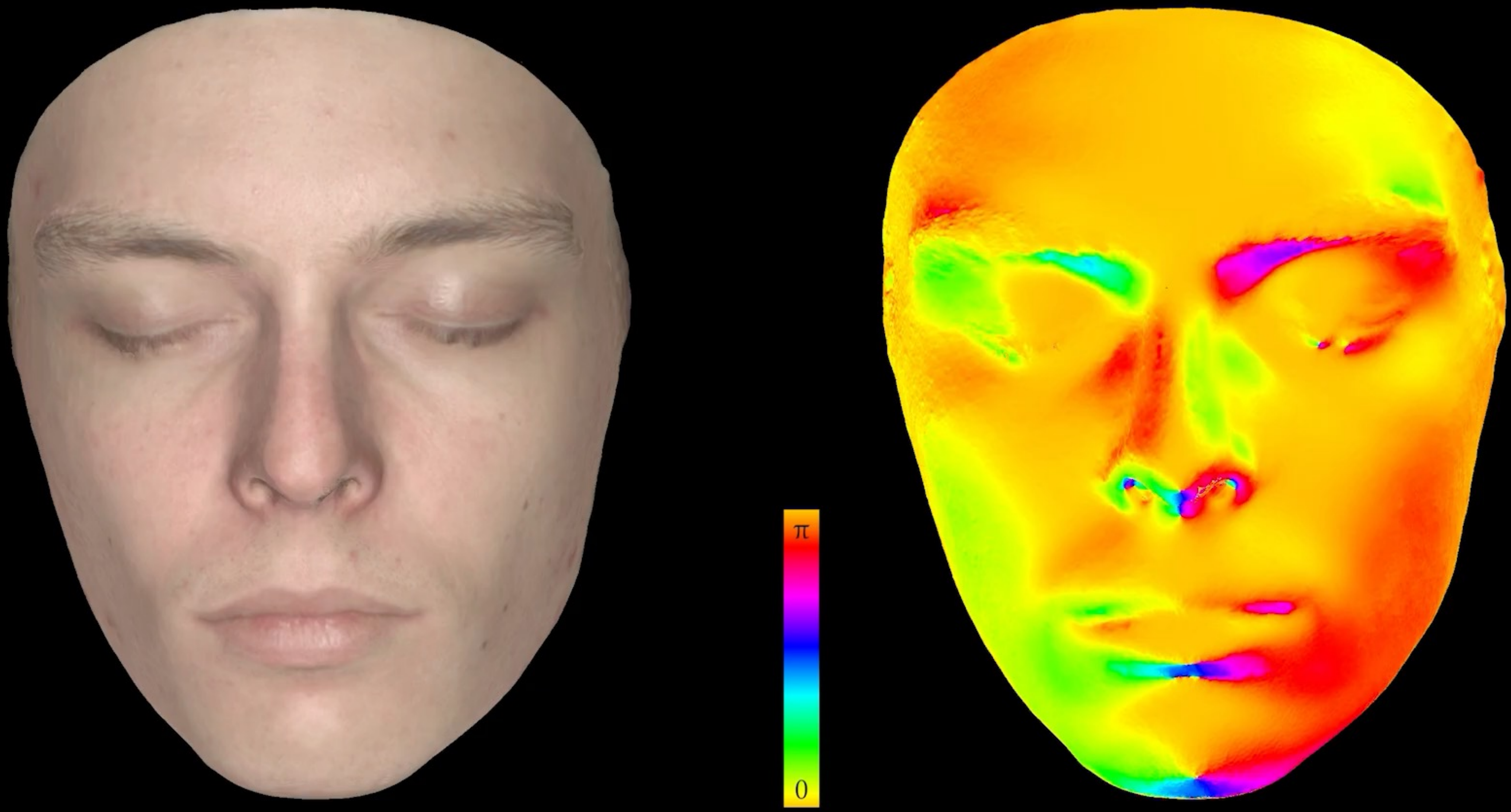
Polarimetric reflectance

Multispectral subsurface scattering

Biophysical parameters

Geometry

Inverse rendering

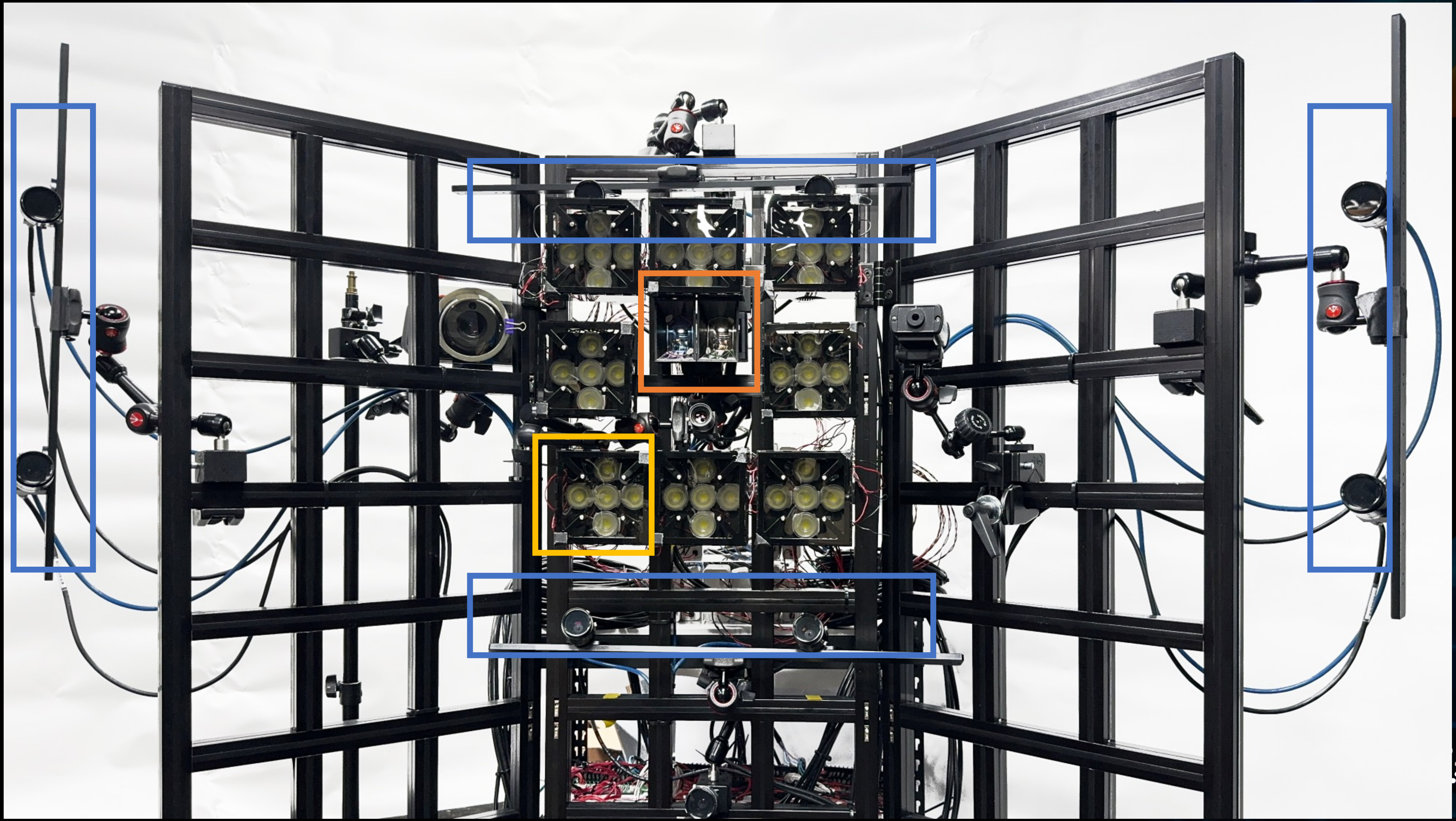


Full rendering

Angle of linear polarization

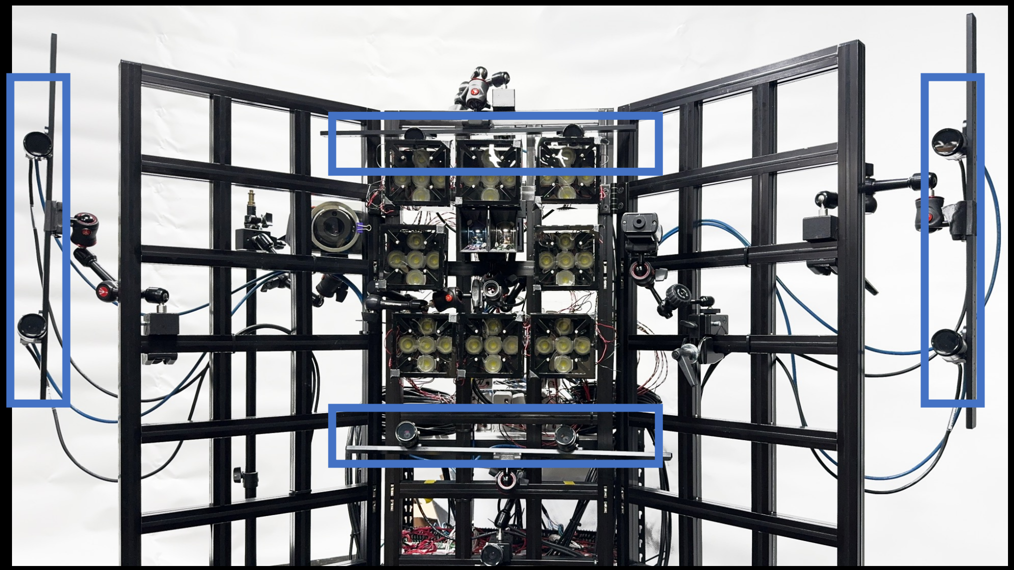
Hardware

- Capture multispectral polarimetric stereo images

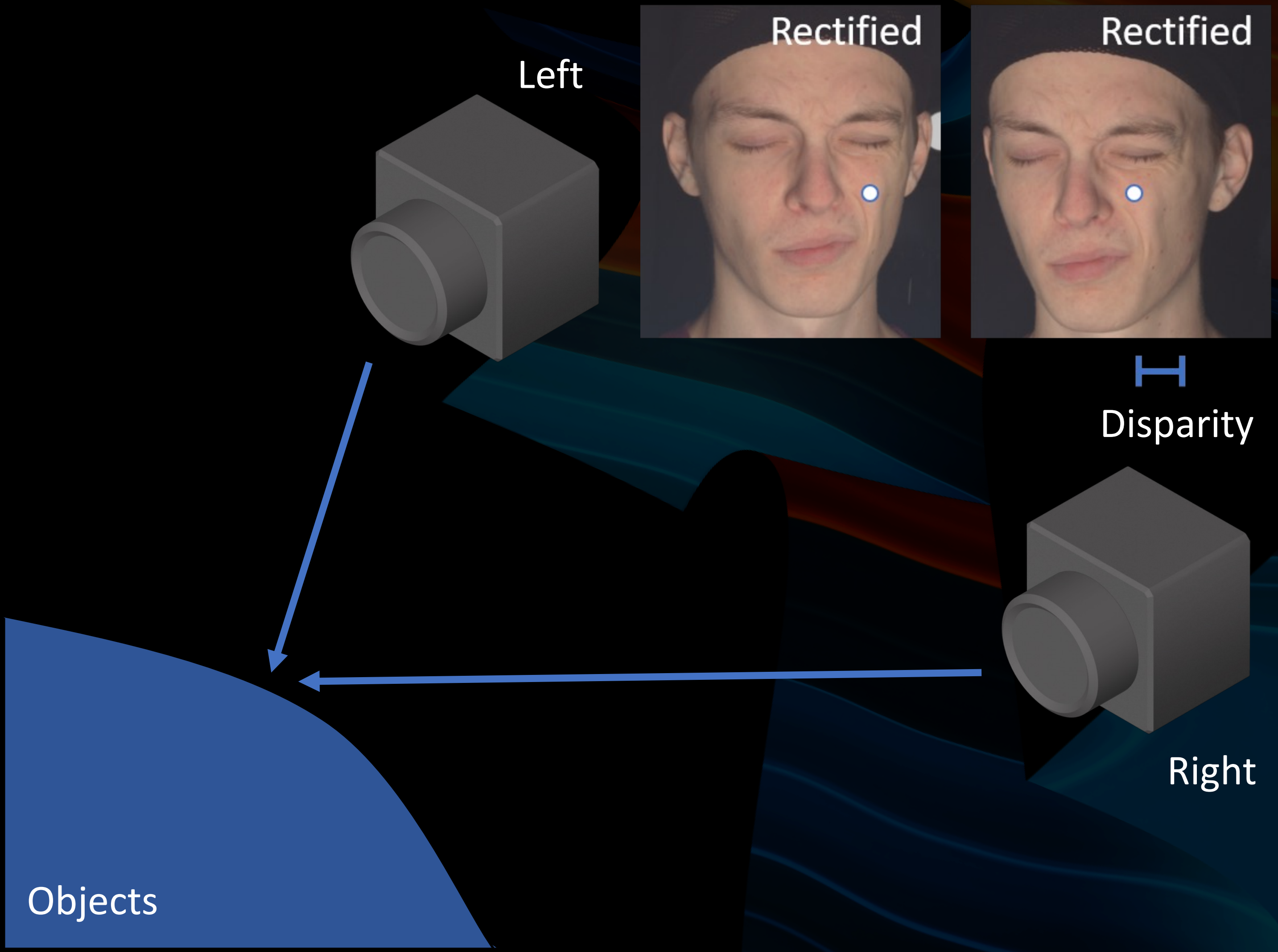


Hardware: Stereo Imaging

Geometric information

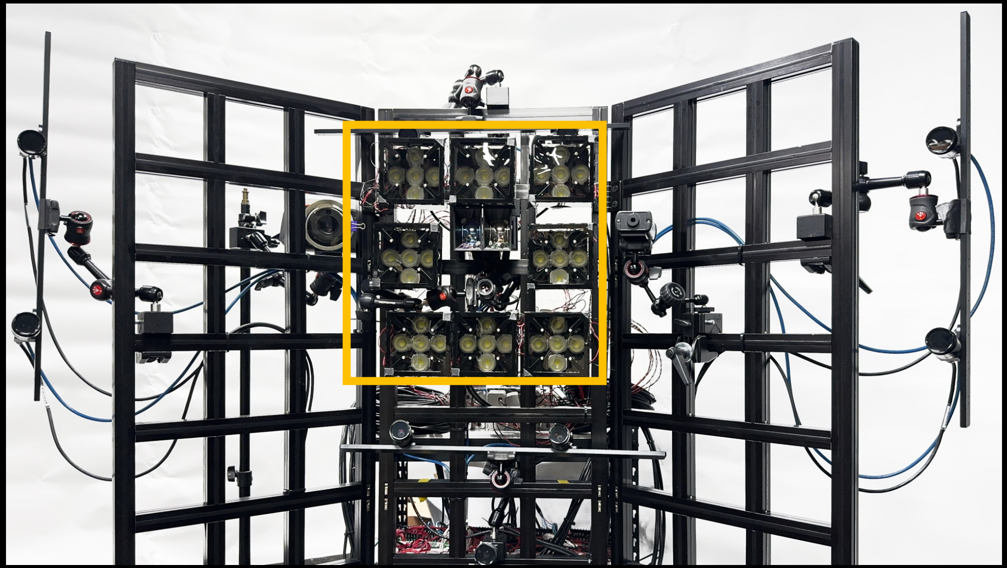


Two color machine vision cameras

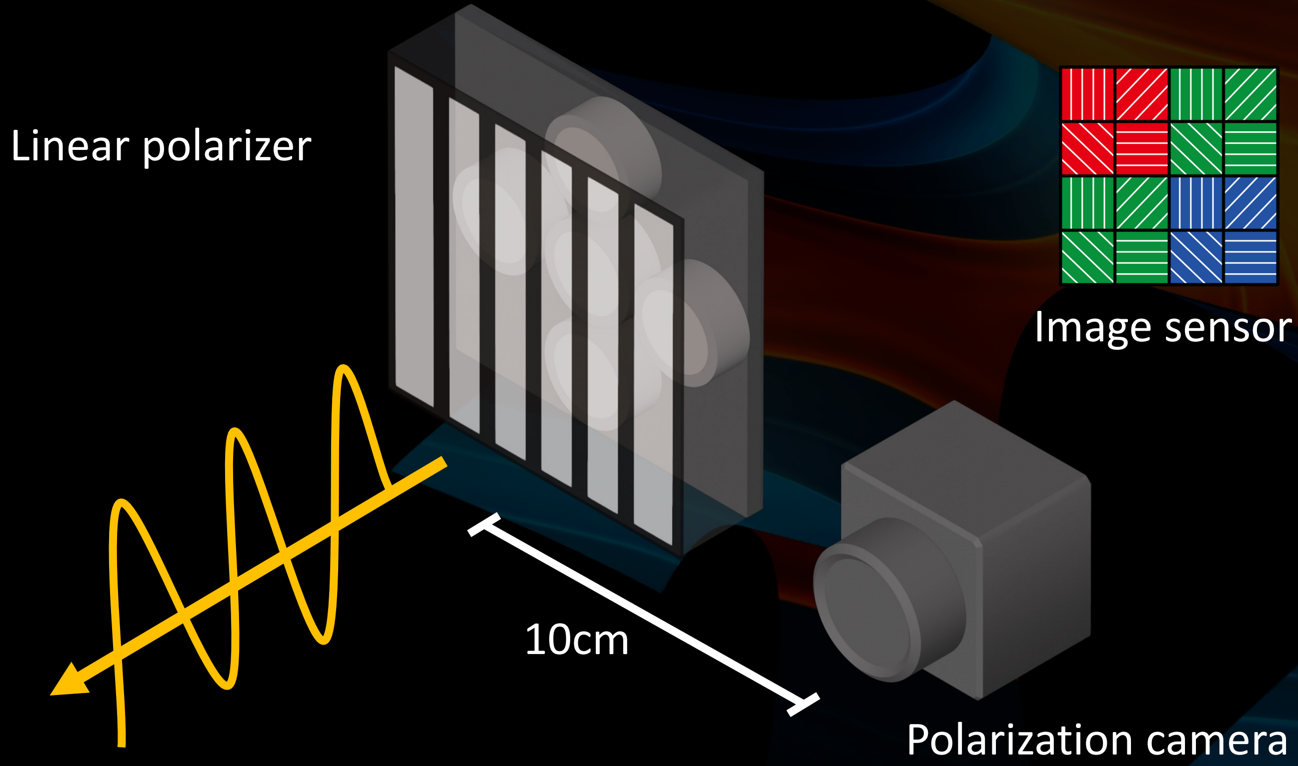


Hardware: Polarimetric Imaging

Polarimetric information



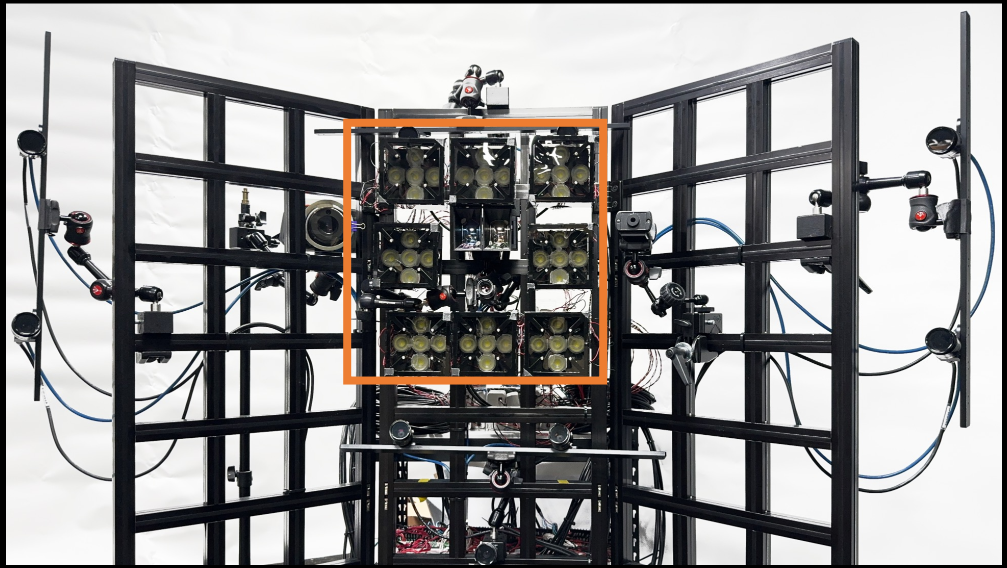
Polarization camera



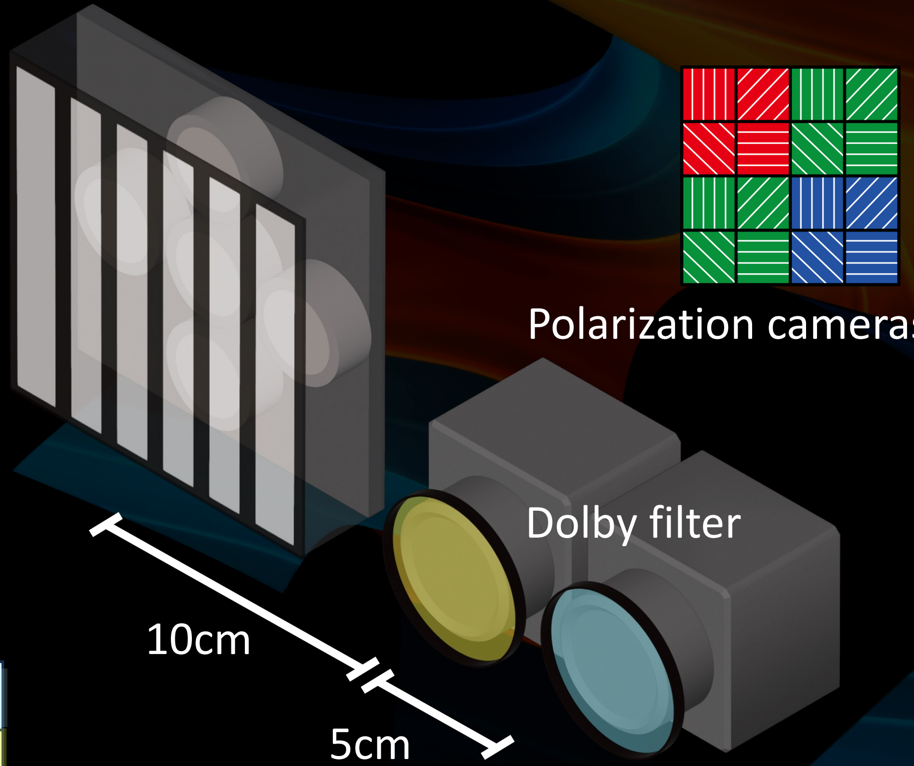
0° images | 90° images | 45° images | 135° images

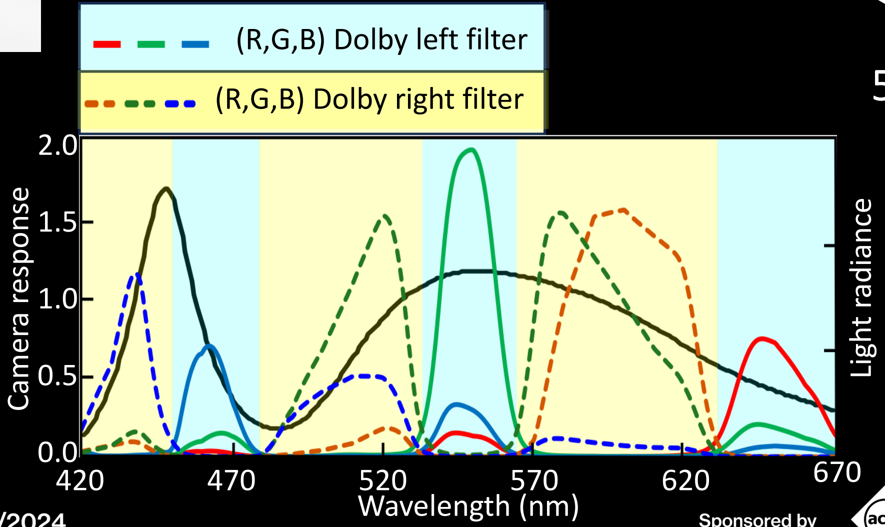
Hardware: Multispectral Imaging

Spectral reflectance information

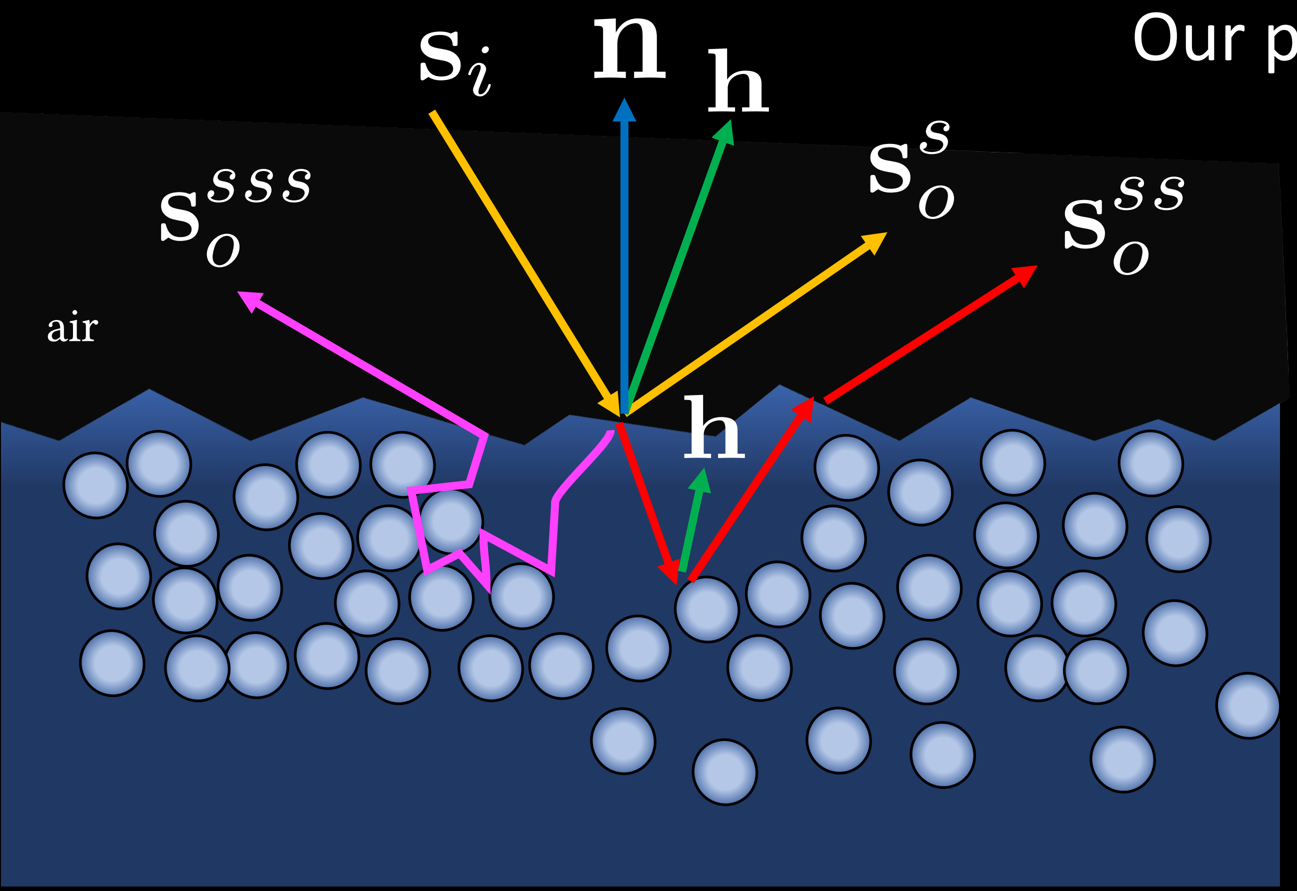


Dolby 3D glasses





Polarimetric Reflectance Model



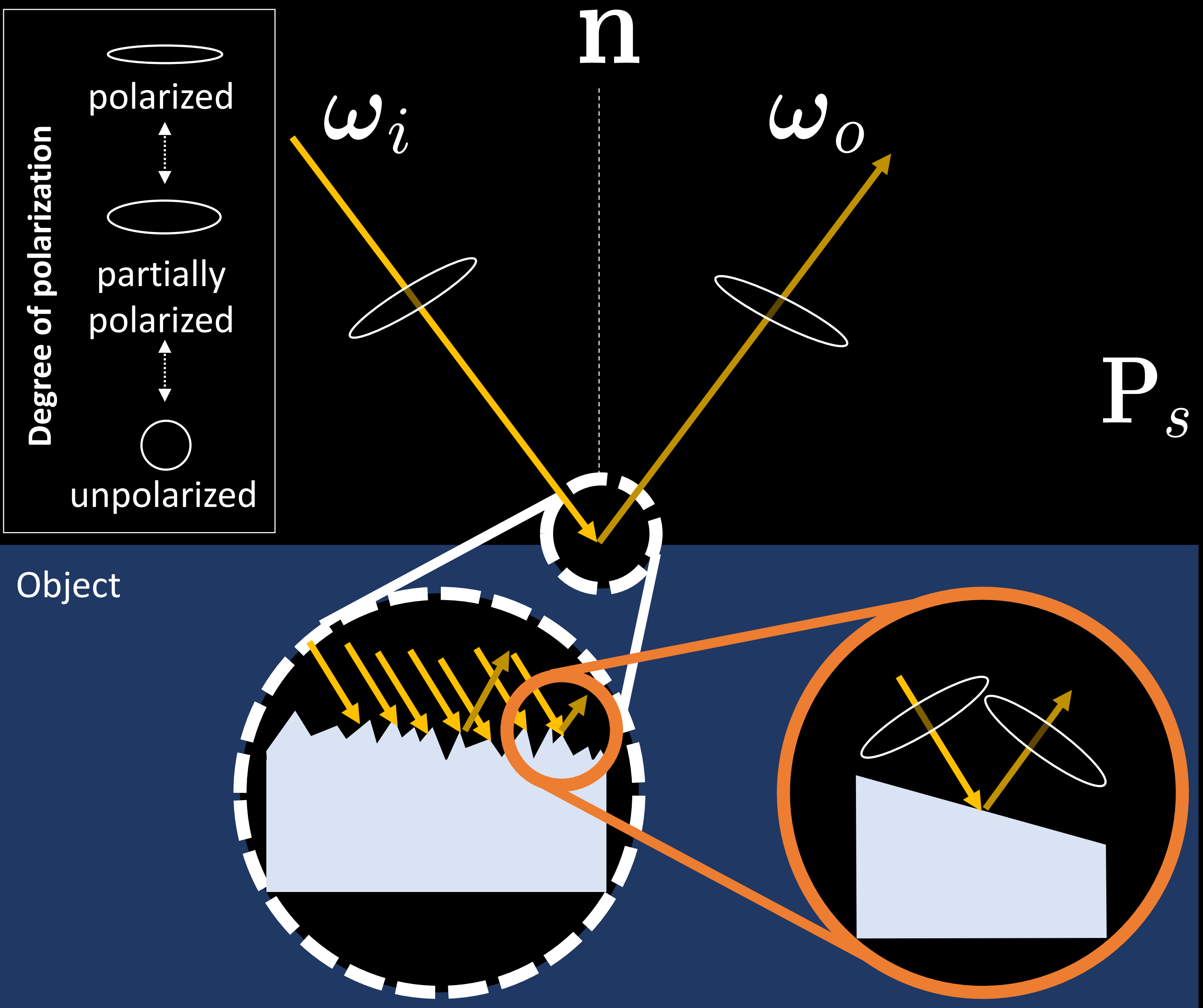
pBSSRDF: $\mathbf{s}_o = \mathbf{P}(\omega_i, \omega_o)\mathbf{s}_i$

Our pBSSRDF includes 3 types of reflection

- Specular
- Single scattering
- Subsurface scattering

$$\mathbf{P} = \mathbf{P}_s + \mathbf{P}_{ss} + \mathbf{P}_{sss}$$

Polarimetric BSSRDF: Specular



$$\mathbf{s}_o = \mathbf{P}(\omega_i, \omega_o)\mathbf{s}_i$$

Baek et al. 2018.

Coordinate conversion | Fresnel reflection | Coordinate conversion

$$\mathbf{P}_s = \kappa_s \mathbf{C}_{h\to o} \mathbf{F}^{\mathcal{R}}(\eta) \mathbf{C}_{i\to h}$$

Refractive index

Specular roughness

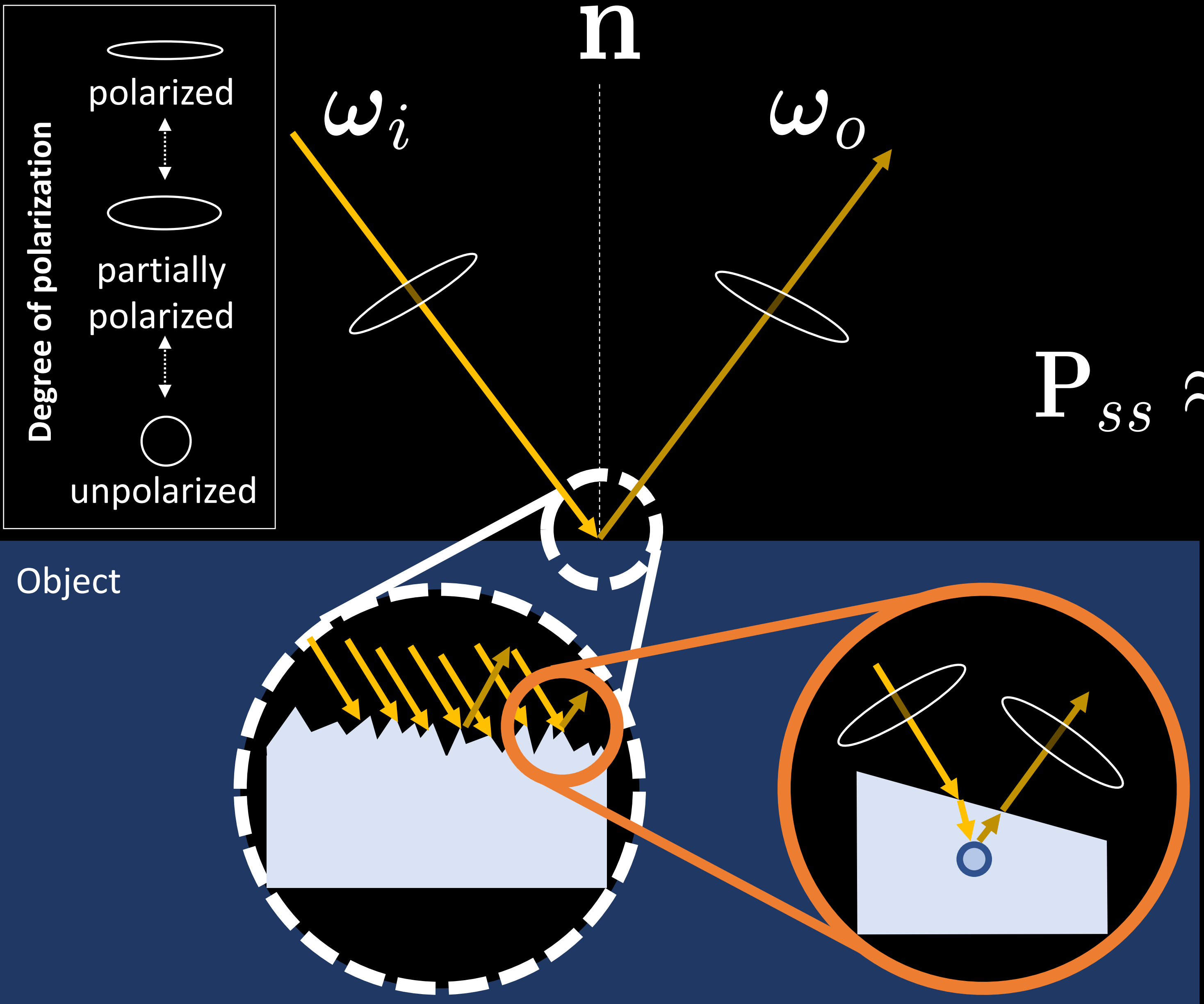
Normal distribution function | Geometric shading

$$\kappa_s = \rho_s \frac{\mathcal{D}(\alpha_s)\mathcal{G}(\alpha_s)}{4(\mathbf{n}\cdot\omega_i)(\mathbf{n}\cdot\omega_o)}$$

Specular intensity

Normal

Polarimetric BSSRDF: Single Scattering



$$\mathbf{s}_o = \mathbf{P}(\omega_i, \omega_o)\mathbf{s}_i$$

Hwang et al. 2022.

Coordinate conversion | Fresnel reflection | Coordinate conversion

$$\mathbf{P}_{ss} \approx \kappa_{ss} \mathbf{C}_{h\to o} \mathbf{F}^{\mathcal{R}}(\eta) \mathbf{C}_{i\to h}$$

Refractive index

Single scat. roughness

Normal distribution function | Geometric shading

$$\kappa_{ss} = \rho_{ss} \frac{\mathcal{D}(\alpha_{ss})\mathcal{G}(\alpha_{ss})}{4(\mathbf{n}\cdot\omega_i)(\mathbf{n}\cdot\omega_o)}$$

Single Scat. intensity | Normal

Polarimetric BSSRDF: Subsurface Scattering

$$\mathbf{s}_o = \mathbf{P}(\omega_i, \omega_o)\mathbf{s}_i$$

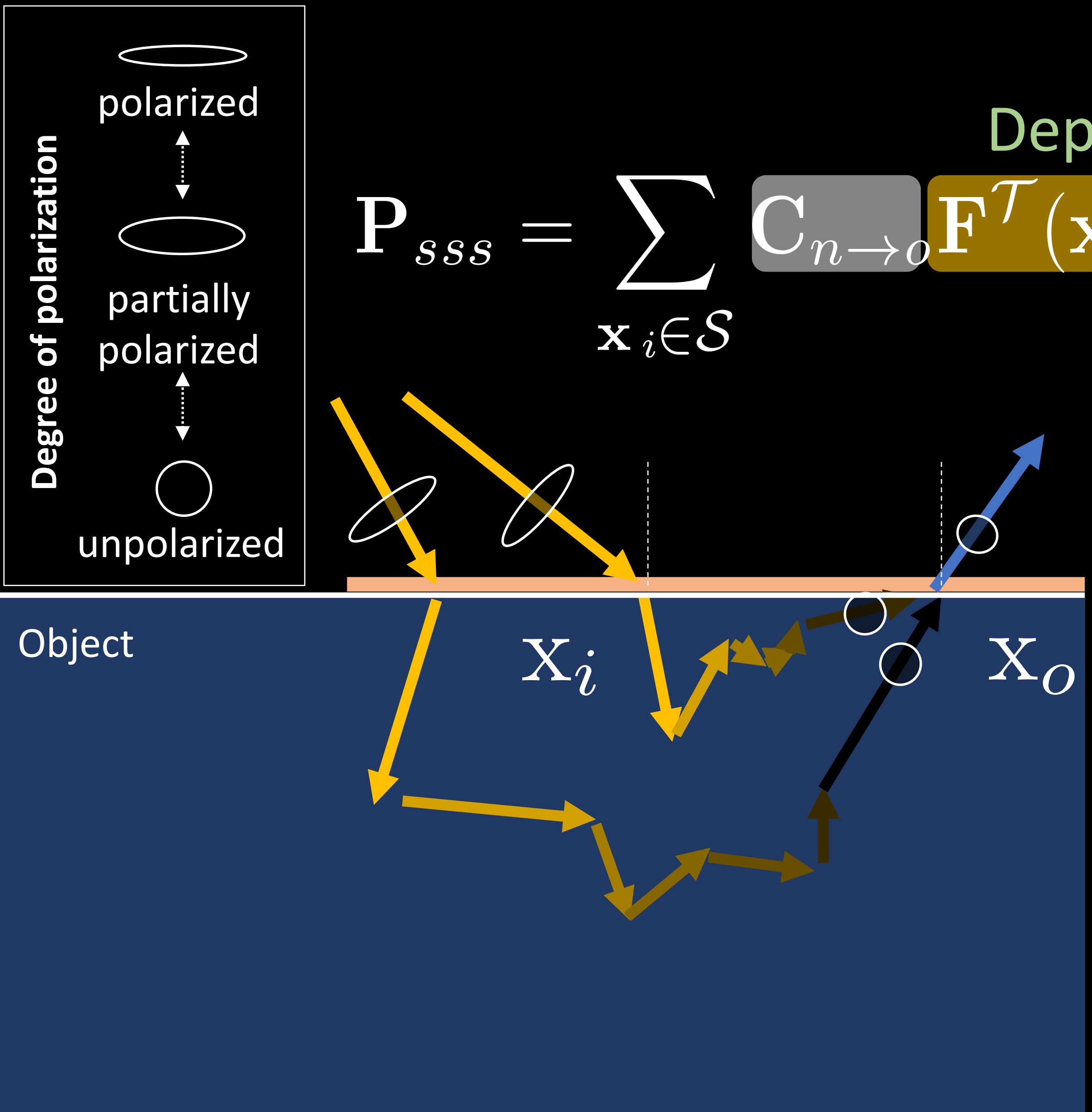
$$\mathbf{P}_{sss} = \sum_{\mathbf{x}_i \in \mathcal{S}} \mathbf{C}_{n\to o}\mathbf{F}^{\mathcal{T}}(\mathbf{x}_o)\mathbf{D}(\rho_{sss}(||\mathbf{x}_i - \mathbf{x}_o||)) \cdot \mathbf{F}^{\mathcal{T}}(\mathbf{x}_i)\mathbf{C}_{i\to n}$$

Depolarization

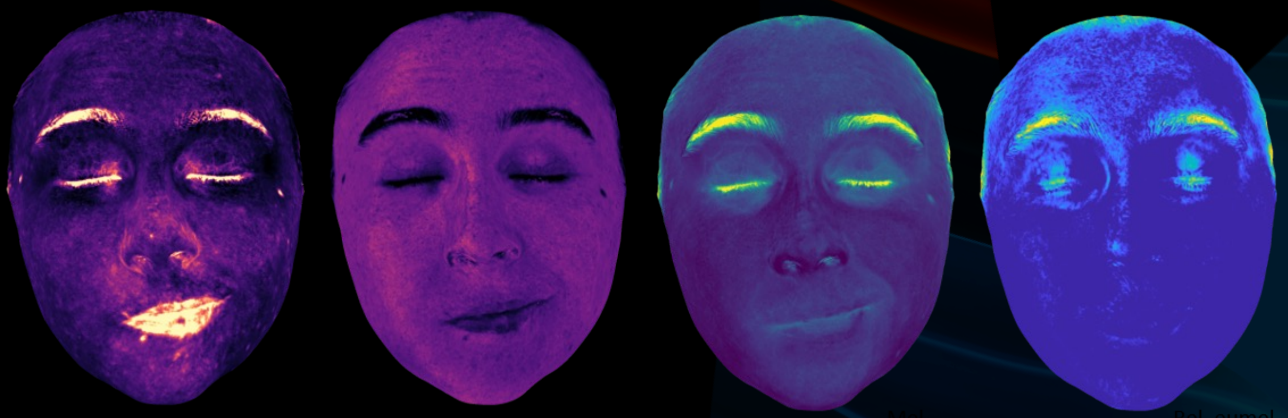
Fresnel transmittance

Subsurface scattering

Coordinate conversion



Biophysical Parameters

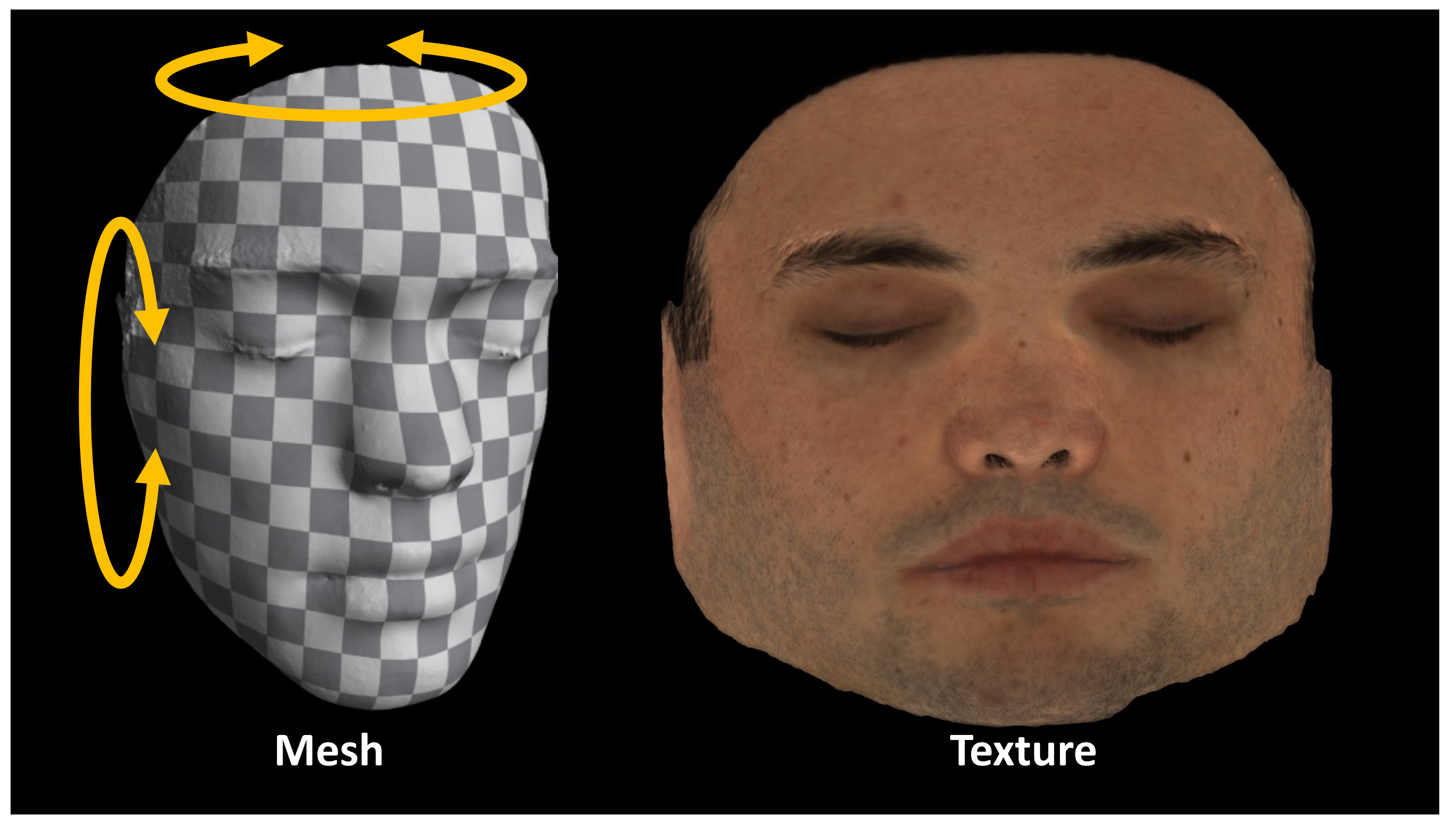


He. (outer)   He. (inner)   Melanin   Rel. eumel.

Optimization Strategy

Static stage

Initial mesh and texture



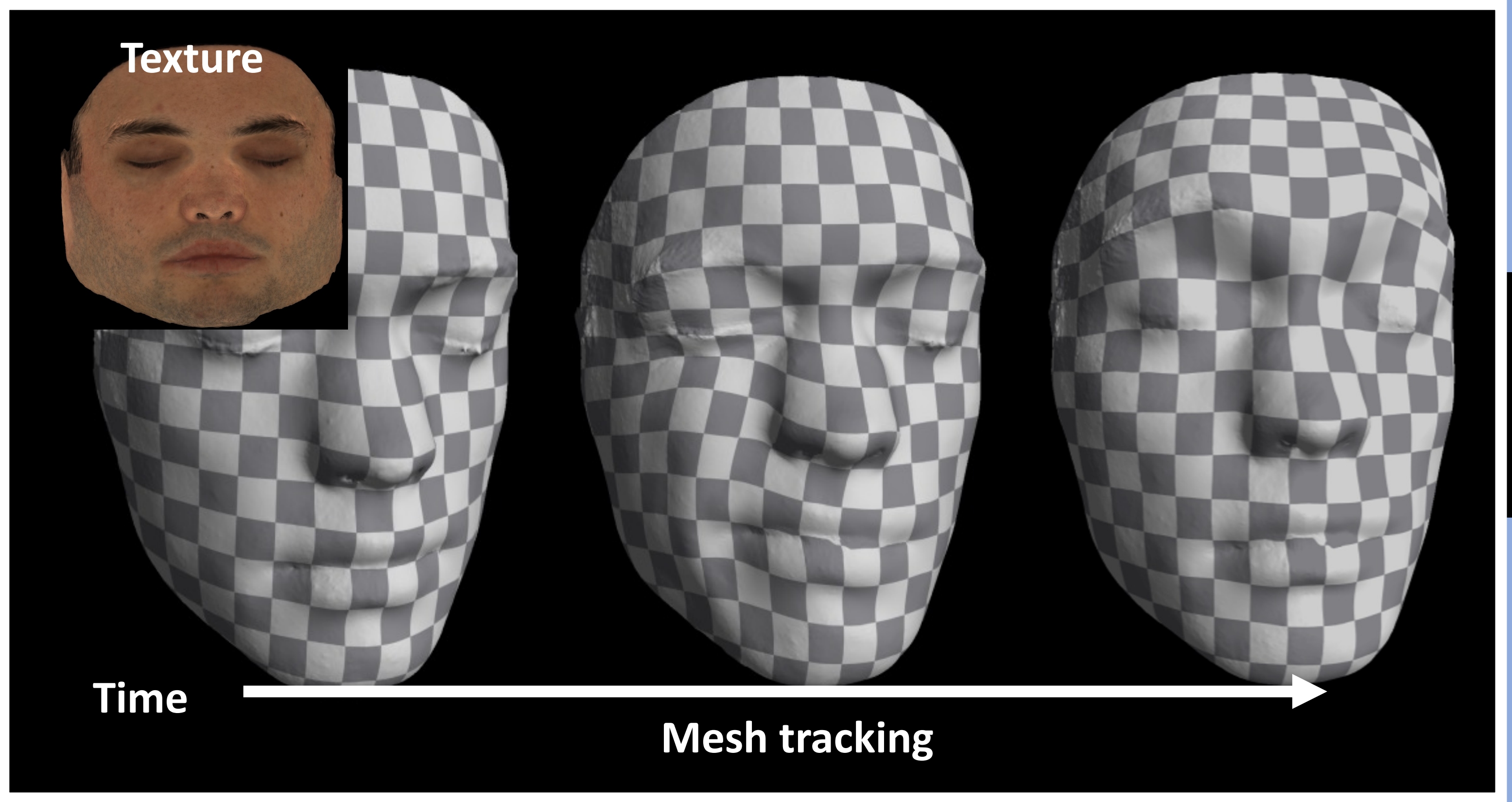
Optimization Strategy

Static stage

Initial mesh and texture

Dynamic stage per frame

Per-frame tracked mesh and texture



Optimization Strategy

Static stage

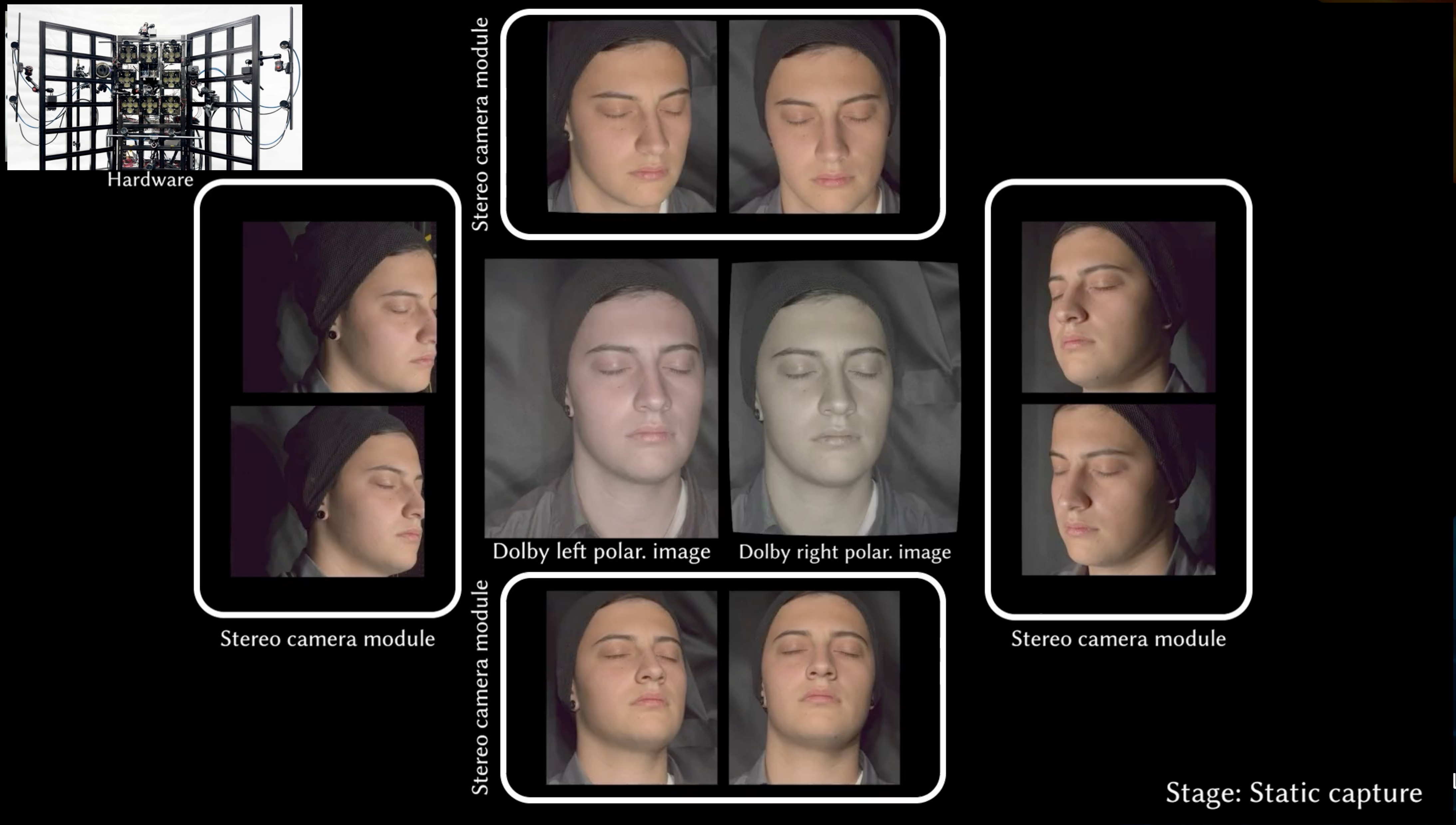
Initial mesh and texture → Polarimetric inverse rendering → Biophysical optimization

↓ Initial parameters

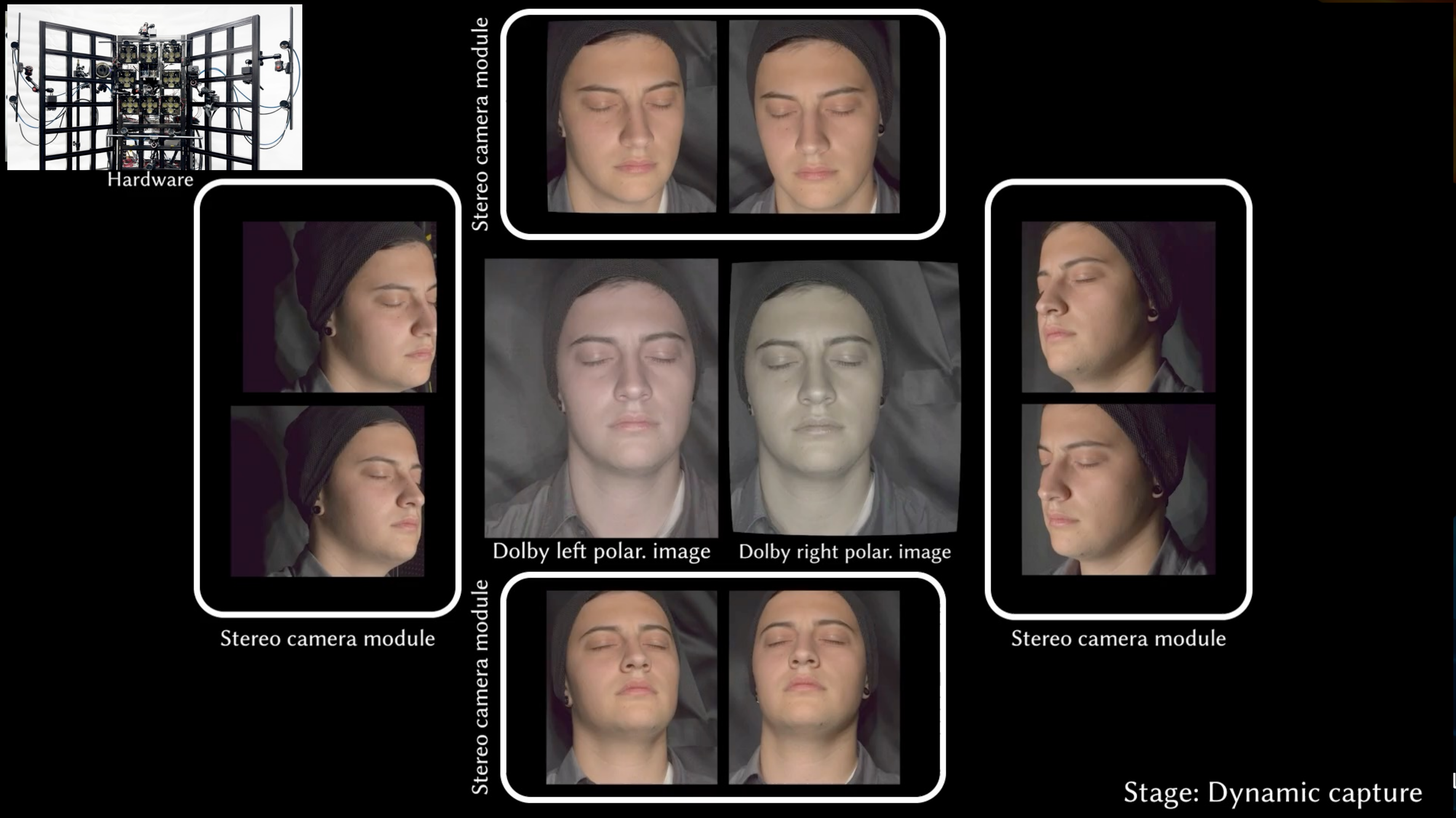
Dynamic stage per frame

Per frame tracked mesh and texture → Polarimetric inverse rendering → Biophysical optimization (loops back to per frame tracked mesh and texture)

Static Capture Stage



Dynamic Capture Stage



Optimization of Polarimetric BSSRDF and Normal

$$\min_{\eta, \alpha_s, \alpha_{ss}, \rho_s, \rho_{ss}, \bar{\rho}_{sss}, H} \lambda_\psi \mathcal{L}_\psi + \lambda_{sss} \mathcal{L}_{sss} + \lambda_s \mathcal{L}_s + \lambda_\phi \mathcal{L}_\phi + \mathcal{L}_{\text{reg}}$$

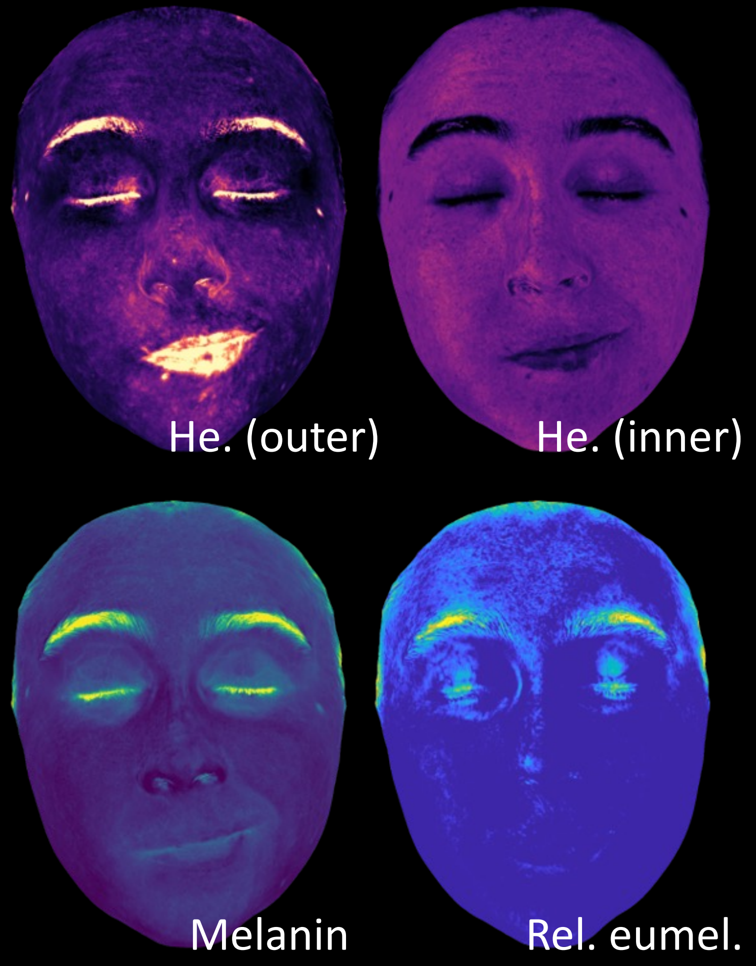
$\mathcal{L}_\psi$: refractive index loss

$\mathcal{L}_{sss}$: subsurface scattering loss

$\mathcal{L}_s$: specular and single scattering loss

$\mathcal{L}_\phi$: normal loss

Optimization of Biophysical Parameters



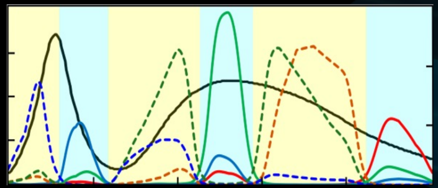
Parameter map

Rendering each wavelength (420nm ~ 670nm)

Optimization of Biophysical Parameters

Gradient descent

Camera response



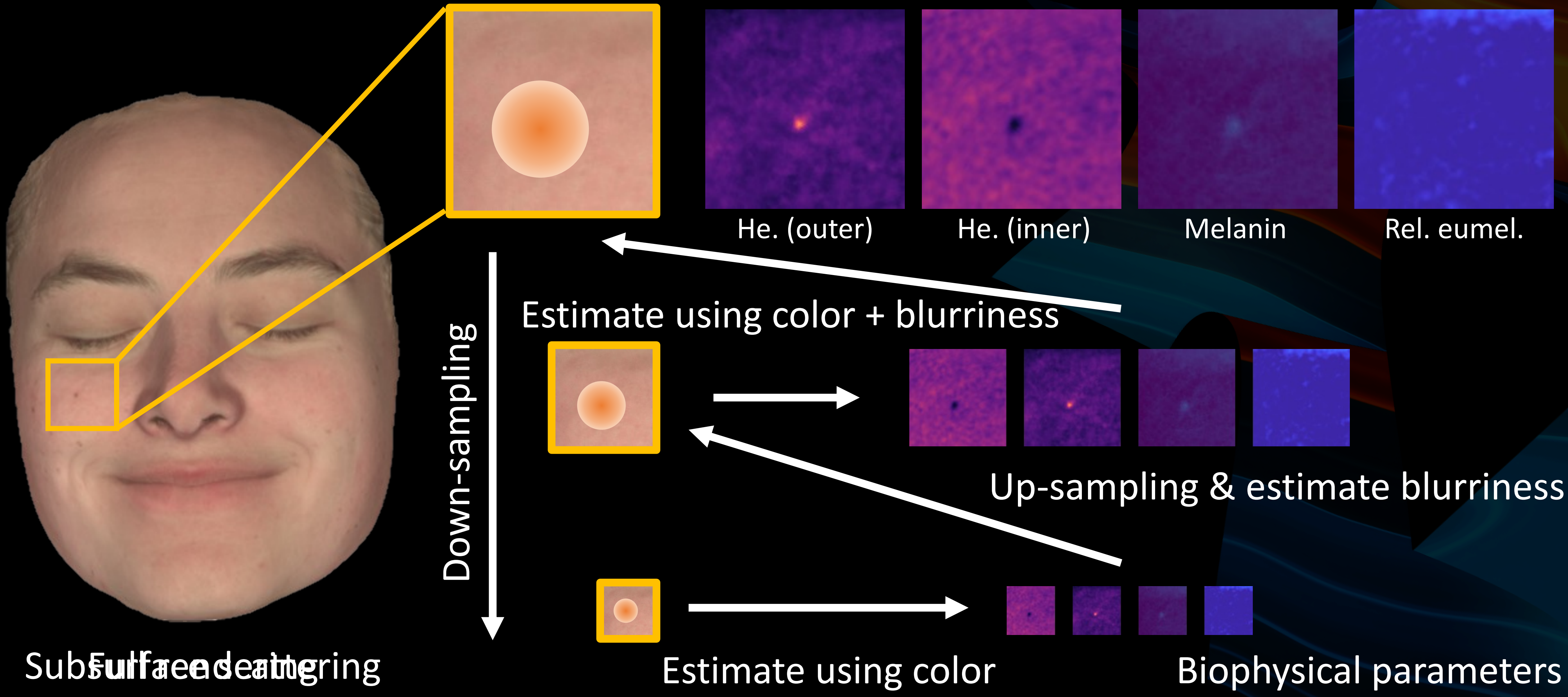
Dolby left

Dolby right

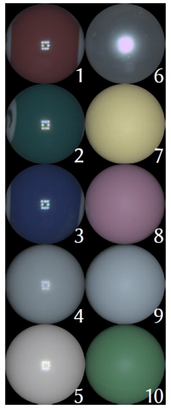
Rendering each wavelength (420nm ~ 670nm)

Target cameras

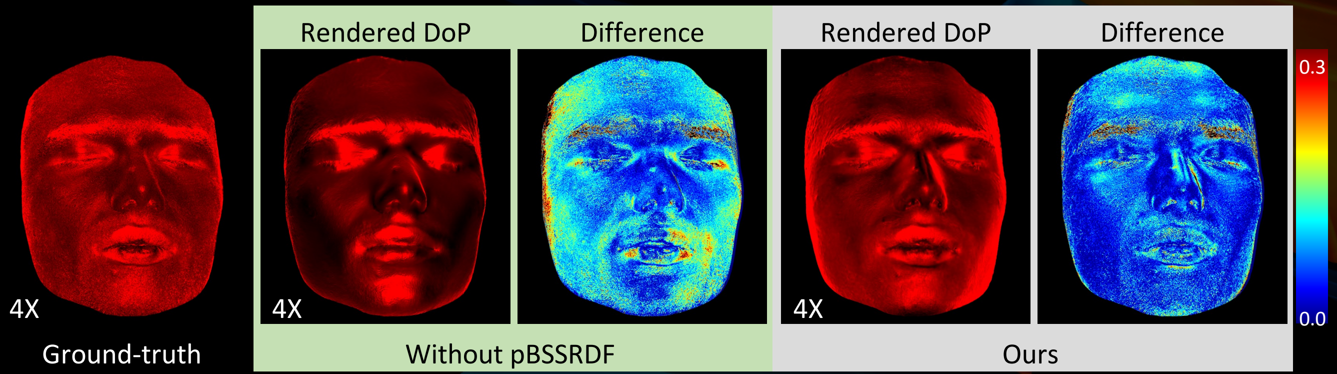
Hierarchical Optimization of Biophysical Parameters

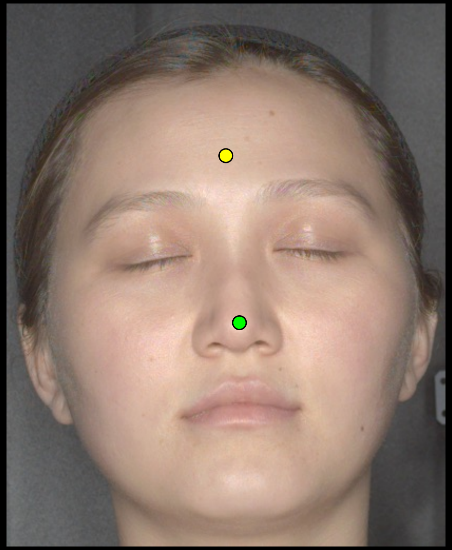


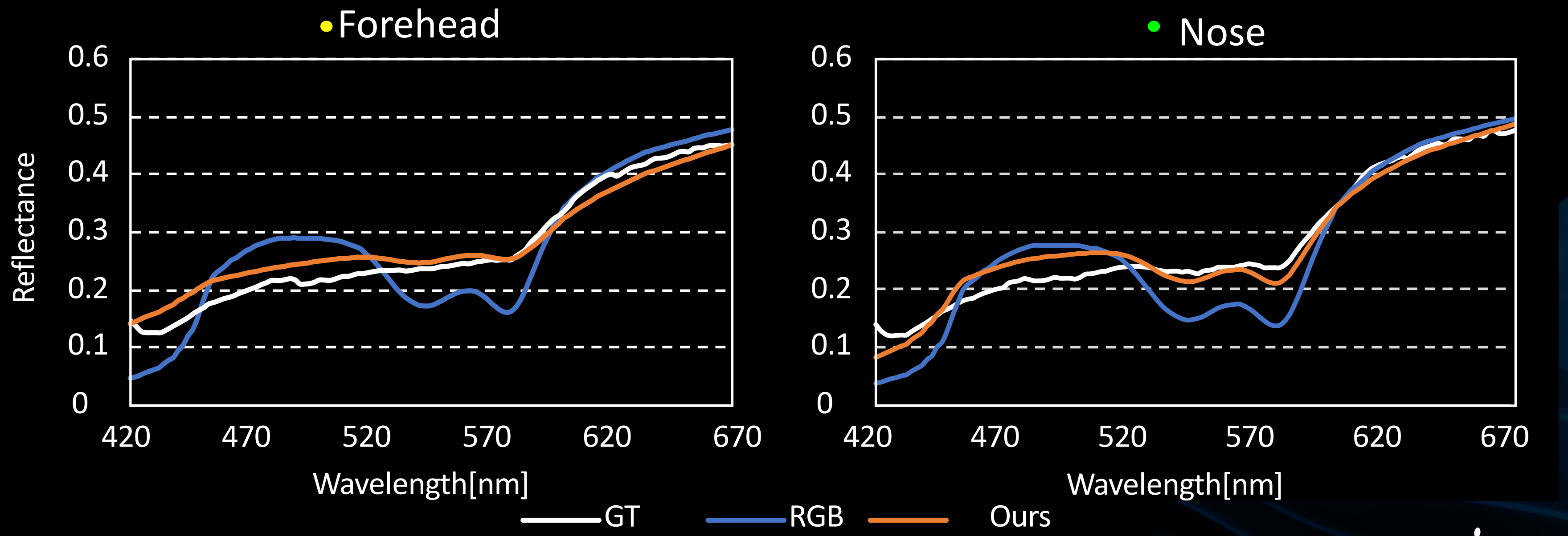
Validation



Object	Material	η_{gt}	η_{ours}	Diff.
1	Red billiard	1.485	1.446	0.038
2	Green billiard	1.469	1.516	0.047
3	Blue billiard	1.504	1.503	0.001
4	White billiard	1.463	1.410	0.053
5	POM	1.462	1.447	0.015
6	Fake pearl	2.295	2.263	0.032
7	Yellow silicone	1.303	1.297	0.005
8	Pink silicone	1.177	1.211	0.034
9	White silicone	1.248	1.272	0.024
10	Light green silicone	1.343	1.311	0.032





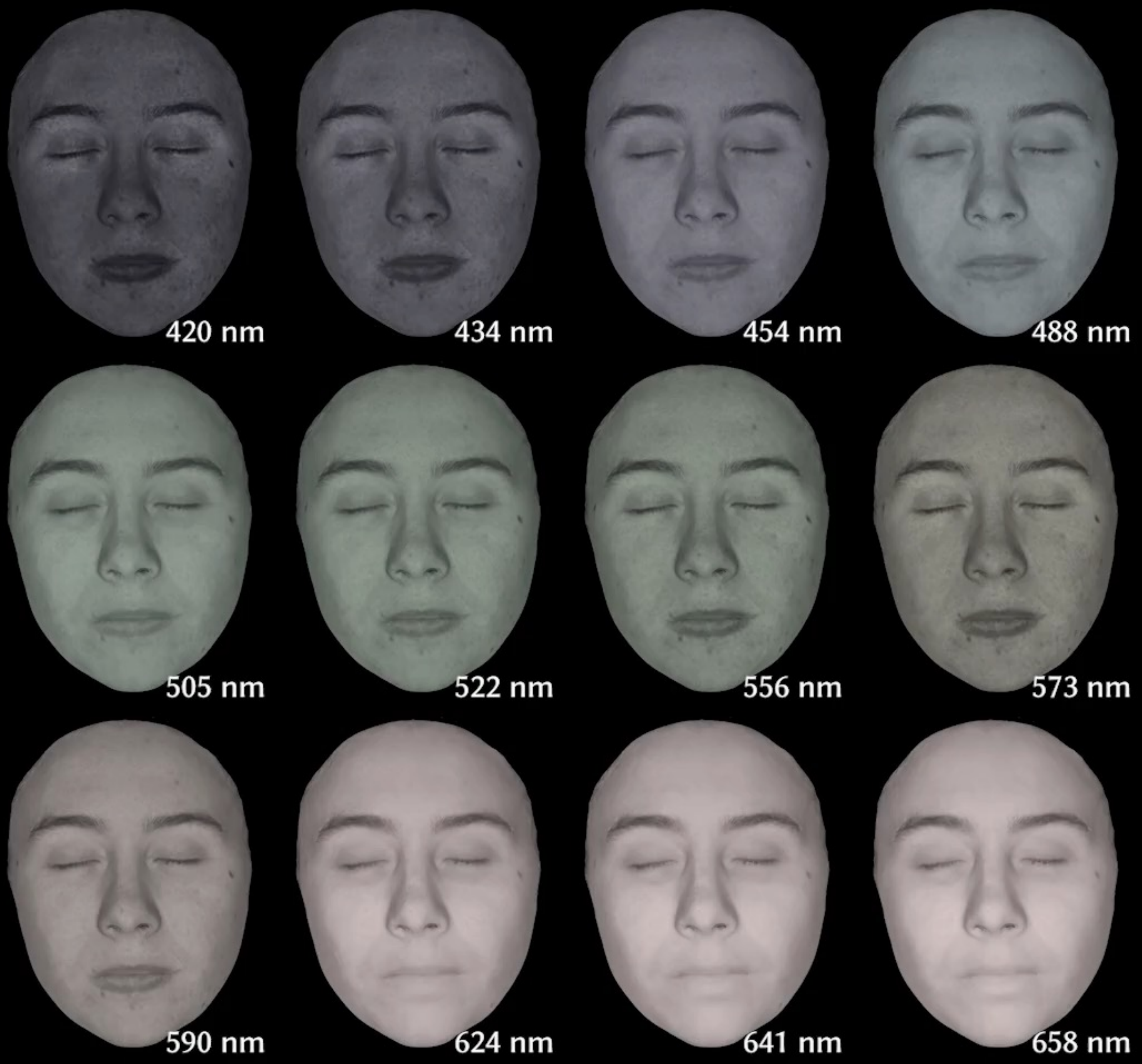


Rotating a linear polarization filter on the camera

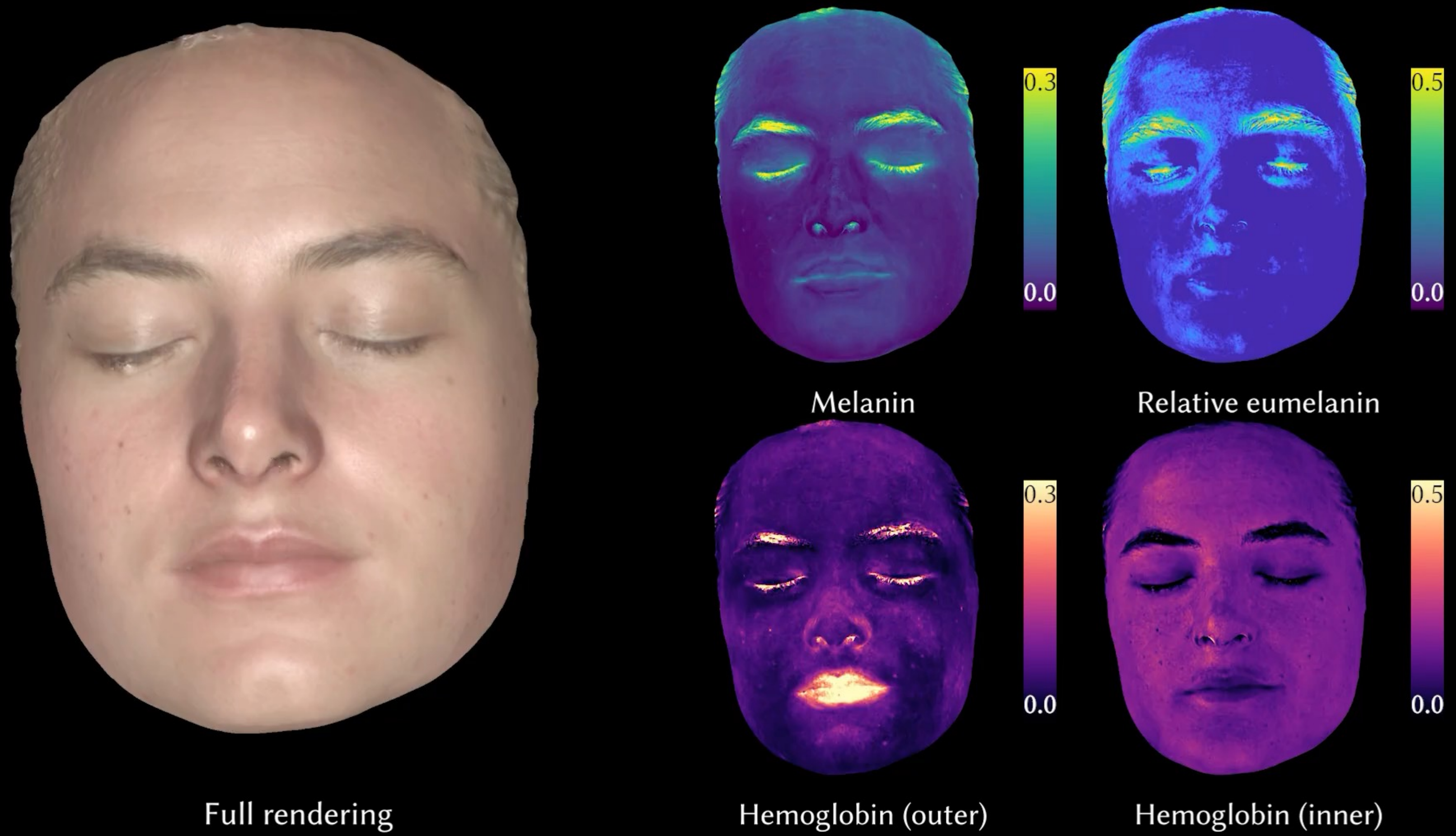
Rotating a linear polarization filter on the light

Polarization rendering

Full rendering



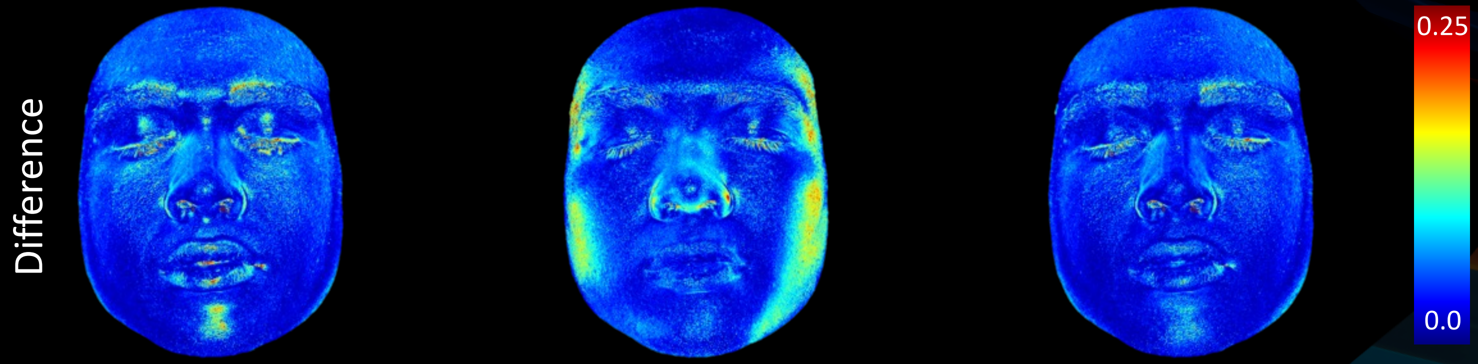
Multispectral two-layer subsurface scattering


0.3
0.0
Melanin
0.5
0.0
Relative eumelanin
0.3
0.0
Hemoglobin (outer)
0.5
0.0
Hemoglobin (inner)
Full rendering

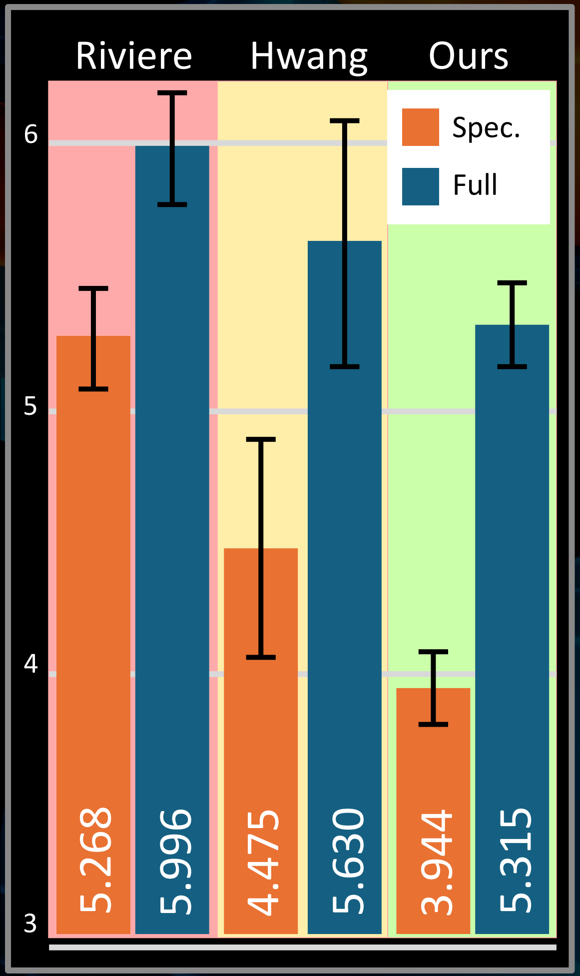
Pressing forehead

Comparison

Photograph

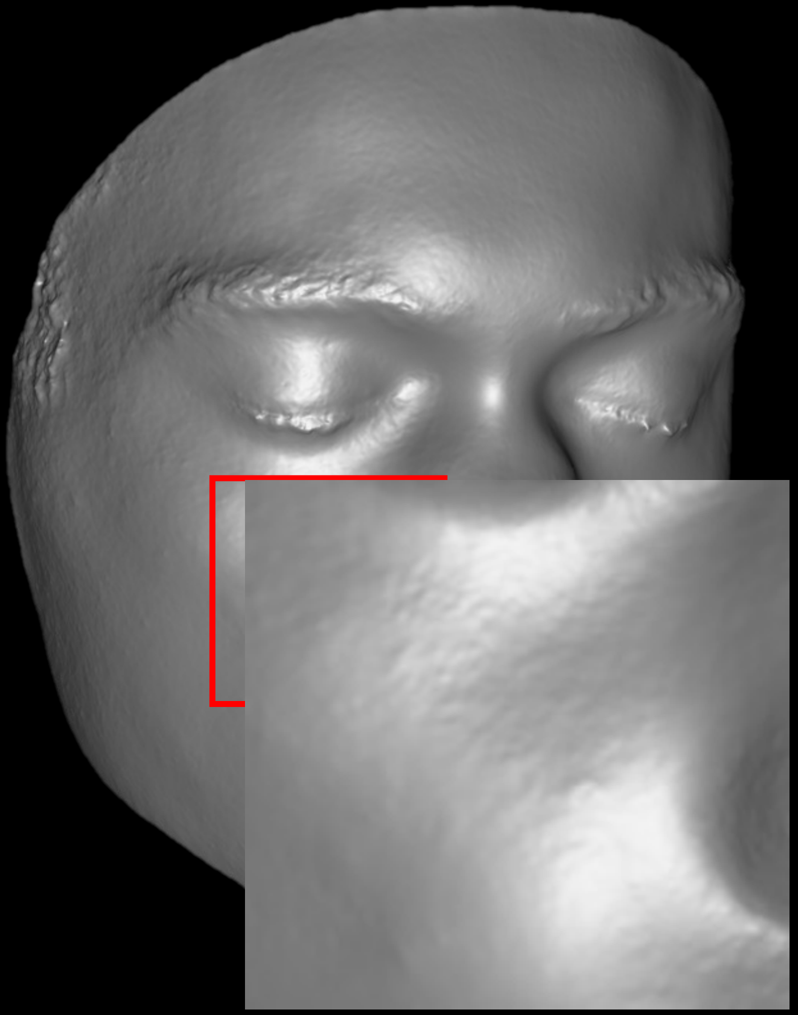


Full rendering (Riviere et al. [2020]) Full rendering (Hwang et al. [2022]) Full rendering (ours)

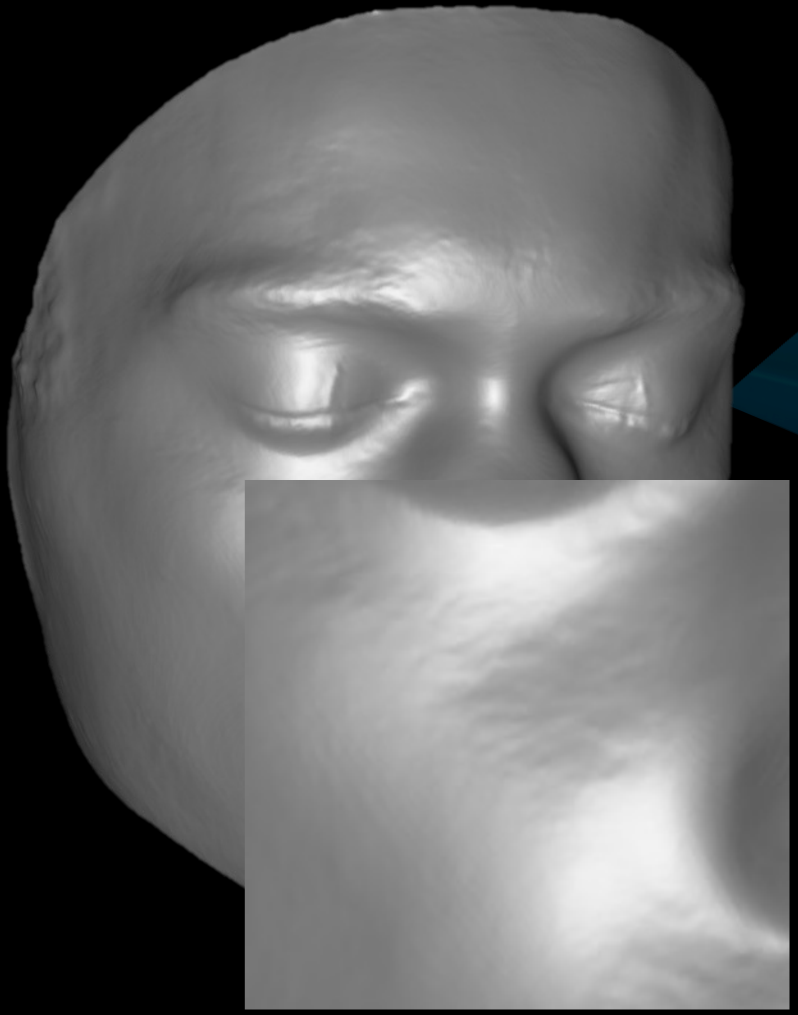


11 participants RMSE ($X10^{-2}$)

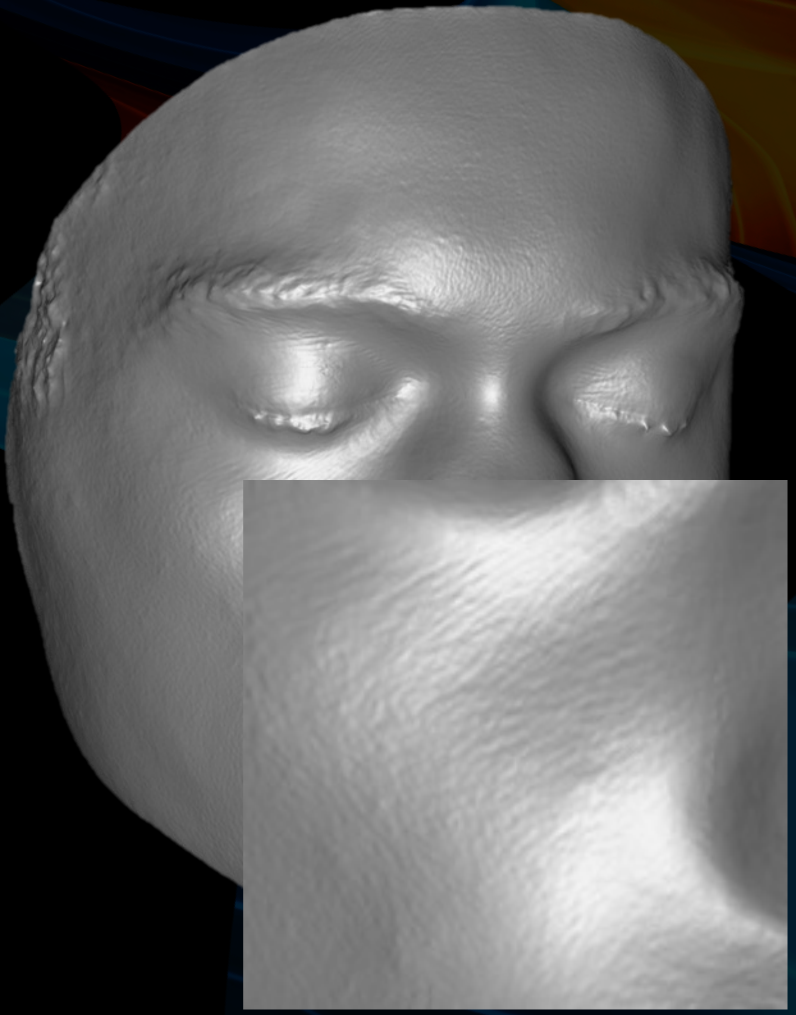
Geometry Comparison



Stereo matching (Beeler et al. 2010)

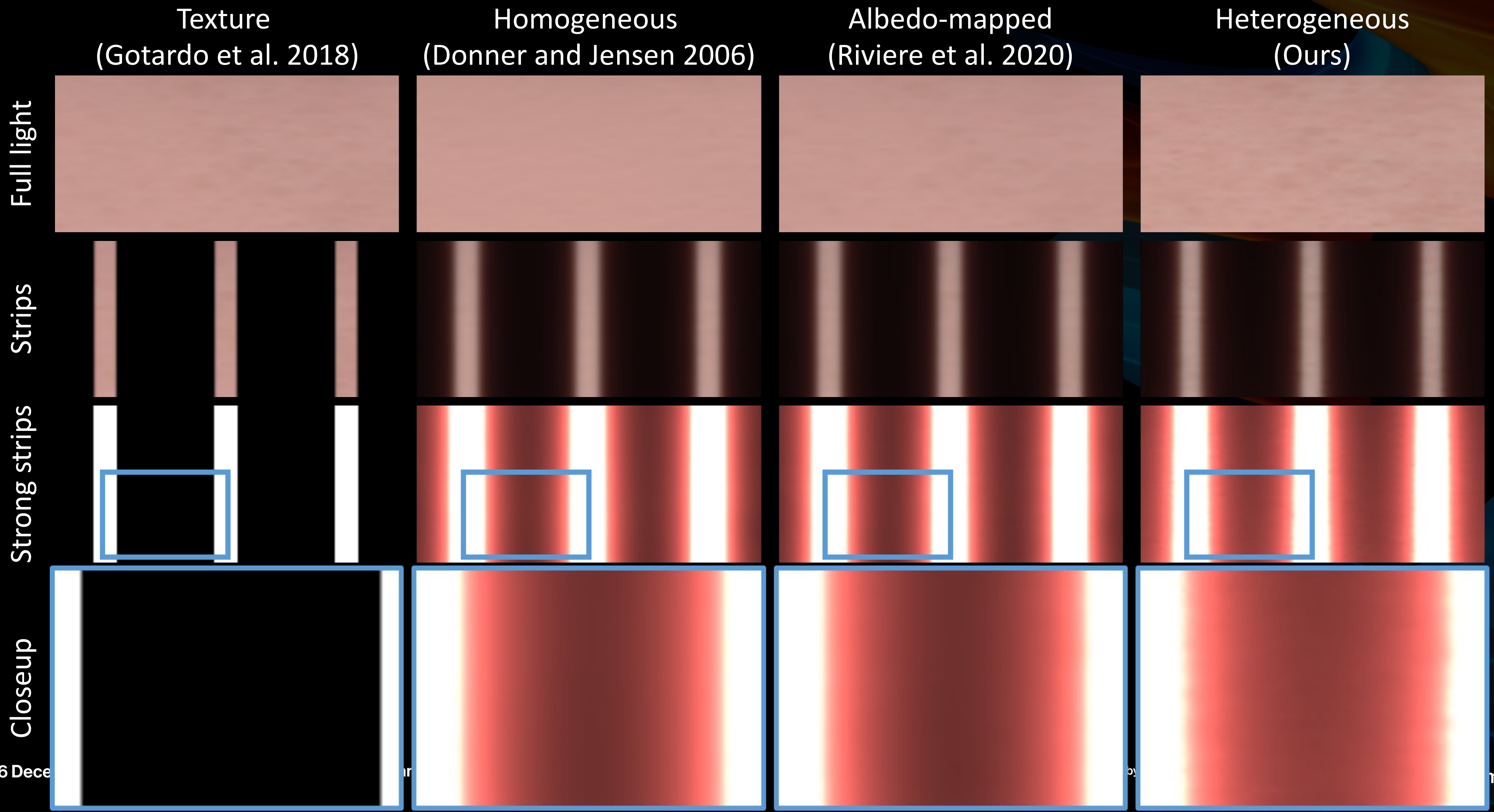


Hwang et al. 2022



Ours

Heterogeneous Multi-layered Translucent Materials



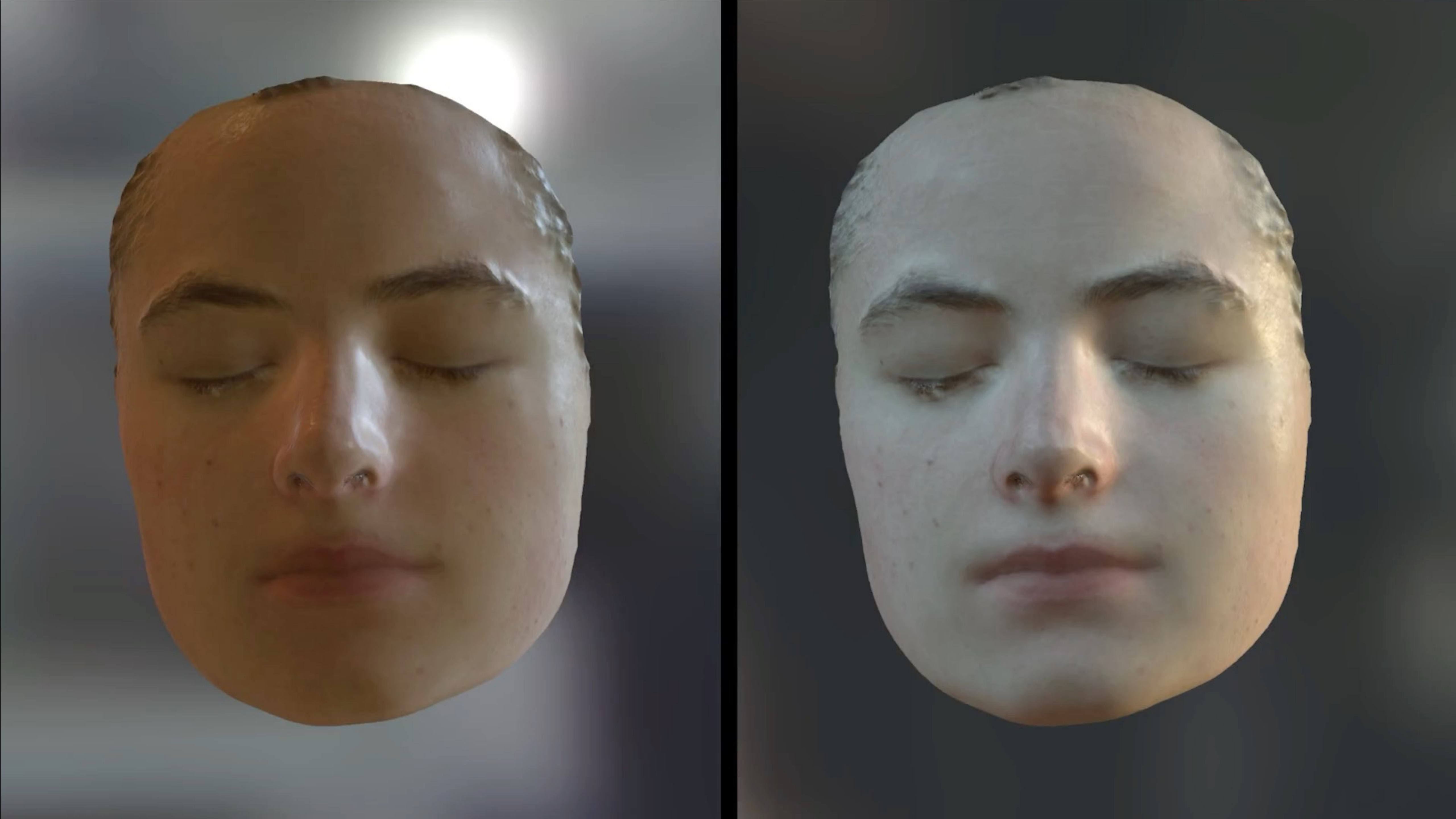
Editing Face Parameters

Photograph

Rendering

Increase outer hemoglobin

Increase melanin



Limitations and Future work

Restrict by the two-layer skin model

- Future research could be on eyes and ears
- Darker skin cannot be estimated properly

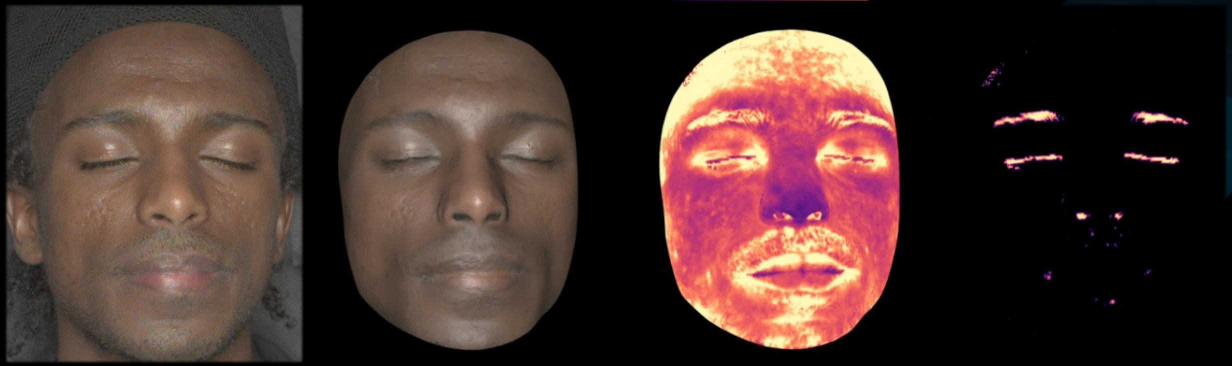


Photo. Render He. (outer) He. (inner)

Quality restricted by hardware

- Low resolution and SNR compared to RGB
- Near-coaxial setup of camera and light

SIGGRAPH ASIA 2024 TOKYO 東京

Interactive discussion at Table 8

Project Website

https://vclab.kaist.ac.kr/siggraphasia2024

Thank you

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