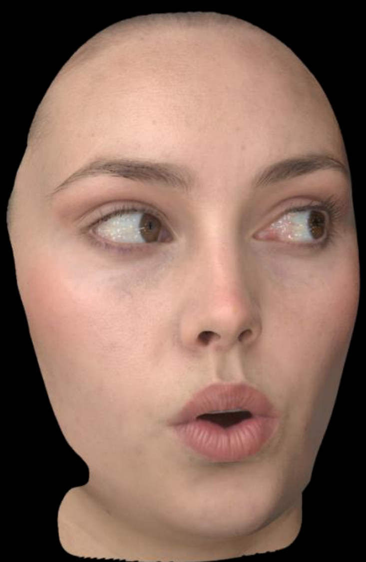
BMVC 2016 Tutorial:
Measurement Based Appearance Modelling





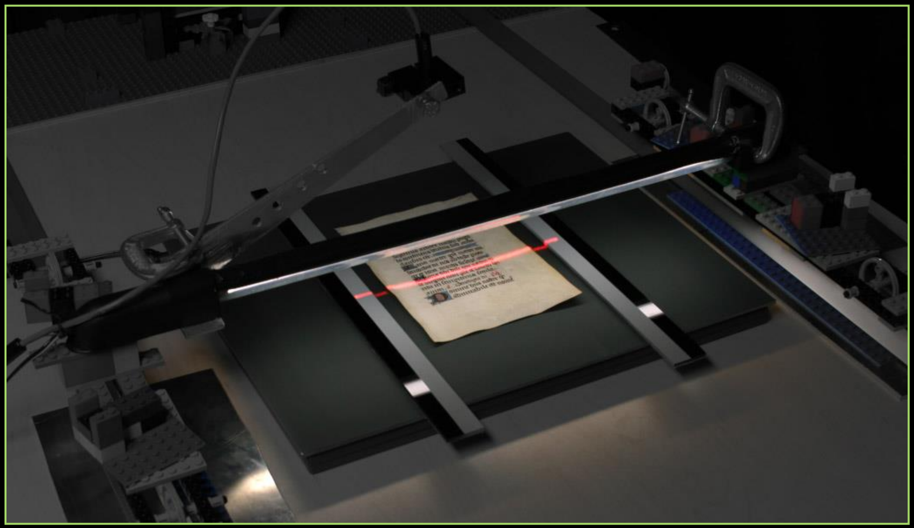


Abhijeet Ghosh

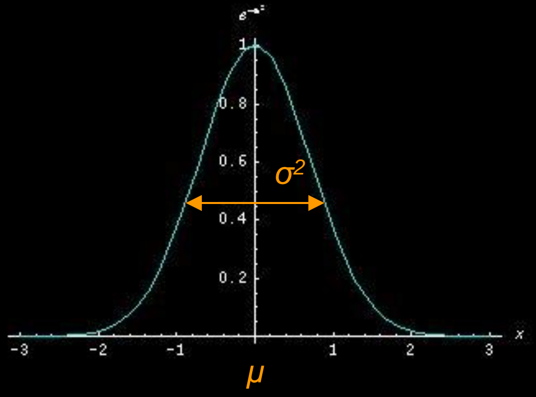
Imperial College London

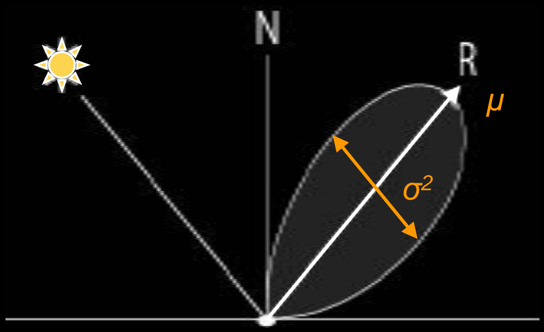
Material reflectance capture techniques

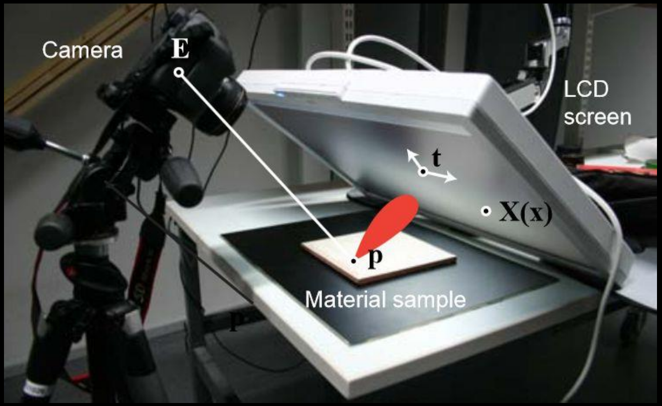
BRDF



SVBRDF





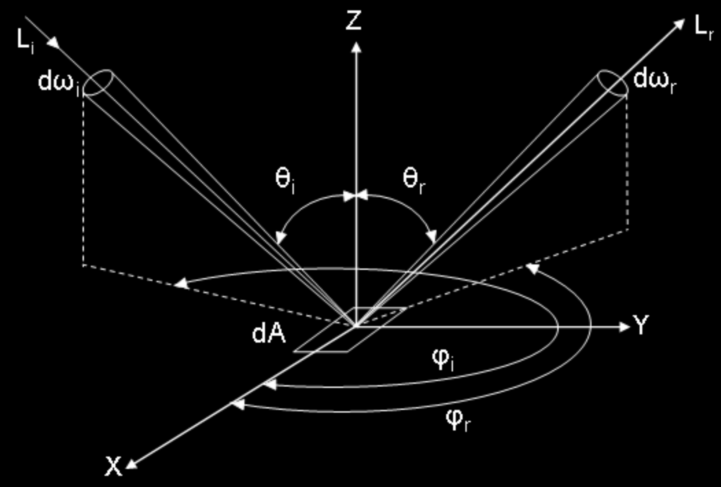


Surface appearance

- Bidirectional Reflectance Distribution Function (BRDF)
  - 4D general case, 3D isotropic
  - Surface reflection at one surface point

- Spatially Varying BRDF (SVBRDF)
  - 6D, BRDF per surface point
- Bidirectional Texture Function (BTF)
  - 6D, more general includes inter-reflection & scattering
  - Data-driven representation of reflectance functions

BRDF



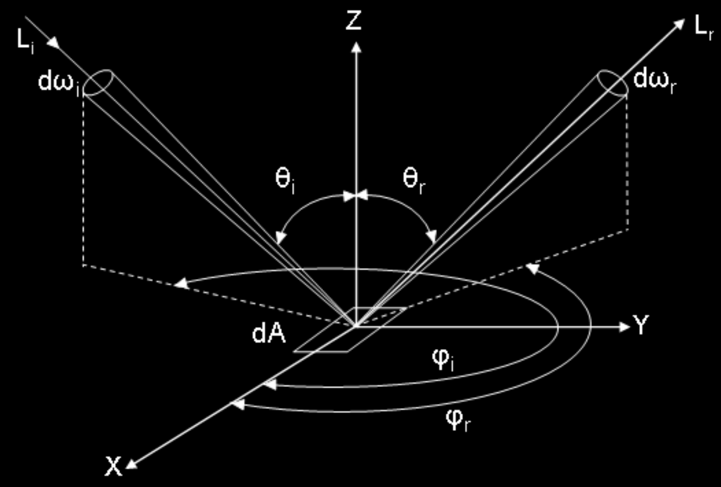
- Defined as the ratio of reflected radiance to incident irradiance:

$$f_r(x, \omega_r, \omega_i) = dL_r(x, \omega_r)/dE_i(x, \omega_i)$$

$$= dL_r(x, \omega_r)/(L_i(x, \omega_i)\cos\theta\, d\omega_i).$$

  – the units of a BRDF are inverse steradian [1/sr].

BRDF



- Physically based BRDFs have 2 important properties:

Helmholtz Reciprocity: $f_r\,(x, \omega_r, \omega_i) = f_r\,(x, \omega_i, \omega_r)$.

and

Energy Conservation: $\int_\Omega f_r\,(x, \omega_r, \omega_i) \cos\theta_i \, d\omega_i \leq 1$, for all ω_r in Ω.

Reflection Models

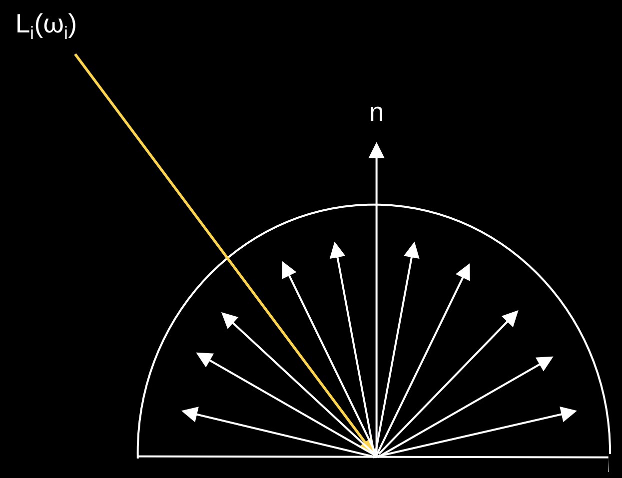
- Mathematical representation a class of BRDFs
  - typically with a small number of parameters
- Types of BRDF models
  - Phenomenological
  - Physically based
- Parameter fitting
  - Measured data

Phenomenological Models

- Equations that describe the "qualitative behavior" of surfaces
  - matte, glossy or plastic, roughness

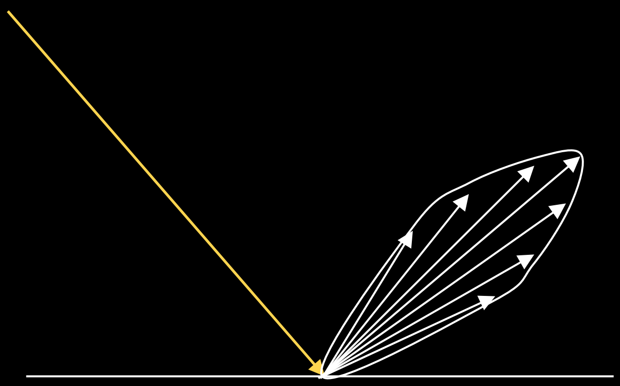
- Examples
  - Lambertian diffuse reflection
  - Phong specular reflection [Phong75]

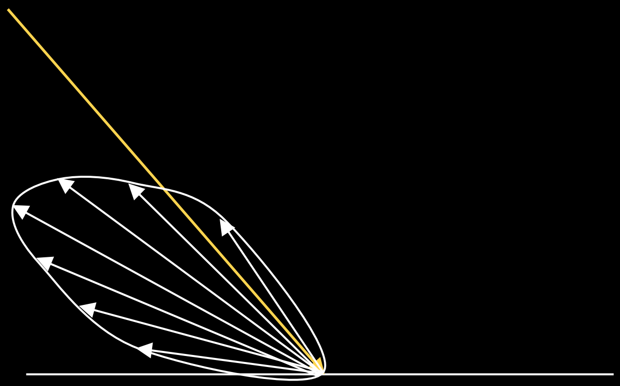
Lambertian Reflection



- $f_r(\omega_r, \omega_i) = \rho_d / \pi$
  - ρ_d is the diffuse reflection coefficient [0,1]
  - $\pi = \int_\Omega \cos\theta \, d\omega$, is the normalization constant!
  - Well suited for measurements

Glossy and Retro-reflective

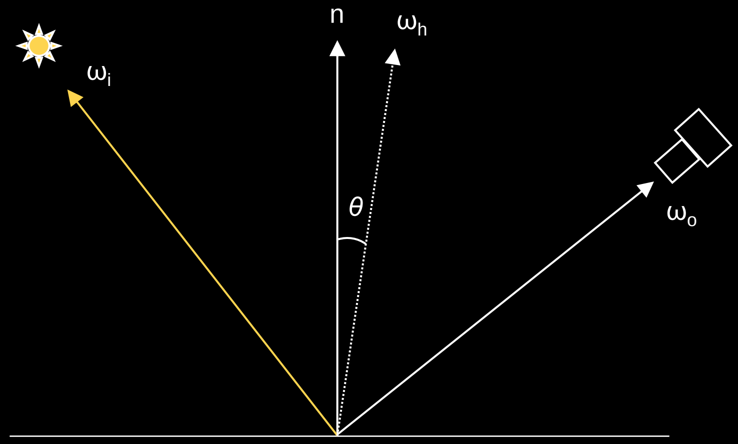


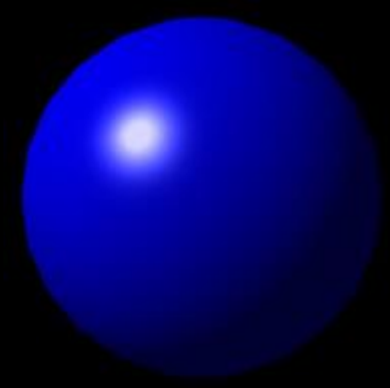


- Glossy surfaces – plastic, high gloss paints, polished wood
- Retro-reflective – velvet, moon’s surface, road signs, bike reflectors

Blinn-Phong Model

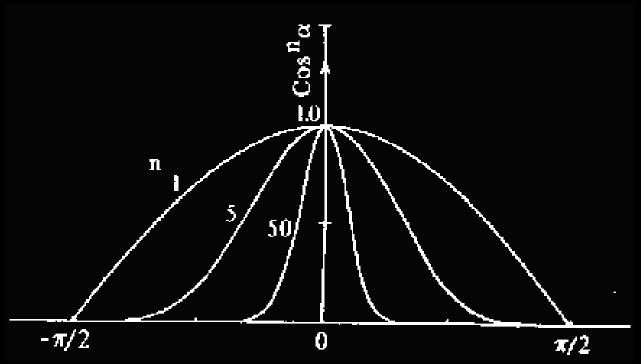
$$\omega_h = (\omega_i + \omega_o) / \|\omega_i + \omega_o\|$$



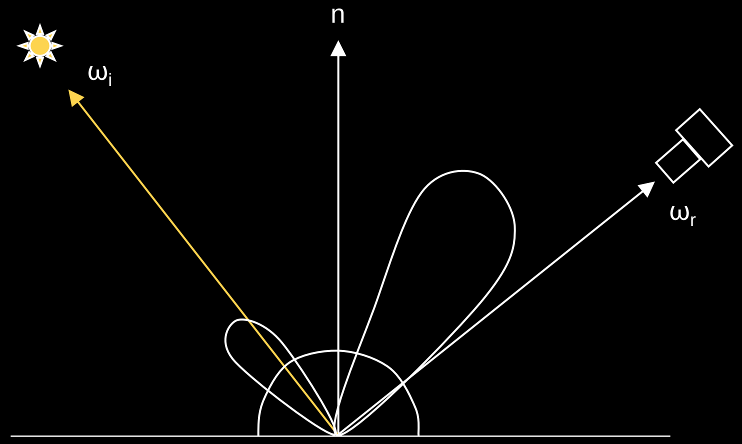


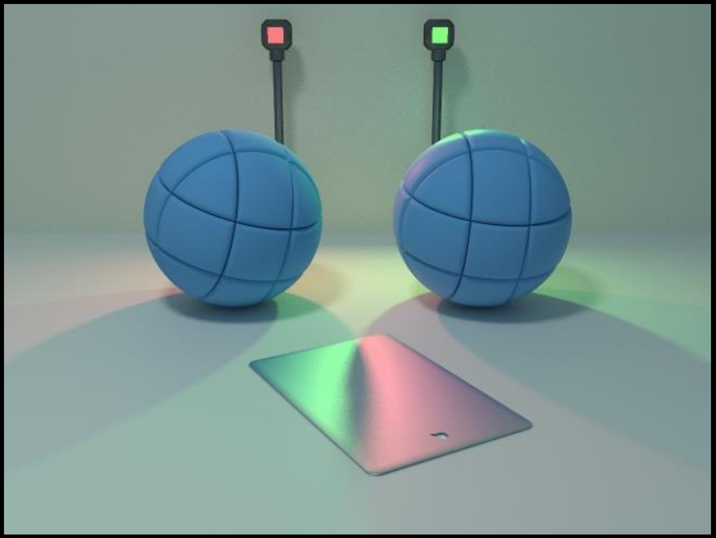
- $f_r(\omega_o, \omega_i) = \rho_d / \pi + \rho_s (n \cdot \omega_h)^s / (n \cdot \omega_i)$

  $= \rho_d / \pi + \rho_s (\cos\theta)^s / (n \cdot \omega_i)$



Lafortune Generalized Cosine Lobe



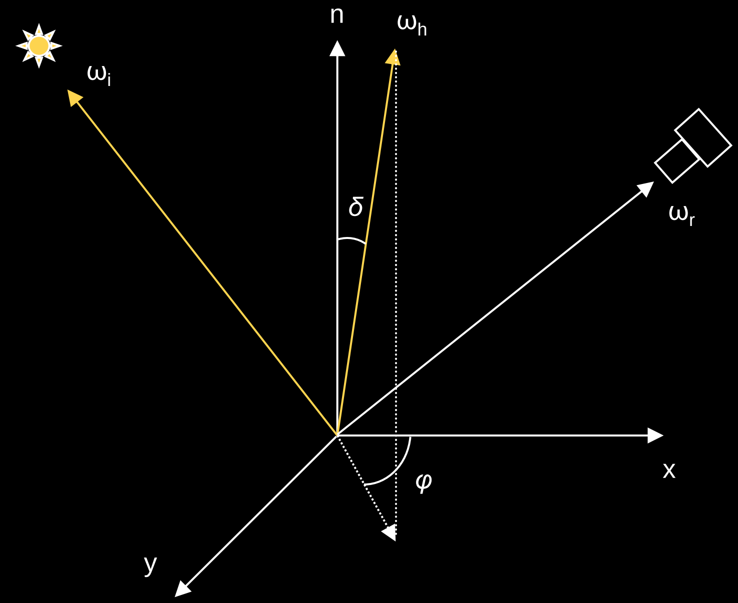


Fits to measured data

- $f_r(\omega_r, \omega_i) = \rho_d / \pi + \sum_j [C_{x,j}(\omega_{i.x} \cdot \omega_{r.x}) + C_{y,j}(\omega_{i.y} \cdot \omega_{r.y}) + C_{z,j}(\omega_{i.z} \cdot \omega_{r.z})]^{s,j}$
  - Off-specularity, retro-reflection, anisotropy
  - Well suited for measured data!

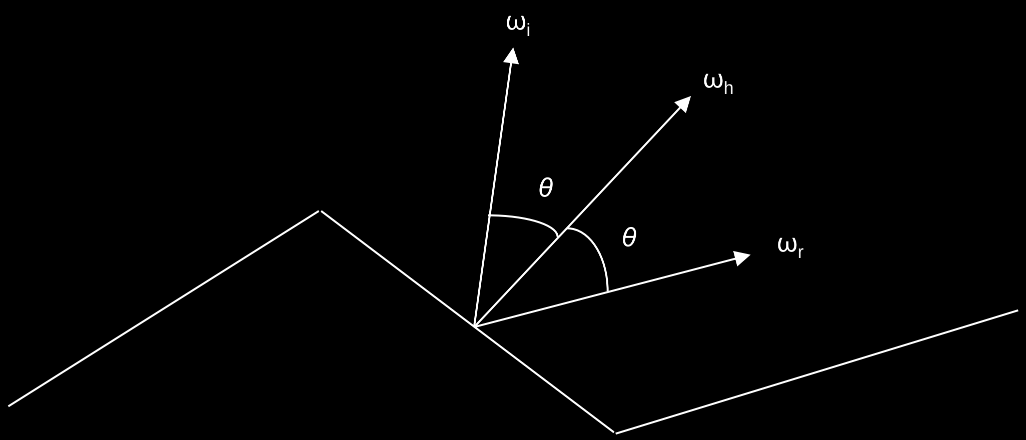
Ward Anisotropic Model

Generlization of microfacet model to account for anisotropy!



- $f_r(\omega_r, \omega_i) = \rho_d / \pi + \rho_s \dfrac{1}{\sqrt{\cos\theta_i \cos\theta_r}} \dfrac{\exp[-\tan^2\delta(\cos^2\varphi/\alpha_x^2 + \sin^2\varphi/\alpha_y^2)]}{4\pi\alpha_x\alpha_y}$
  - elliptical Gaussians, α_x & α_y control standard deviation in x & y
  - energy preserving & reciprocal

Physically Based: Microfacet Model



- $$f_r(\omega_r, \omega_i) = \frac{D(\omega_h)\, G(\omega_r, \omega_i)\, F_r(\omega_h)}{4\,(n \cdot \omega_i)\,(n \cdot \omega_r)}$$
  - D, the distribution term
  - G, the geometric term
  - F, the Fresnel term

Torrance-Sparrow Model

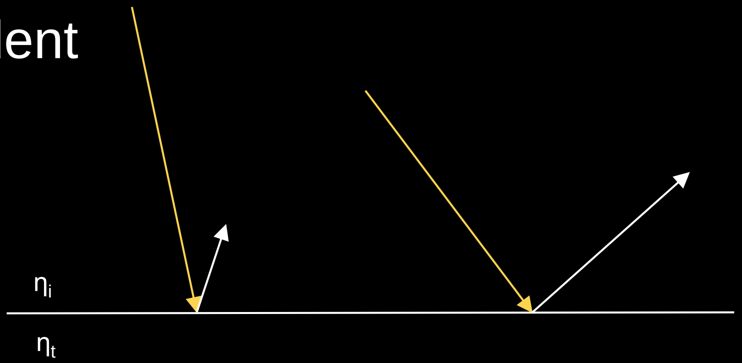
- $D(\omega_h) = \dfrac{\exp-[\tan\delta/m]^2}{m^2 \cos^4\delta}$ Beckman distribution
  - δ, angle between n and ω_h
  - m, root-mean-square slope of microfacets

- $G(\omega_r, \omega_i) = \min\{1, \dfrac{2\,(n \cdot \omega_h)\,(n \cdot \omega_r)}{(\omega_r \cdot \omega_h)}, \dfrac{2\,(n \cdot \omega_h)\,(n \cdot \omega_i)}{(\omega_r \cdot \omega_h)}\}$
  - V-shaped grooves

Fresnel Reflectance

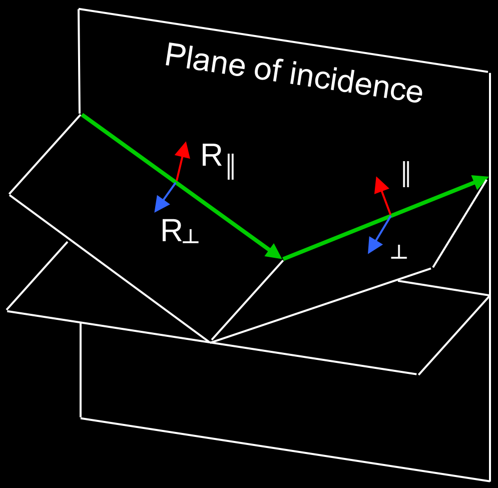
- Reflection from a surface is view dependent

- Fresnel equations
  - Maxwell's equations at smooth surfaces
  - index of refraction and polarization!



- Two kinds of Fresnel equations:
  - Dielectric materials (insulators) – reflection & transmission
  - Conductors (metals) – only reflection & some absorption

Dielectric Fresnel



- Fresnel reflectance for parallel polarized light $r_{\parallel}$:

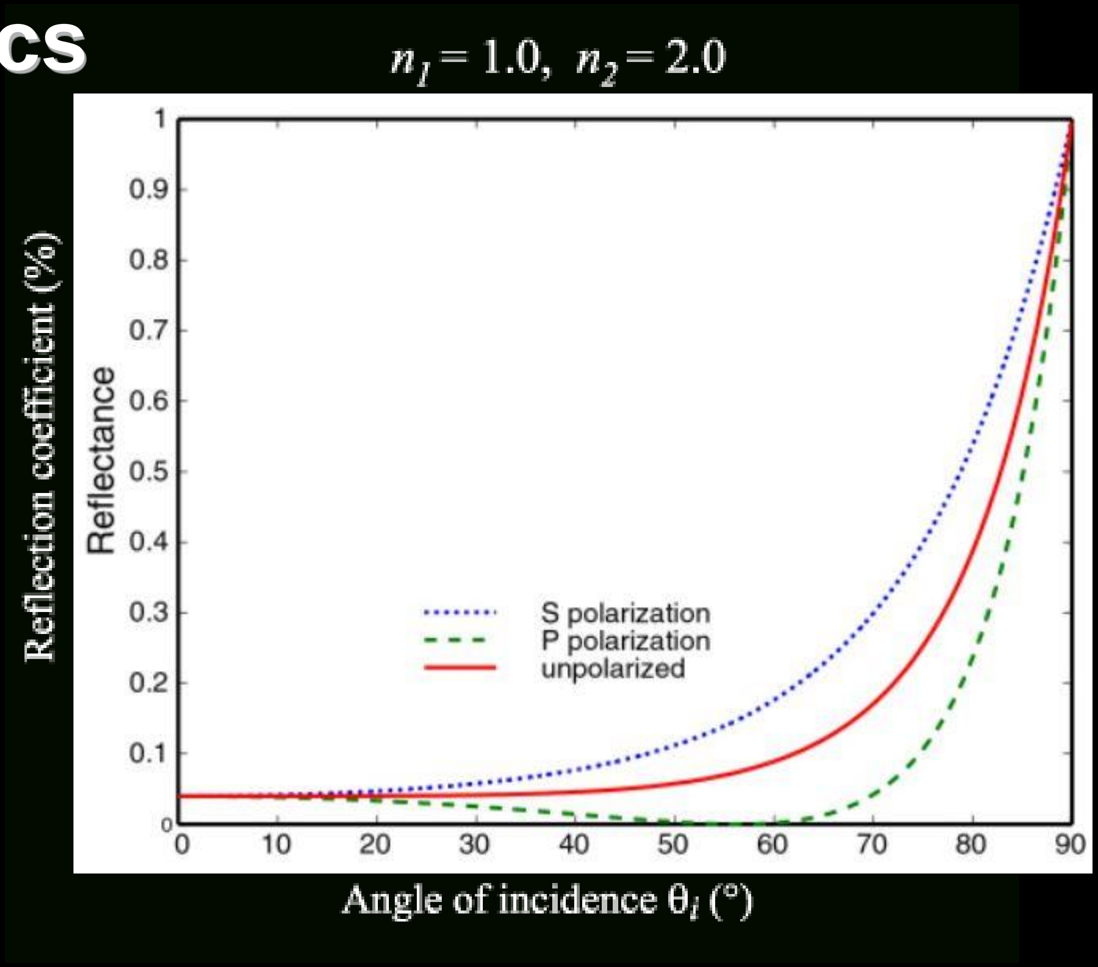
$$R_{\parallel} = \left| \frac{\eta_t \cos\theta_i - \eta_i \cos\theta_t}{\eta_t \cos\theta_i + \eta_i \cos\theta_t} \right|^2$$

- Fresnel reflectance for perpendicular polarized light $r_{\perp}$:

$$R_{\perp} = \left| \frac{\eta_i \cos\theta_i - \eta_t \cos\theta_t}{\eta_i \cos\theta_i + \eta_t \cos\theta_t} \right|^2$$

- Unpolarized reflectance $F_r = ½(R_{\parallel} + R_{\perp})$.
  - Transmittance $T_r = 1 – F_r$.

Dielectrics



- R_p – parallel polarized, R_s – perpendicular polarized
- Schlick approximation given reflectance R_0

Conductors Fresnel

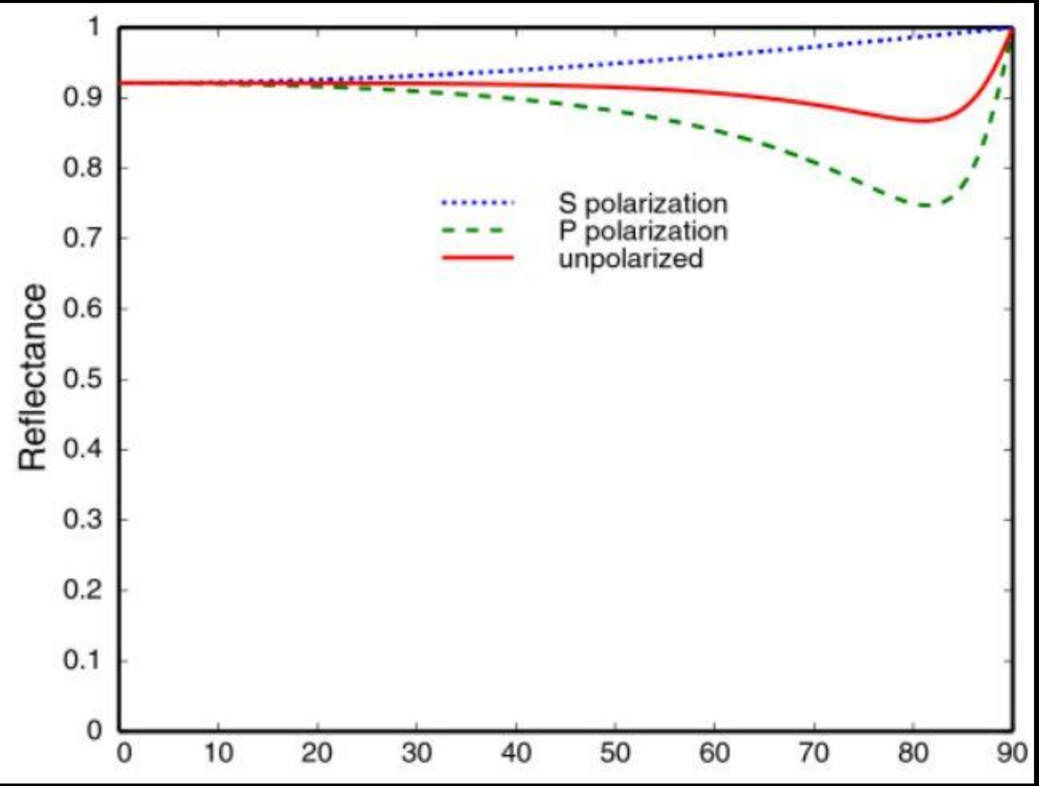
- No transmission, but some absorption k:

$$R_{\parallel} = \frac{(\eta^2 + k^2)\cos\theta_i^{\,2} - 2\eta\cos\theta_i + 1}{(\eta^2 + k^2)\cos\theta_i^{\,2} + 2\eta\cos\theta_i + 1}$$

And

$$R_{\perp} = \frac{(\eta^2 + k^2) - 2\eta\cos\theta_i + \cos\theta_i^{\,2}}{(\eta^2 + k^2) + 2\eta\cos\theta_i + \cos\theta_i^{\,2}}$$

Conductors Fresnel

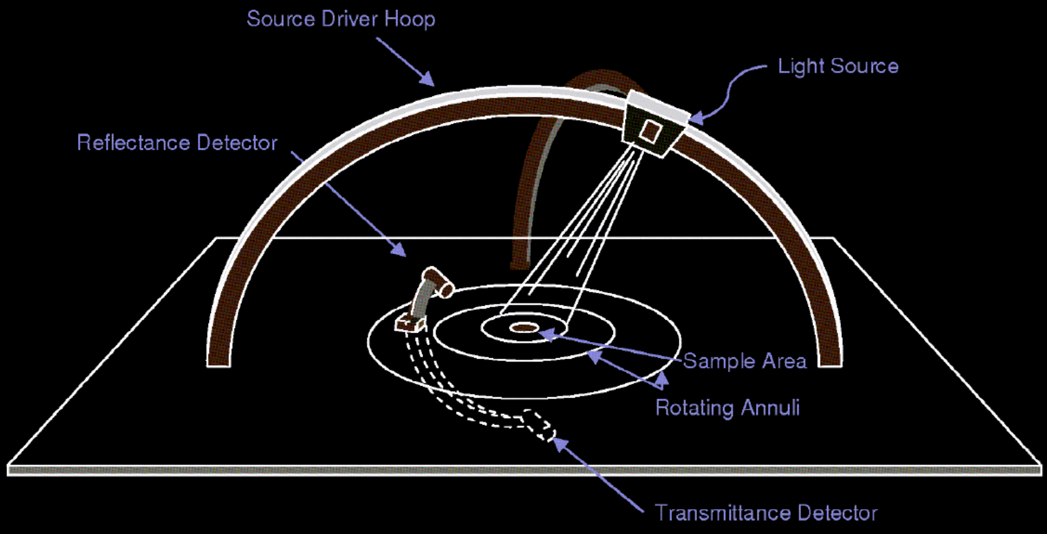


- No transmission, complex index of refraction: η, k
- High reflectance across angles of incidence

BRDF Measurement

- Analytical models have limitations
  - describe specific kinds of surfaces
  - appropriate parameters not easy to obtain!
- Measurement of BRDFs a solution
  - direct usage as tabulated data
  - fit to analytic models or basis functions

Dense Measurements



- Gonioreflectometer
  - Cornell, CUReT, NIST
  - Missing measurements interpolation!

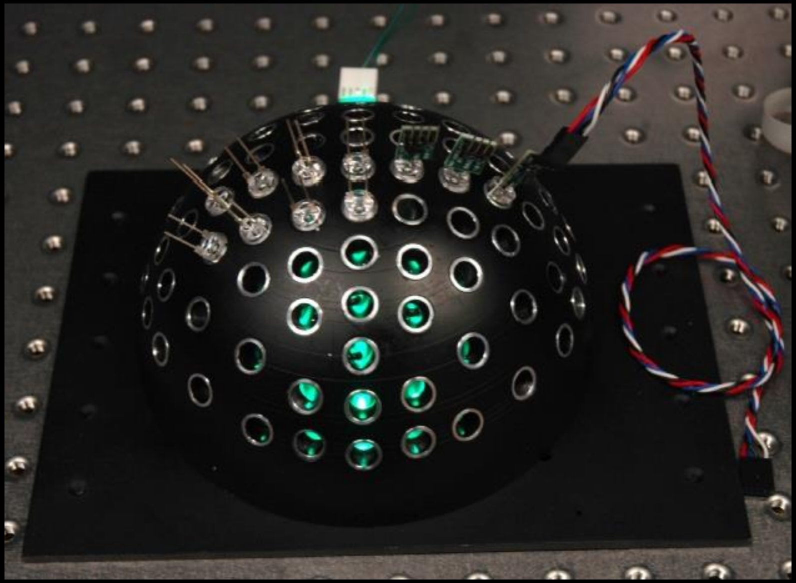
Goneo-reflectometer

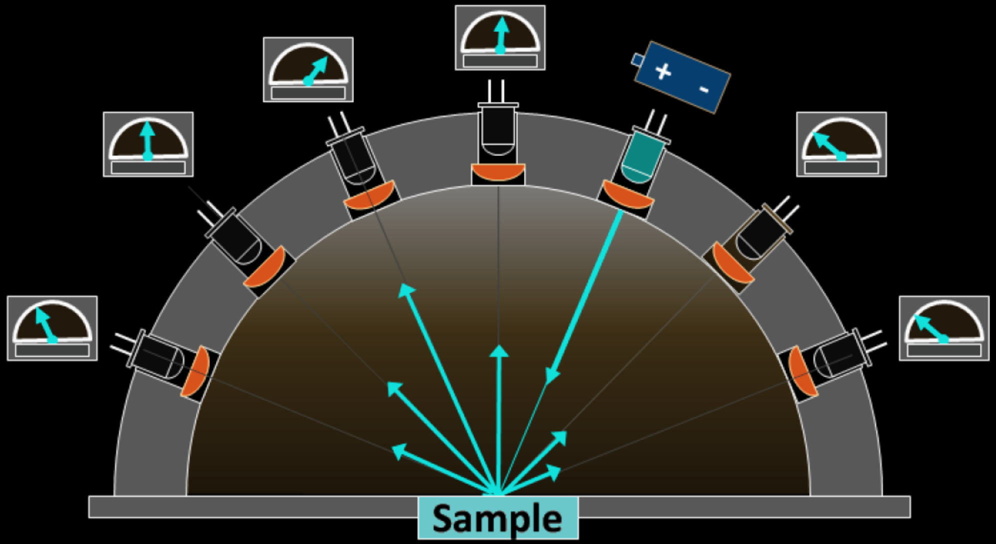
DMS 803

6 motorised axis

SOC210-BDR

LED-based Measurement



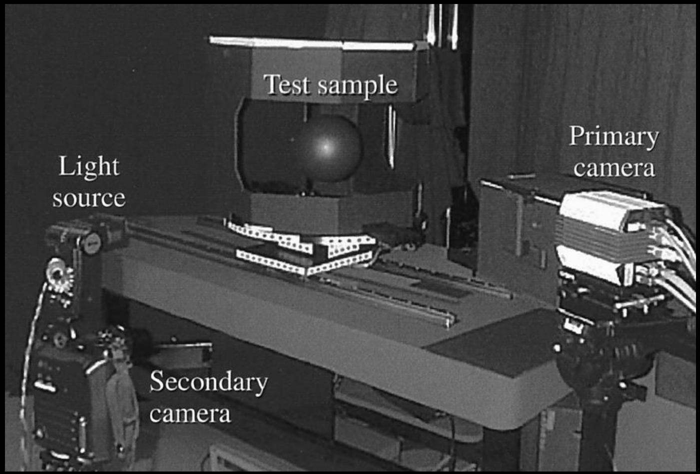


[Ben-Ezra et al. 08]

- LEDs as emitters as well as sensors!
- Parallel measurements with point sampling

Image-based Measurements

Isotropic



[Marschner et al. 00]

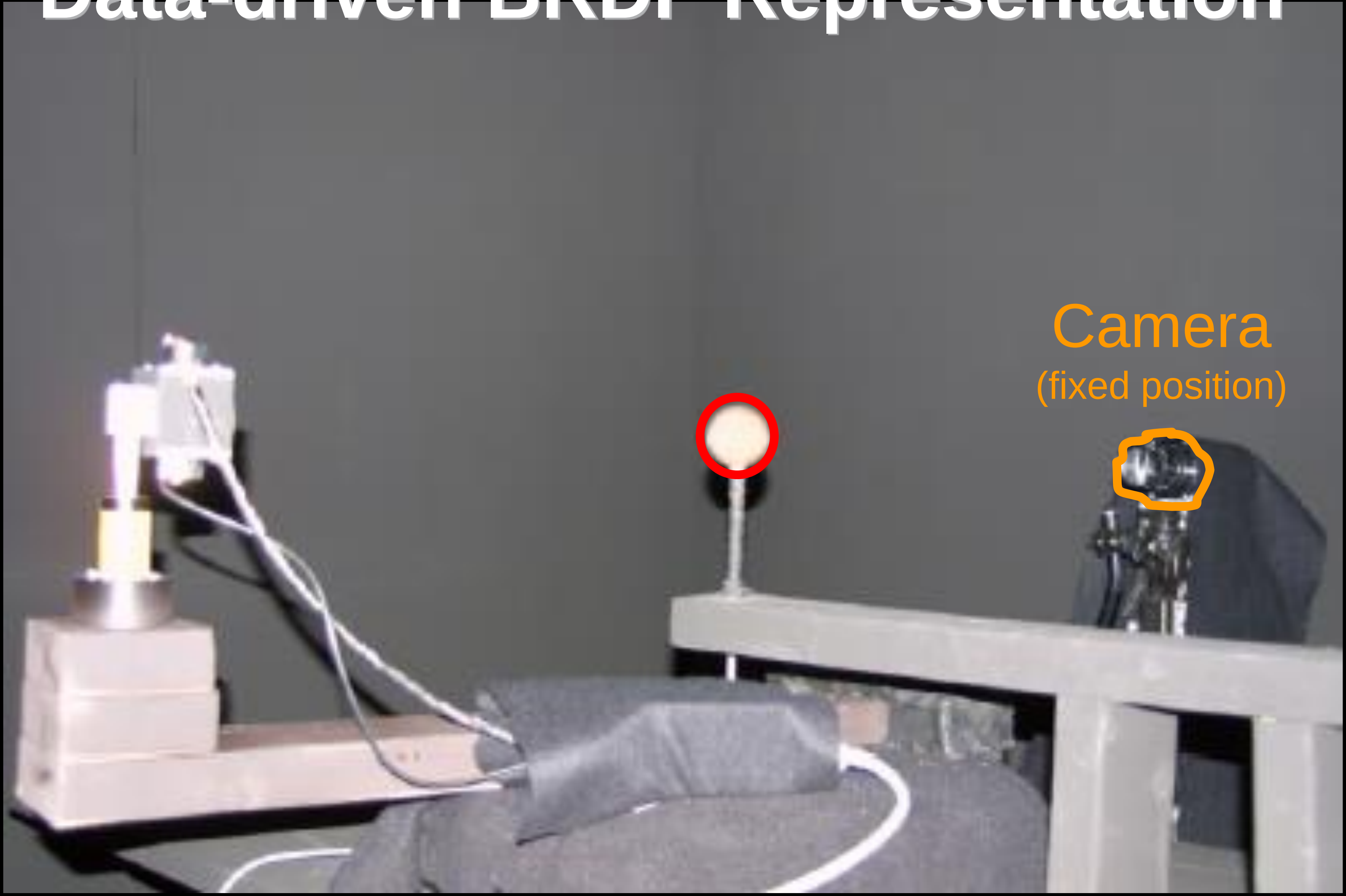
[Matusik et al. 03]

100 BRDFs

MERL database

Data-driven BRDF Representation

Data-driven BRDF Representation

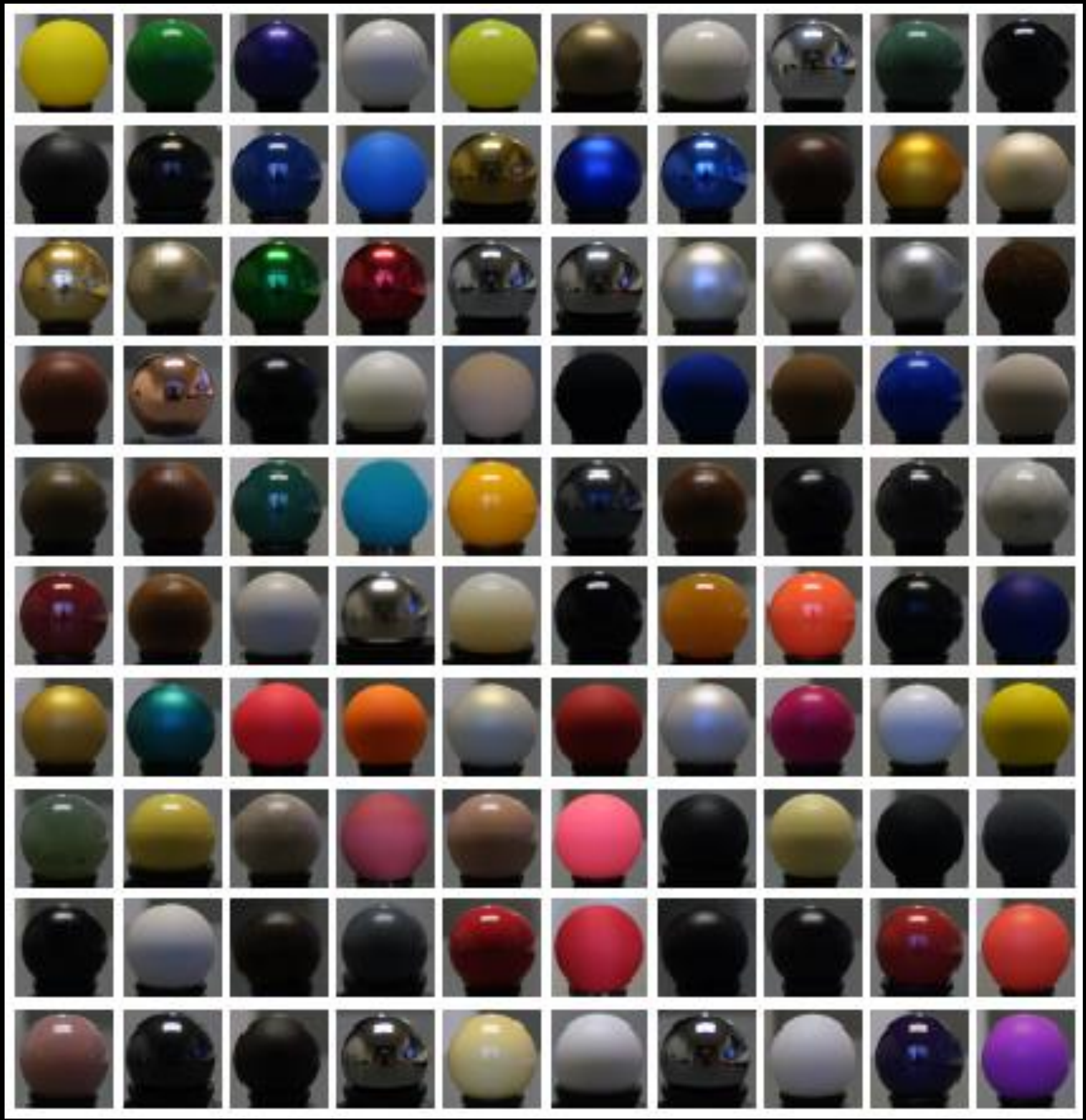


Data-driven BRDF Representation

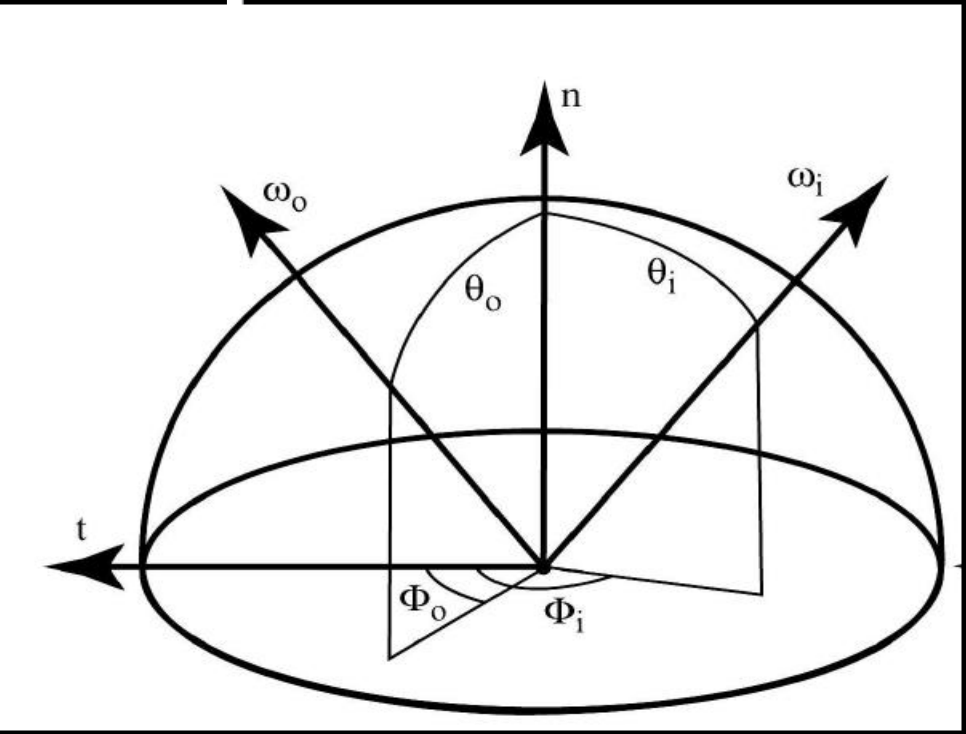
Data-driven BRDF Representation

More than 100 different BRDFs

20-80M Reflectance Measurements per Material

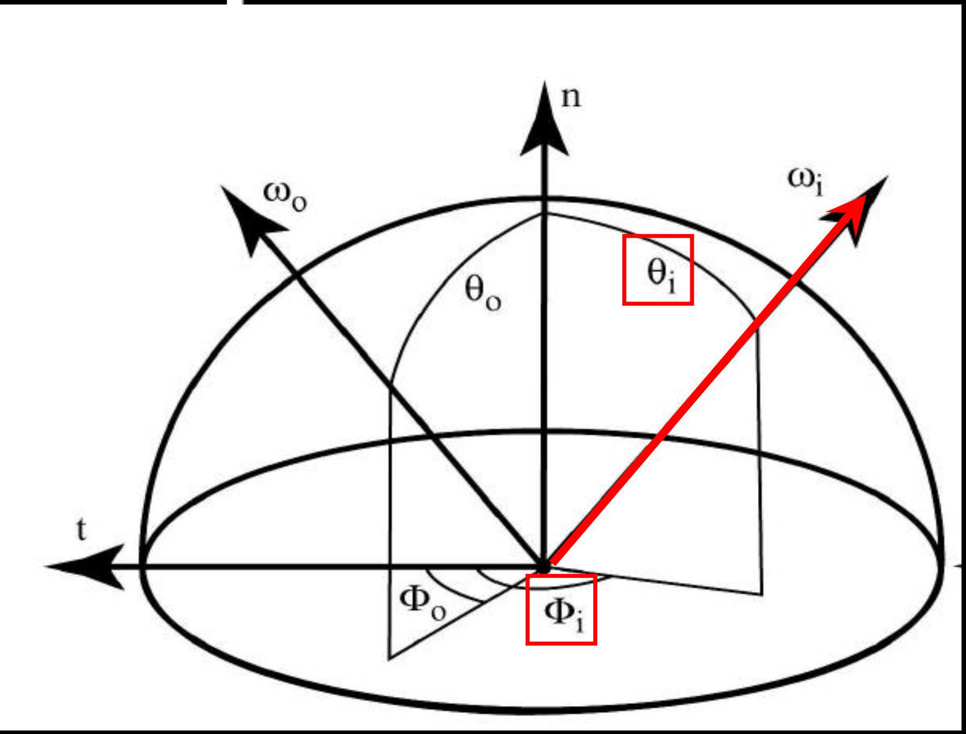


Reparameterization



Standard

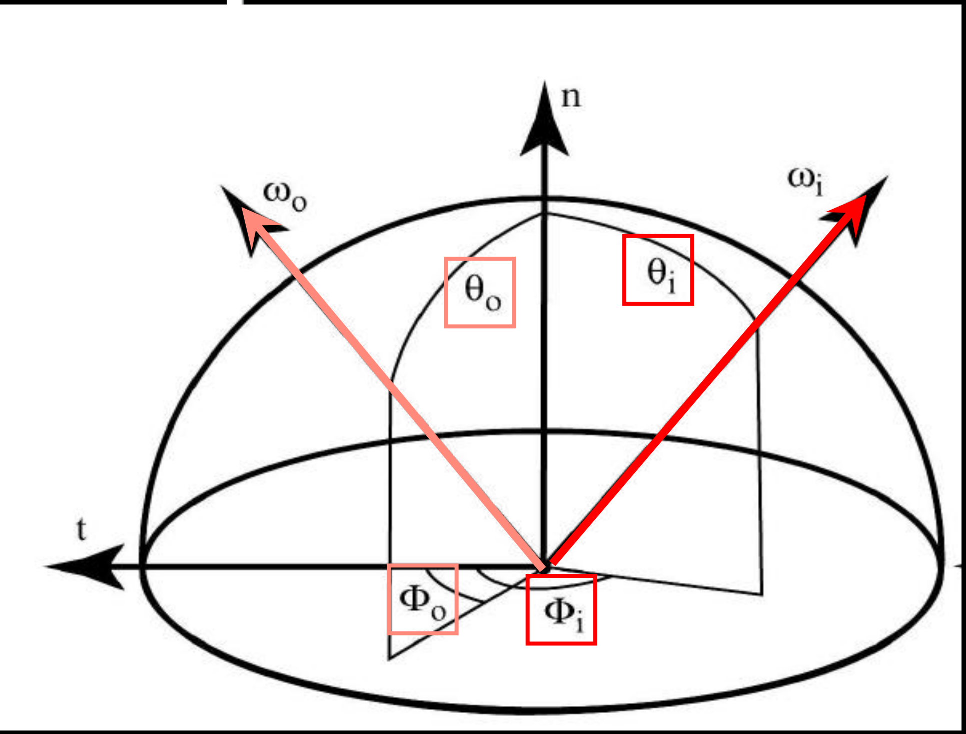
Reparameterization



Standard

Incident: $\omega_i = (\theta_i, \Phi_i)$

Reparameterization

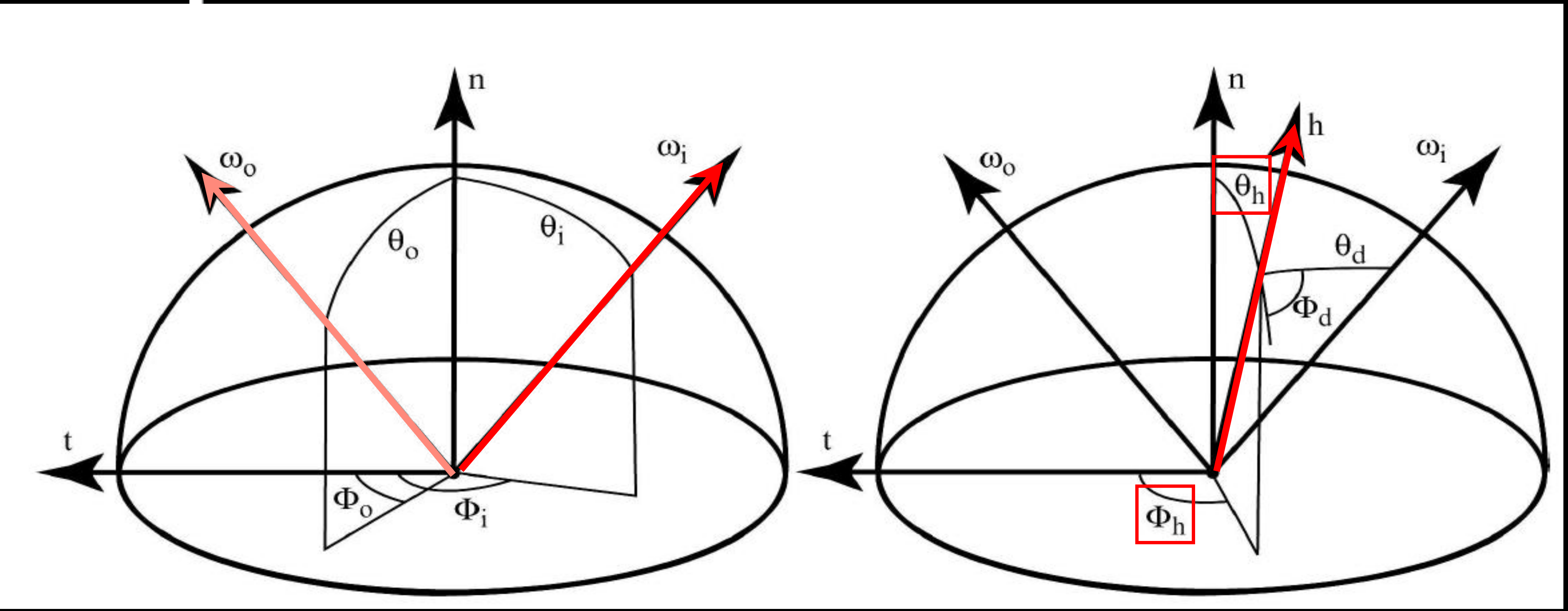


Standard

Incident: $\omega_i = (\theta_i, \Phi_i)$

Exitant: $\omega_o = (\theta_o, \Phi_o)$

Reparameterization



Standard

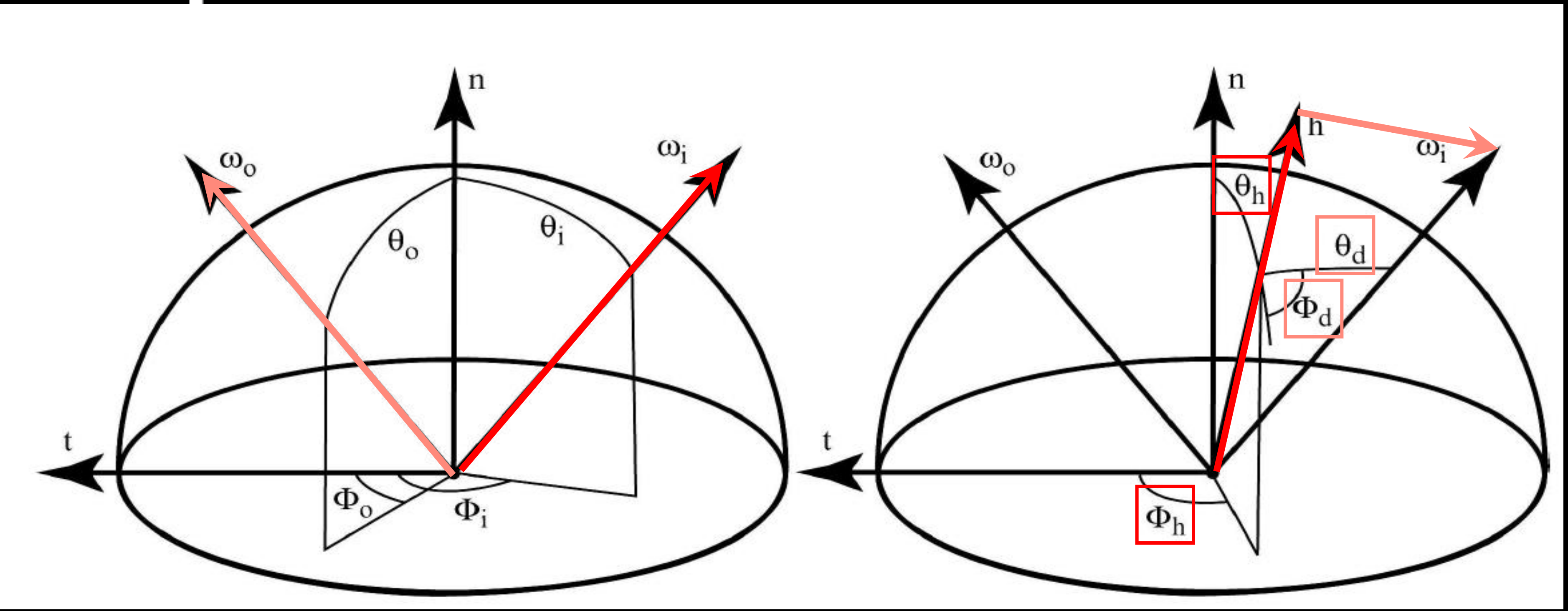
Rusinkiewicz

Incident: $\omega_i = (\theta_i, \Phi_i)$

Exitant: $\omega_o = (\theta_o, \Phi_o)$

Halfway: $\omega_h = (\theta_h, \Phi_h)$

Reparameterization



Standard

Rusinkiewicz

Incident: $\omega_i = (\theta_i, \Phi_i)$

Exitant: $\omega_o = (\theta_o, \Phi_o)$

Halfway: $\omega_h = (\theta_h, \Phi_h)$

Difference: $\omega_d = (\theta_d, \Phi_d)$

Reparameterization

Advantage:

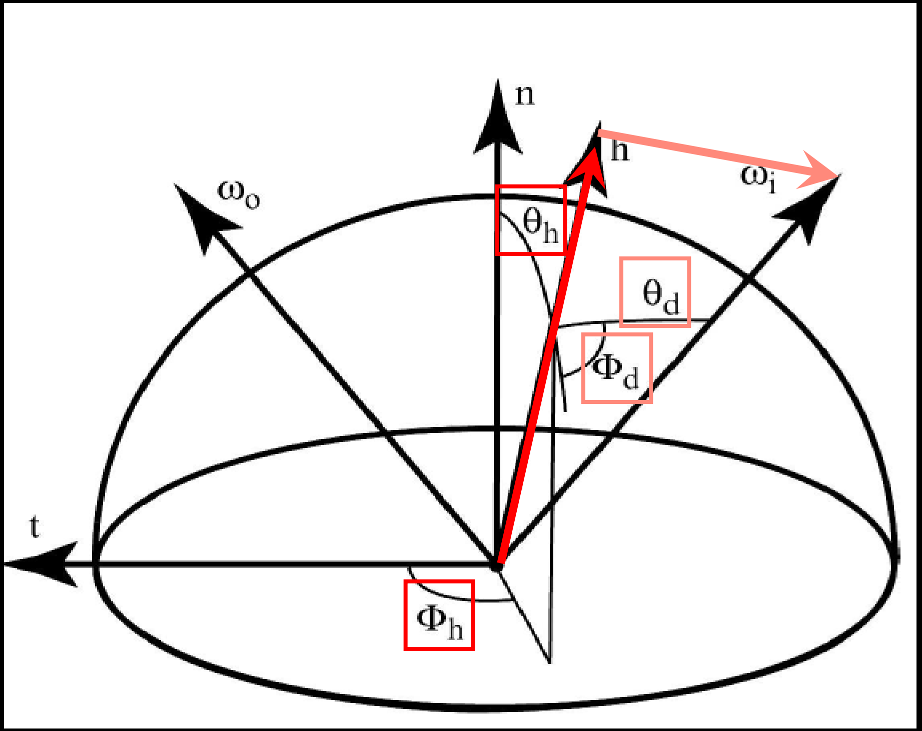
Specular highlight

⇩

Around halfway vector

⇩

$\omega_h = 0$



Rusinkiewicz

Halfway: $\omega_h = (\theta_h, \Phi_h)$

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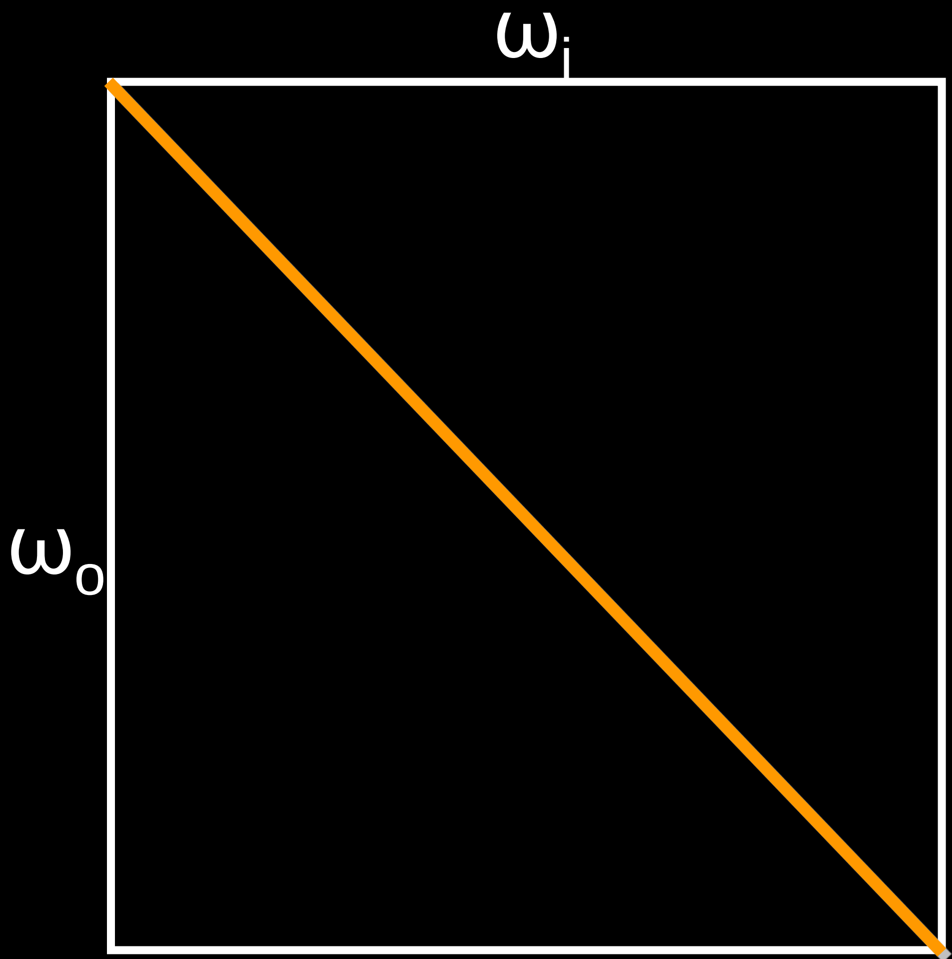
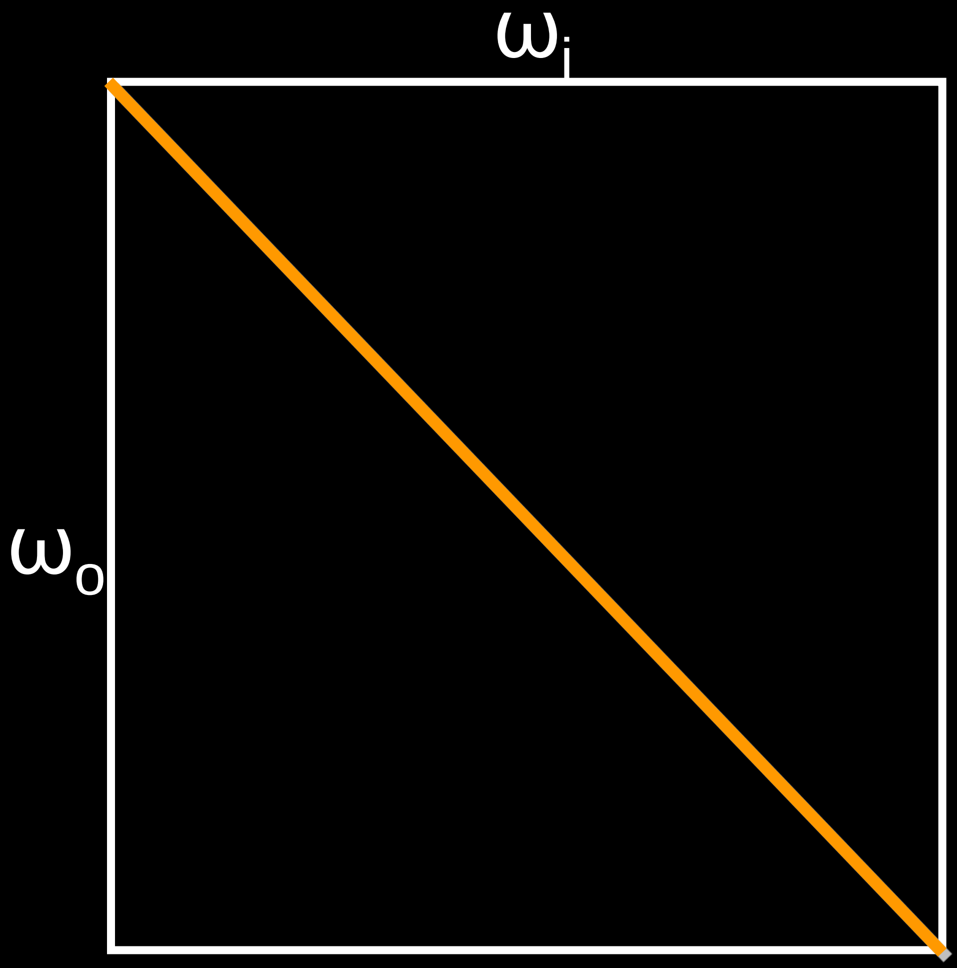
Reparameterization



Standard

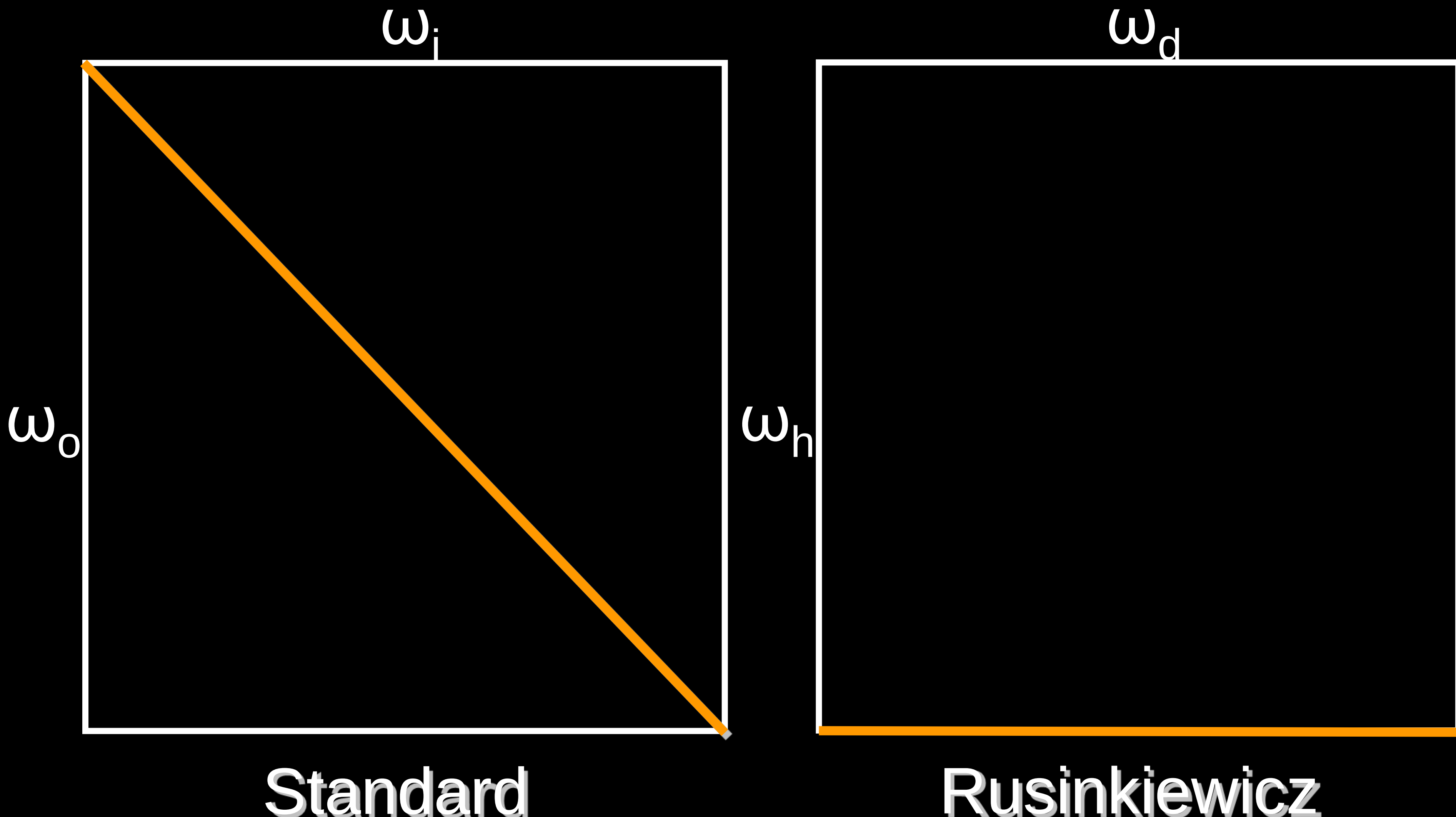
Reparameterization



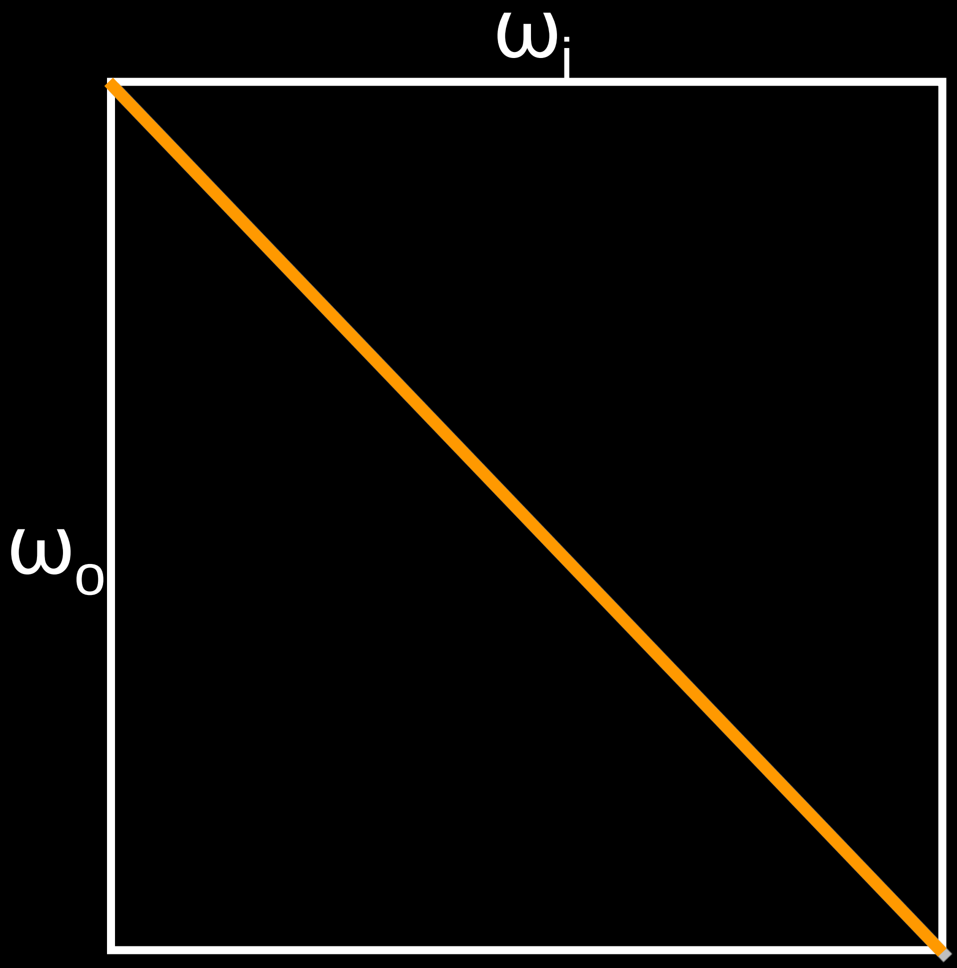
Standard

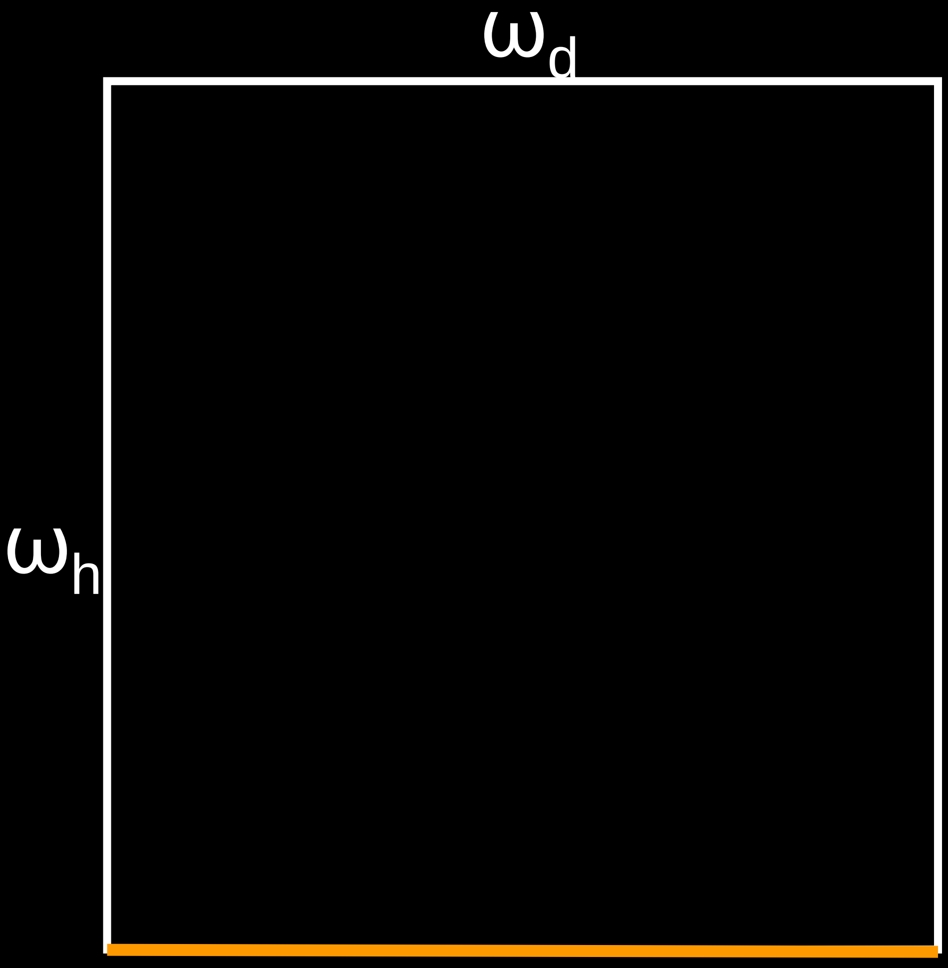
Full Rank!

Reparameterization



Reparameterization





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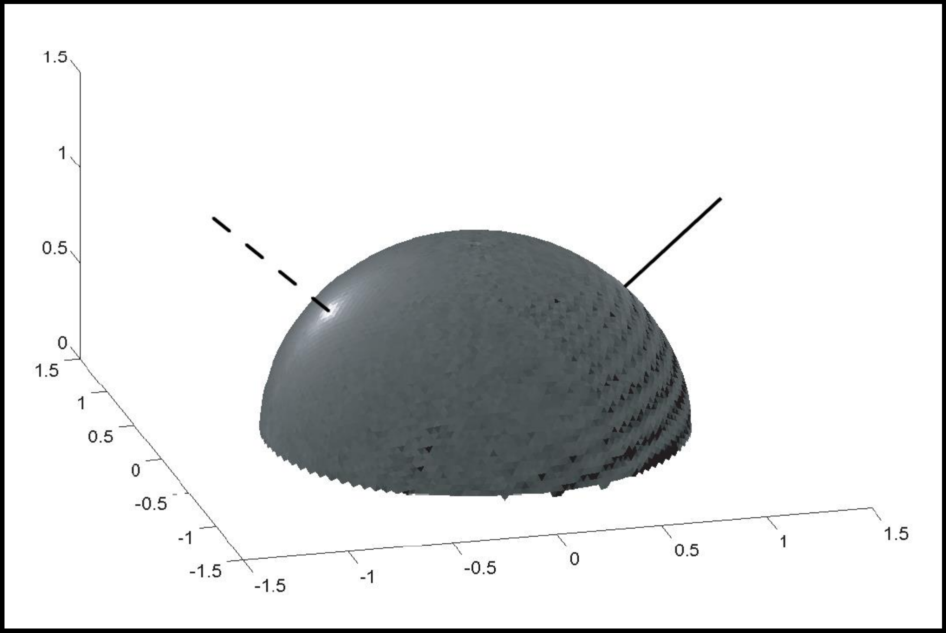
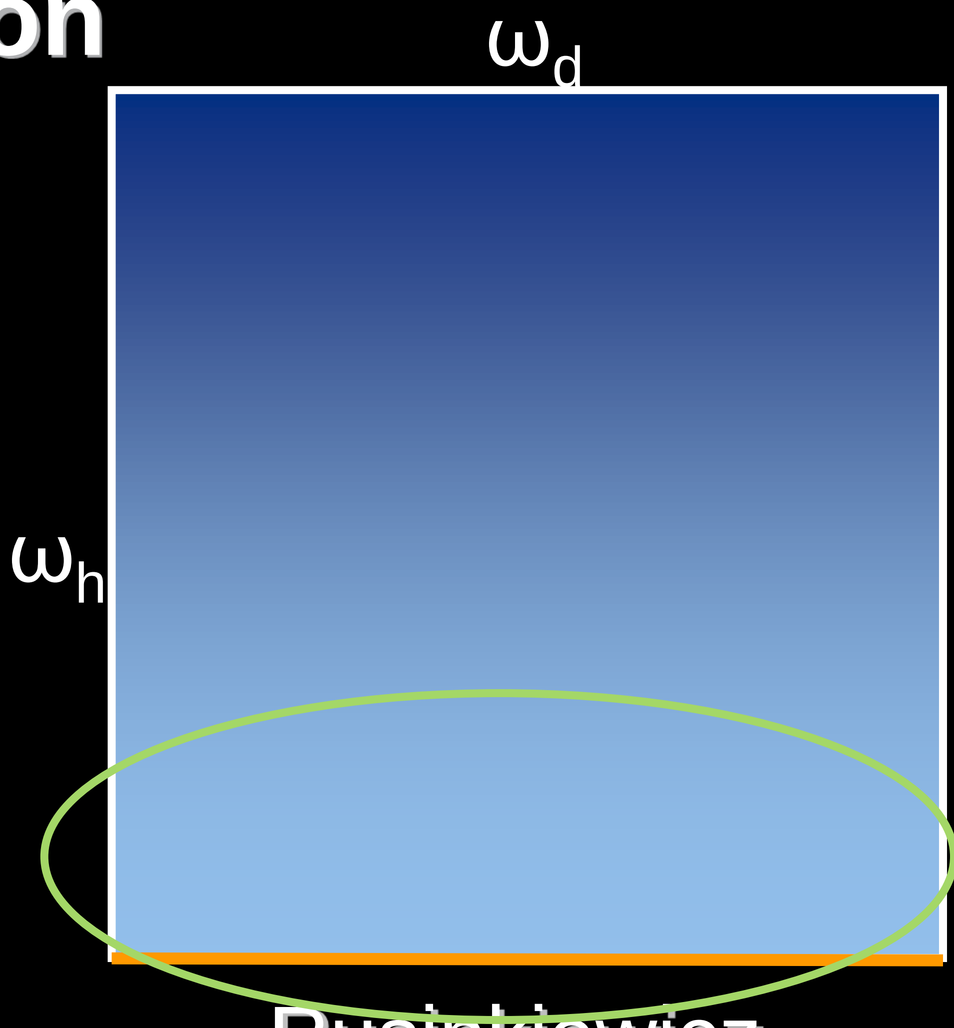


Sample Densely



Rusinkiewicz

Reparameterized data

Tabulated: 90 (θ_h) x 90 (θ_d) x 360 (φ_d)

- Easy to use in rendering system

Disadvantages:

- Requires 17Mb / BRDF
- 12 Hours to capture

Direct Visualization (Tabulated)

Data-driven BRDF Representations

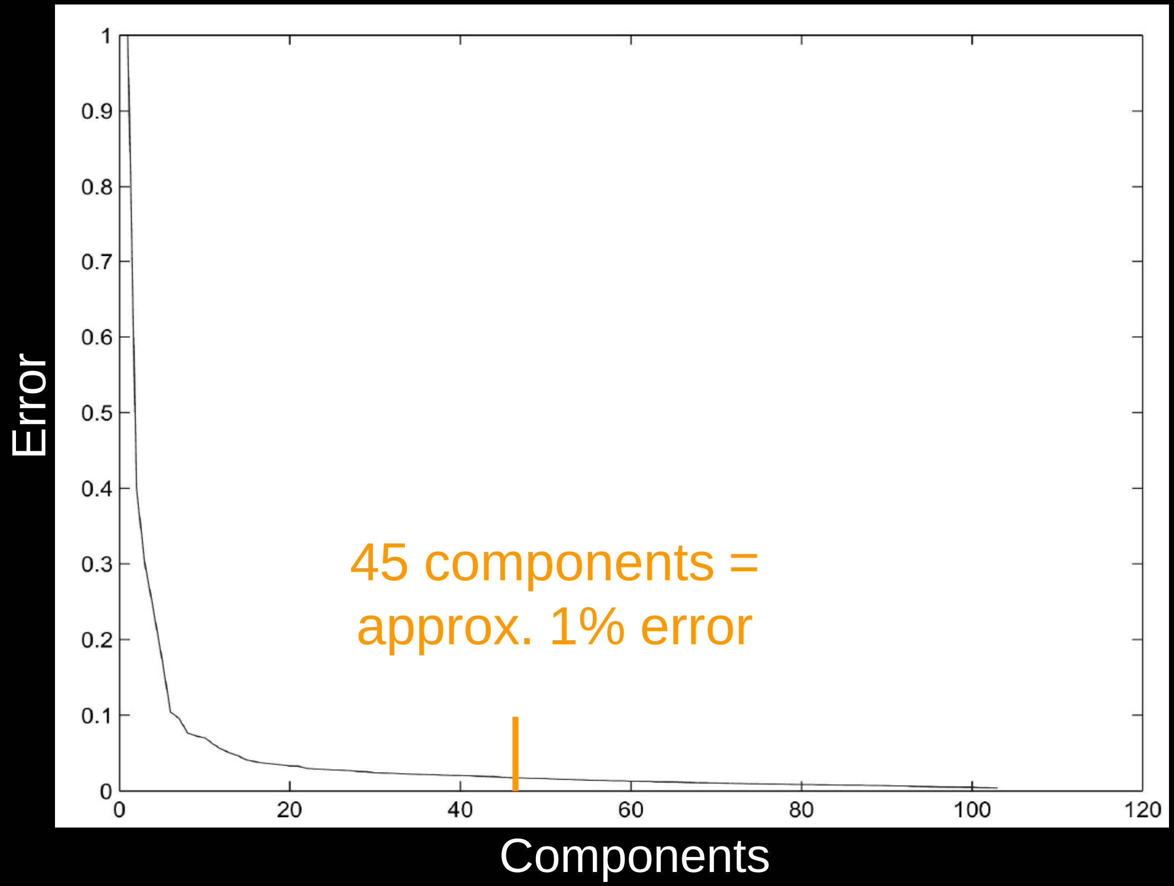
Data-driven Analysis

- Linear Data Analysis (PCA)
- Non-linear Data Analysis
- BRDFs as data driven basis

[Matusik et al. 2003]

Linear Data Analysis (PCA)

- Linearize each BRDF in a (long) vector
- Apply PCA on **all** these vectors
- Keep n largest principal vectors



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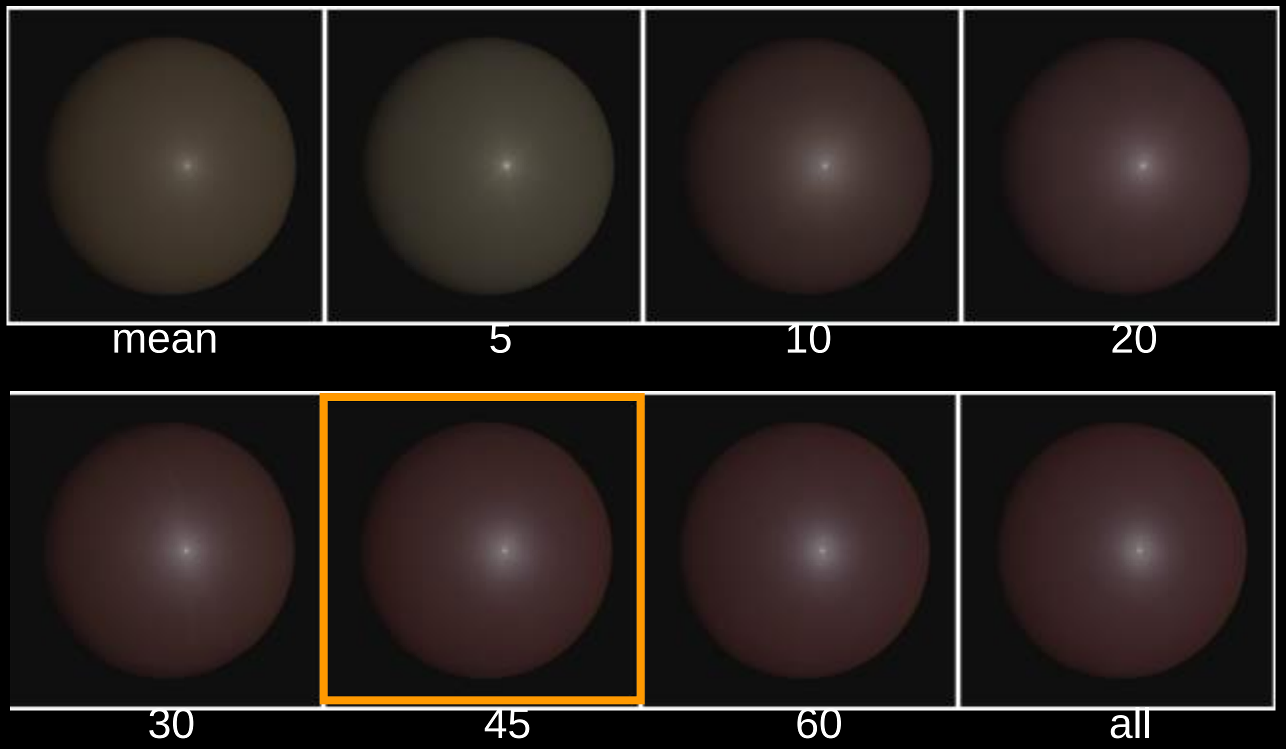
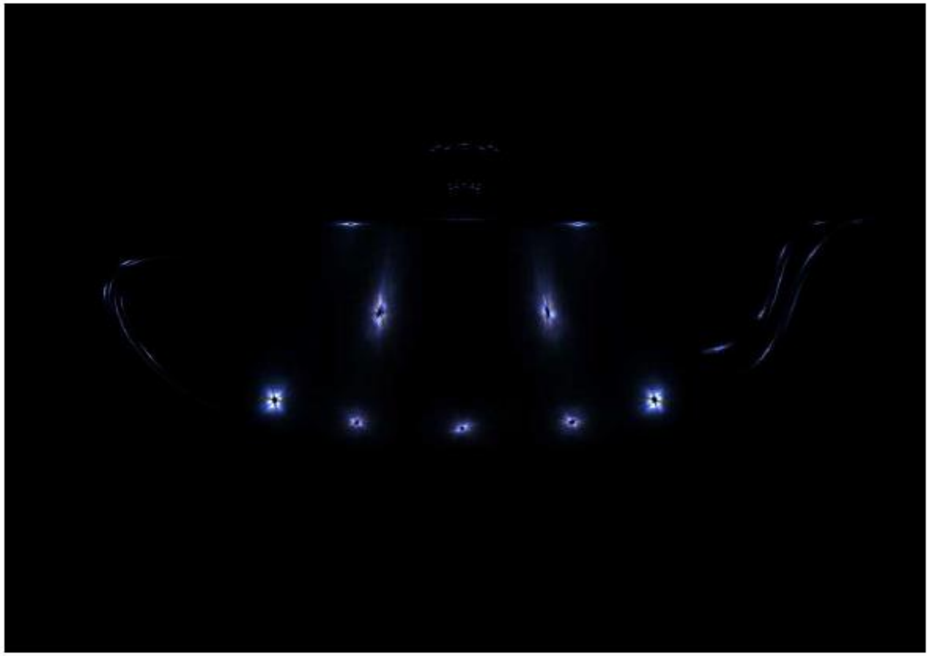


PCA space exploration

Problem: non-physical BRDFs

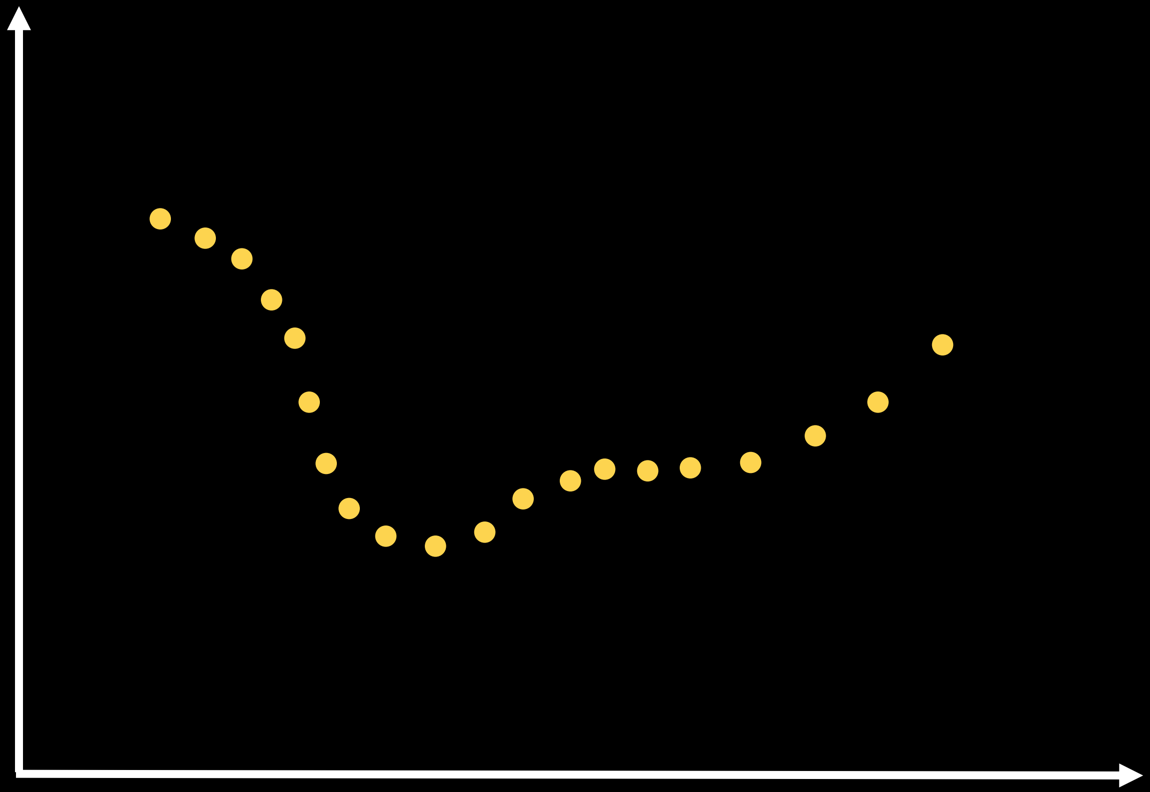
45D space contains non-physical BRDFs

Measured BRDF
(point A in 45D space)



Non-physical BRDF
(point close to A in 45D space)

Why does it fail?



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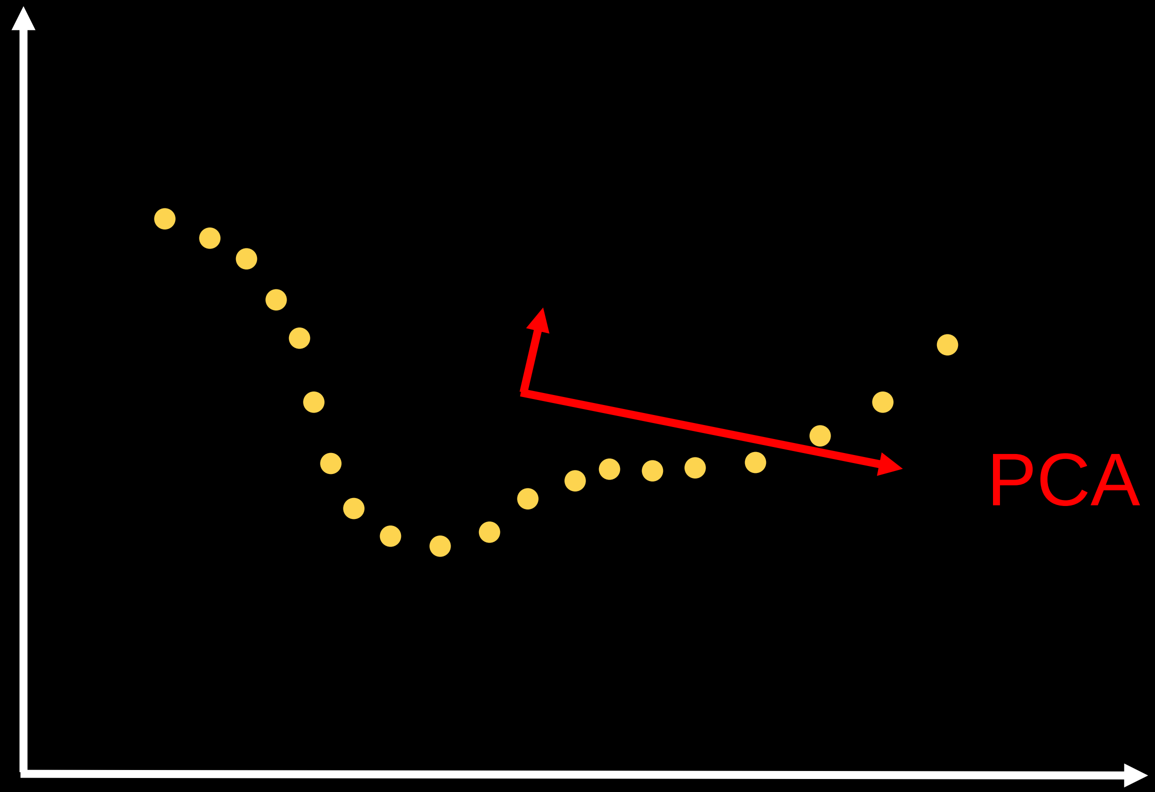

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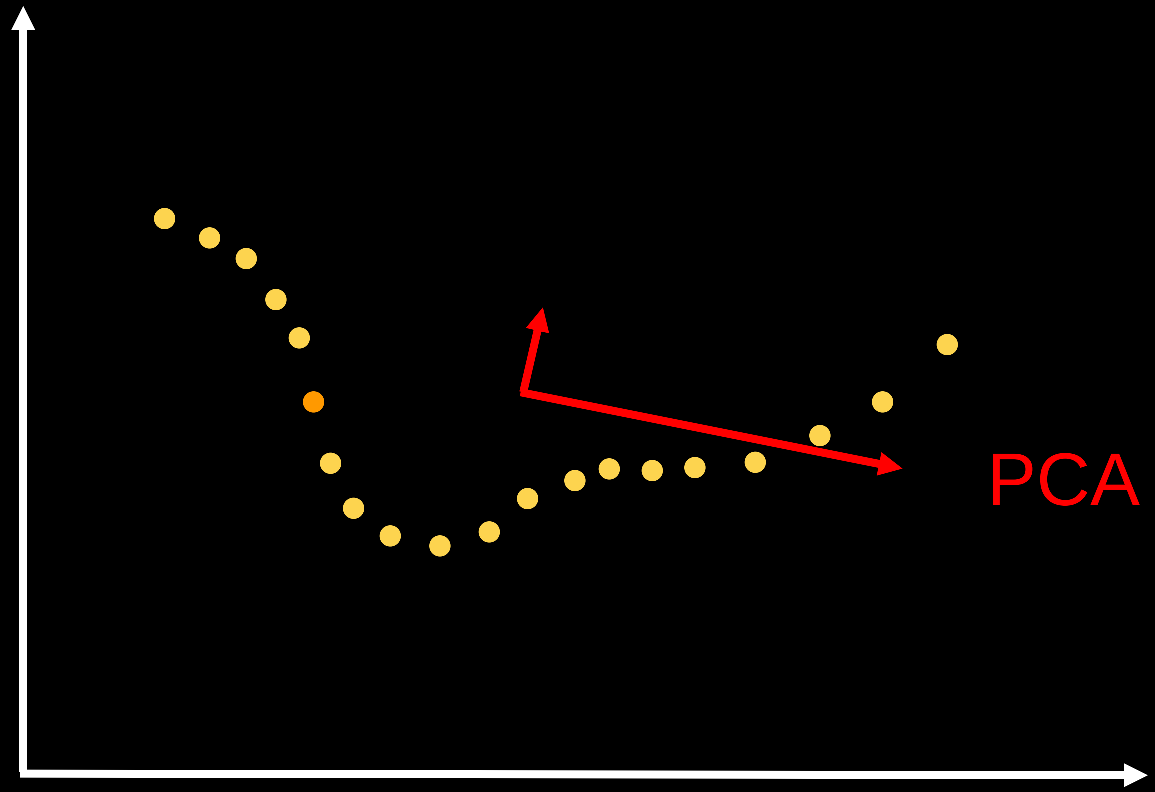
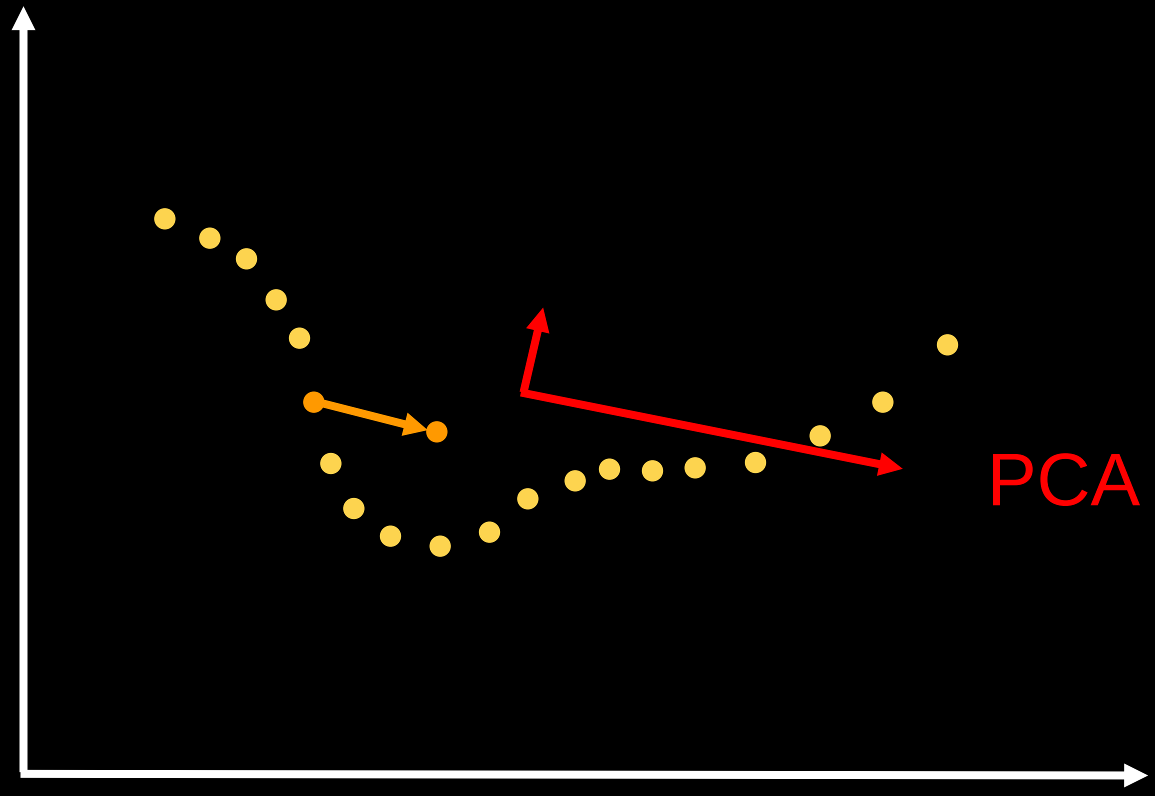
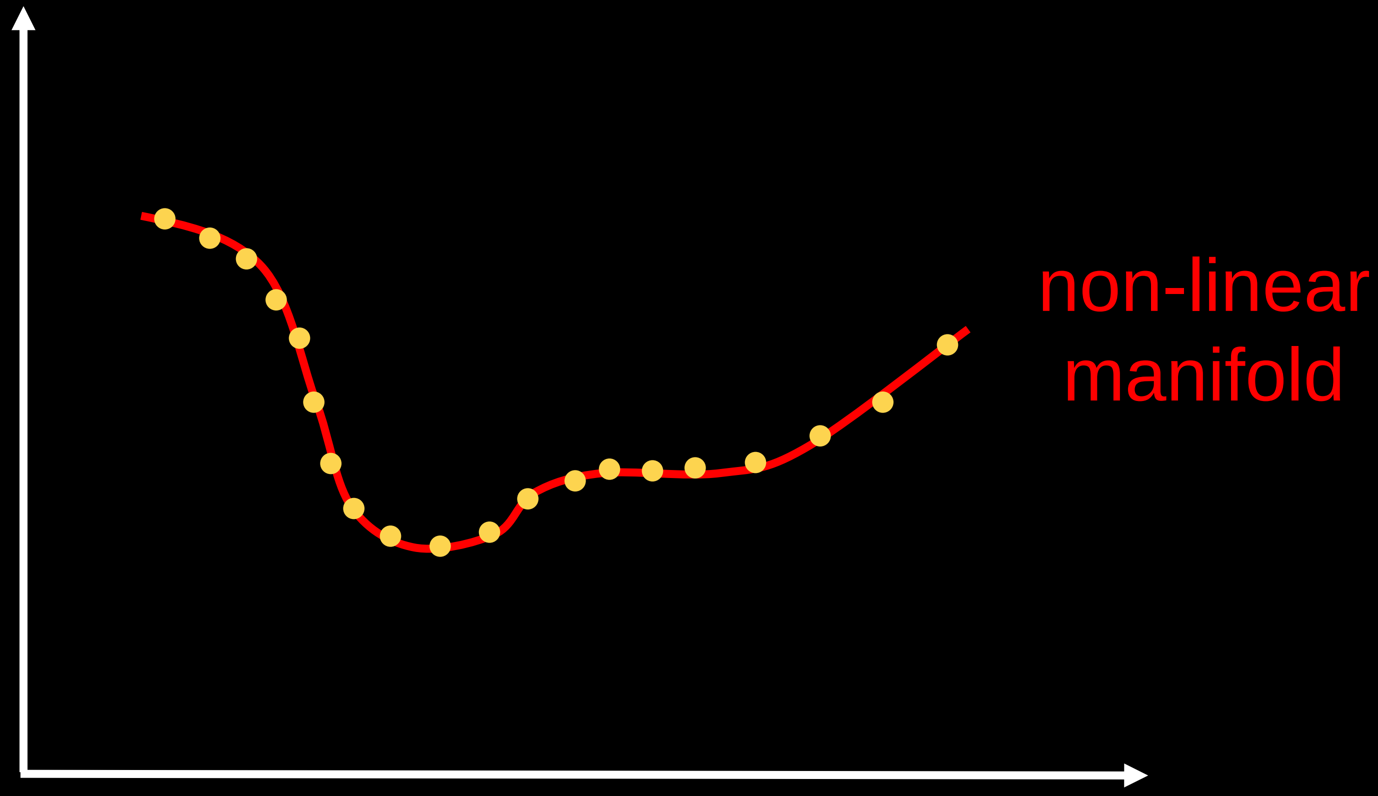


Why does it fail?



Move a little => fall outside measured space

Why does it fail?



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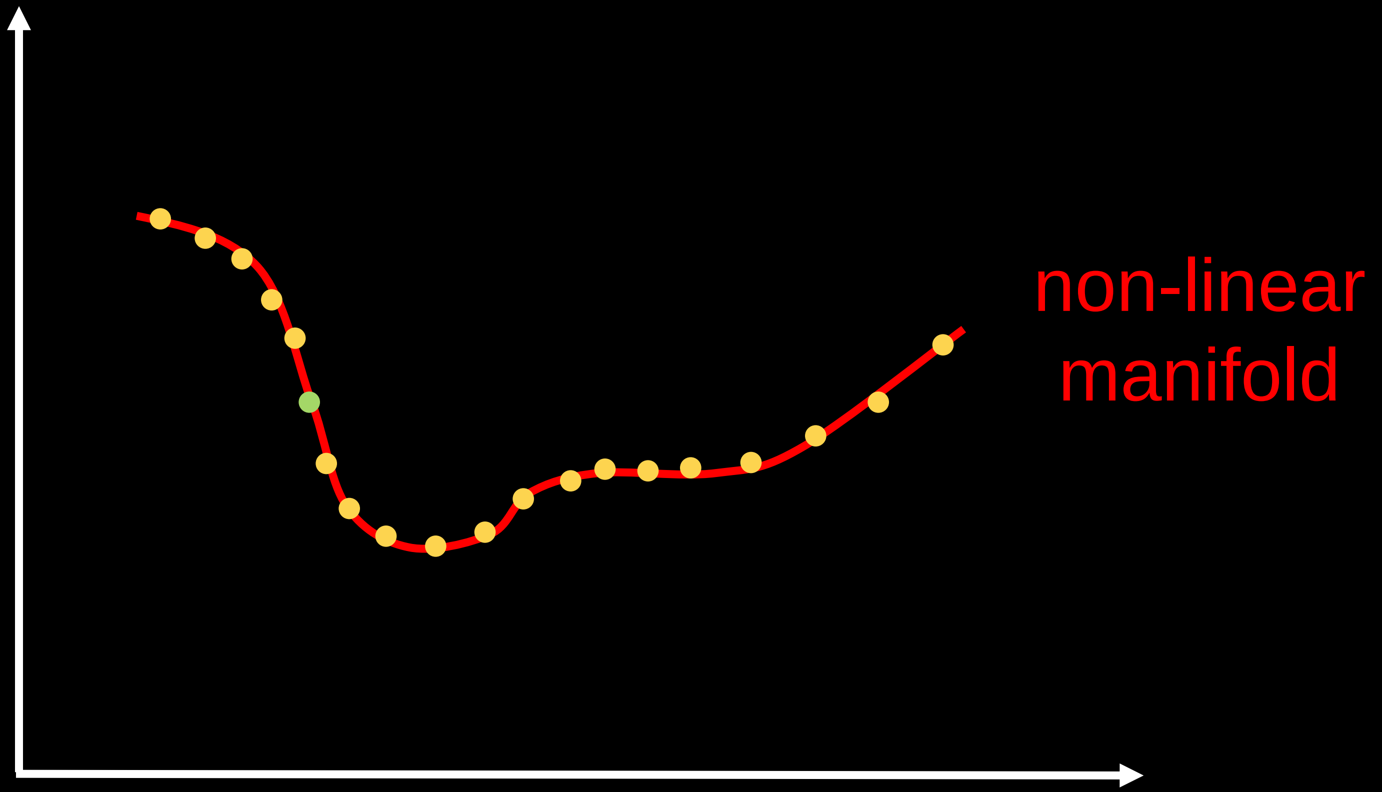

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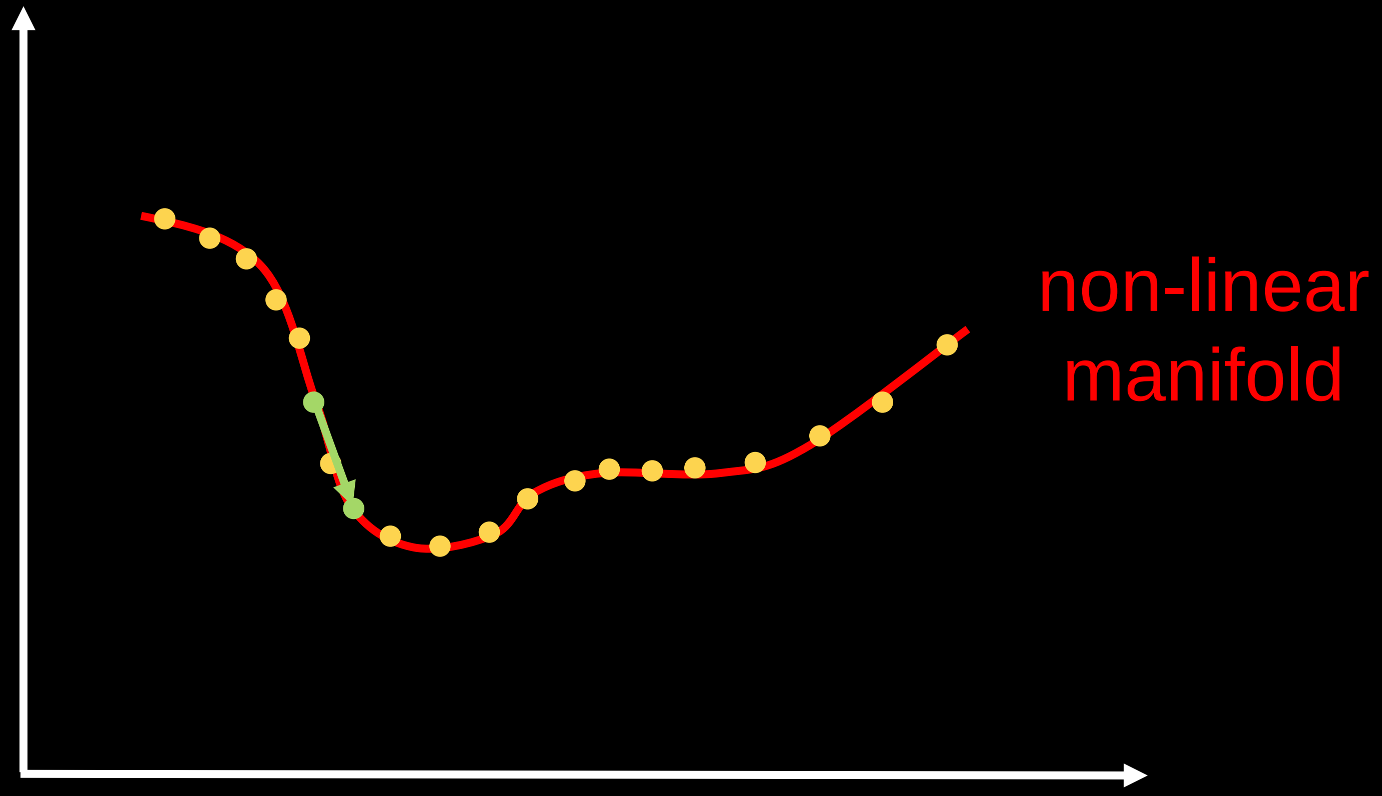
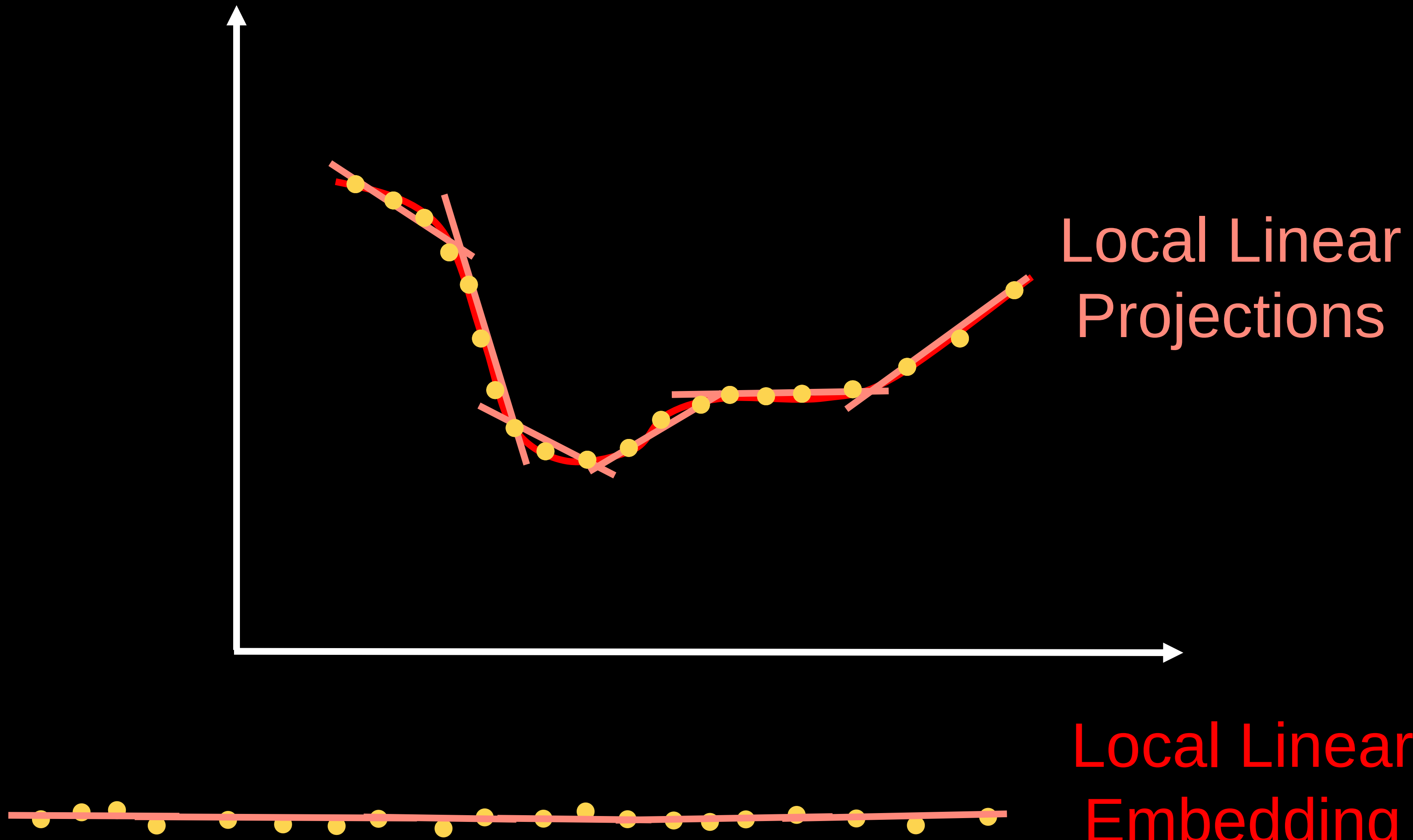
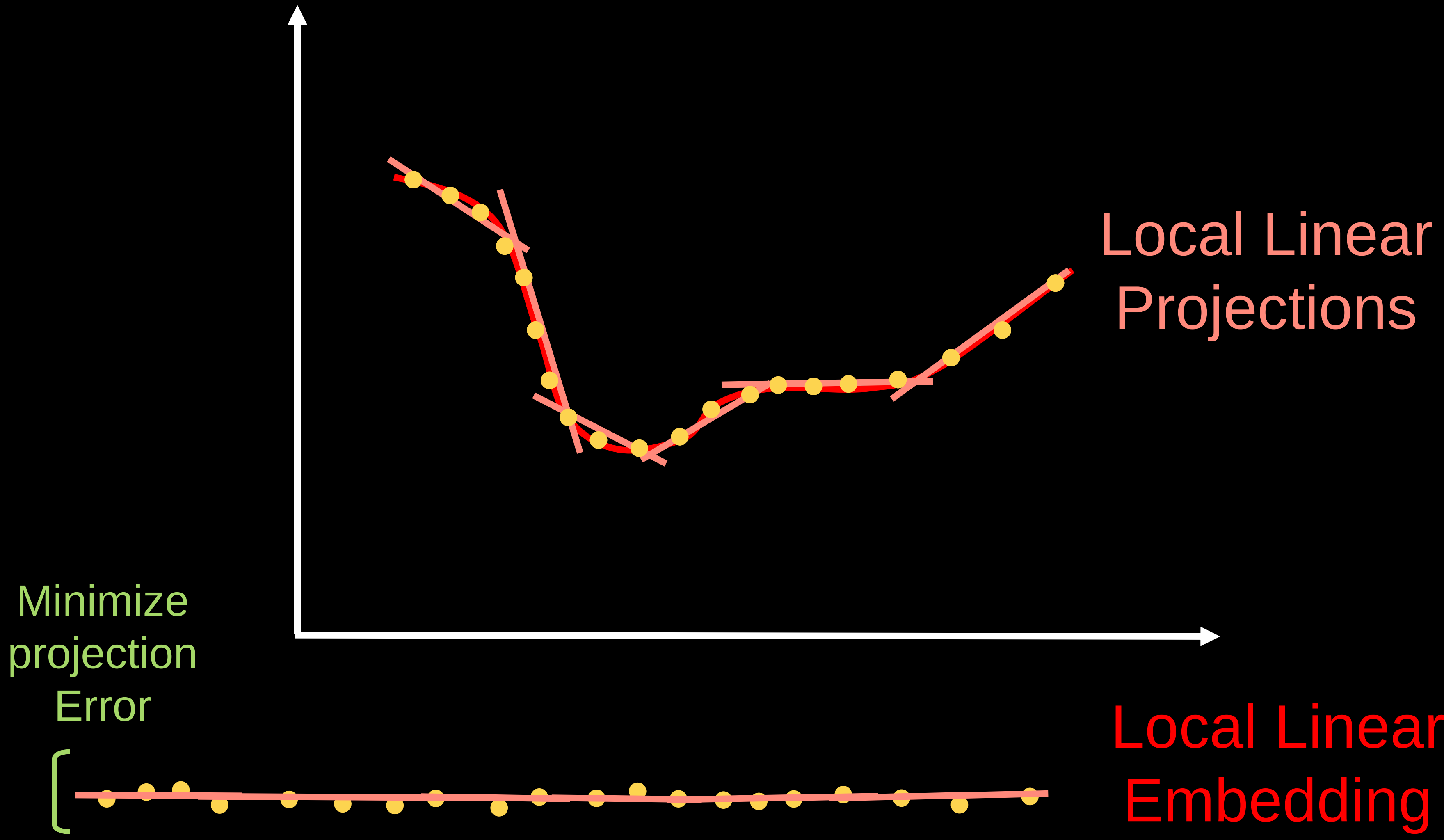


Only move over manifold!

Non-linear Data Analysis

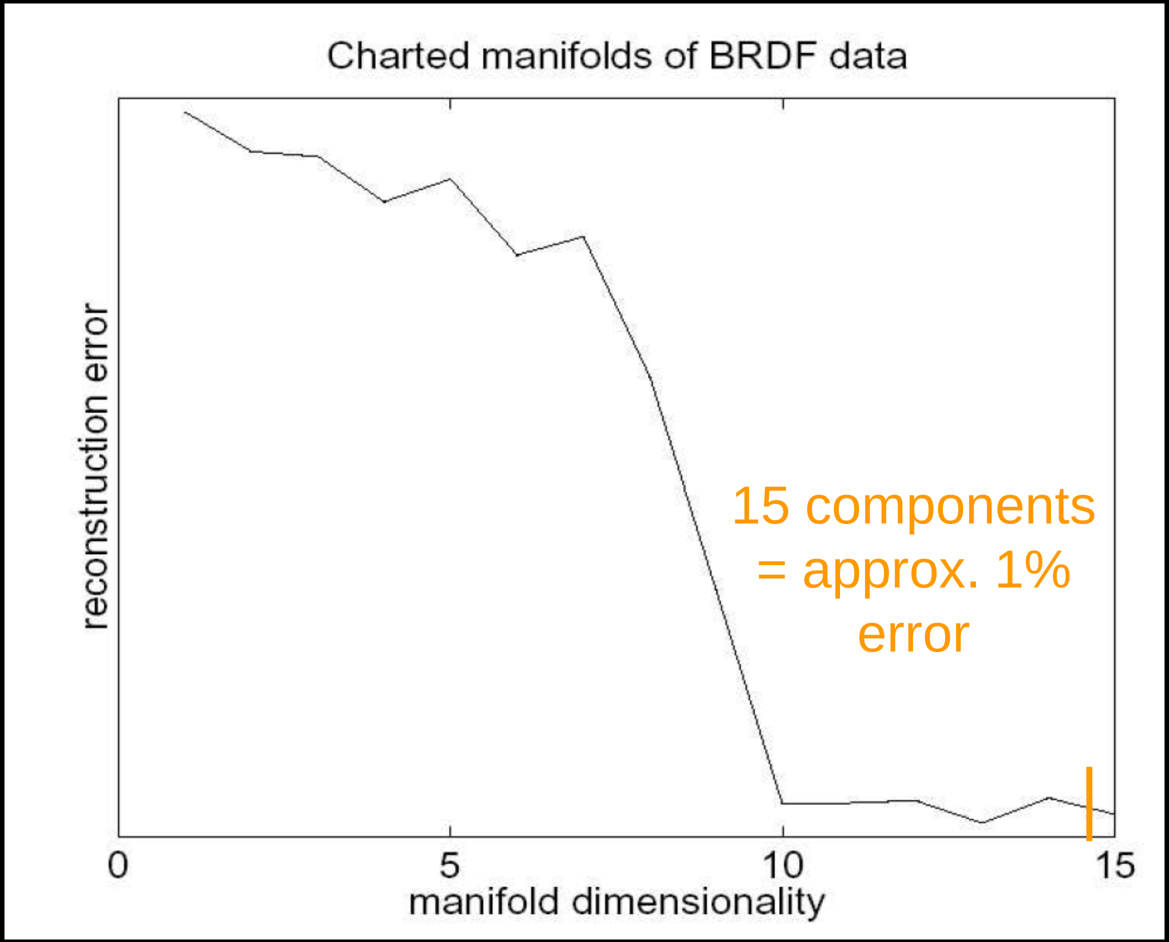


Non-linear Data Analysis



Non-linear Data Analysis

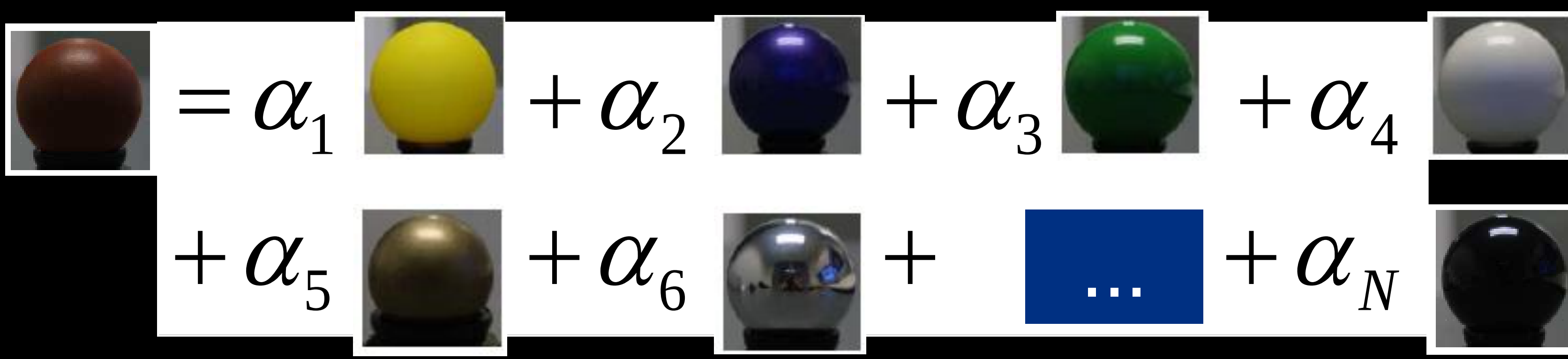
Charter Method [Brand 2003]: kernel-based mixtures of projections that minimizes distortions of local neighborhoods



Non-linear manifold exploration

BRDFs as Basis Functions

Representing a new BRDF as a linear combination of the 100 measured BRDFs



Solution

Linear equation: $b = Pa$

b = linearized BRDF (4M x 1) (new data)

P = matrix of all BRDFs (4M x 100) (MERL database)

a = unknowns (100 x 1)

Hugely over-constrained

(many more knowns than unknowns)

Alternate randomized solution

- 800 rows from the original P (randomly selected)

$$b' = P'a$$

b' = 800 x 1 vector

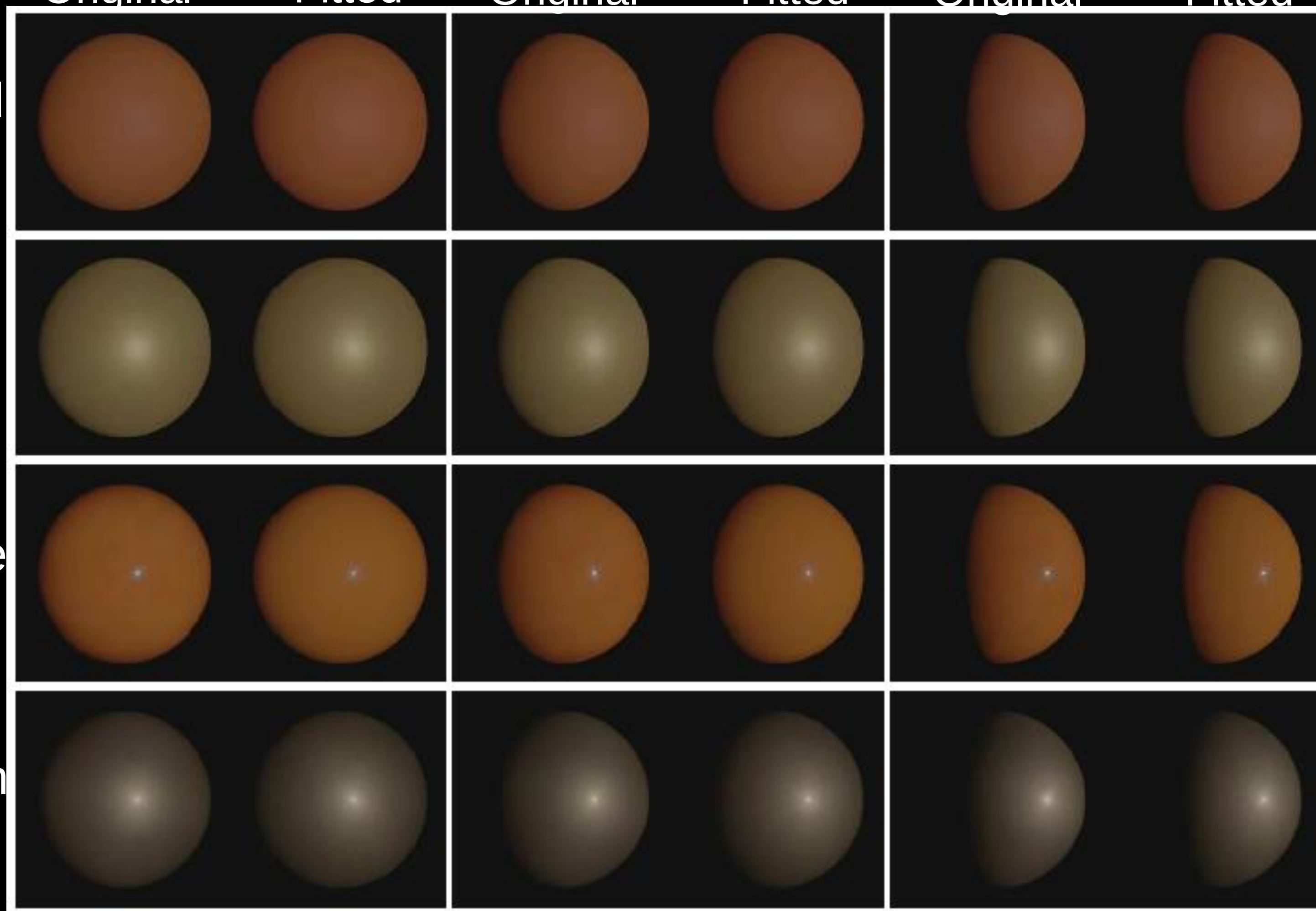
P' = 800 x 100 vector

a = 100 x 1 vector

- 800 (ω_i, ω_o) samples (measurements)

BRDFs as Basis Functions

Original Fitted Original Fitted Original Fitted



Dark-red paint 1.8%

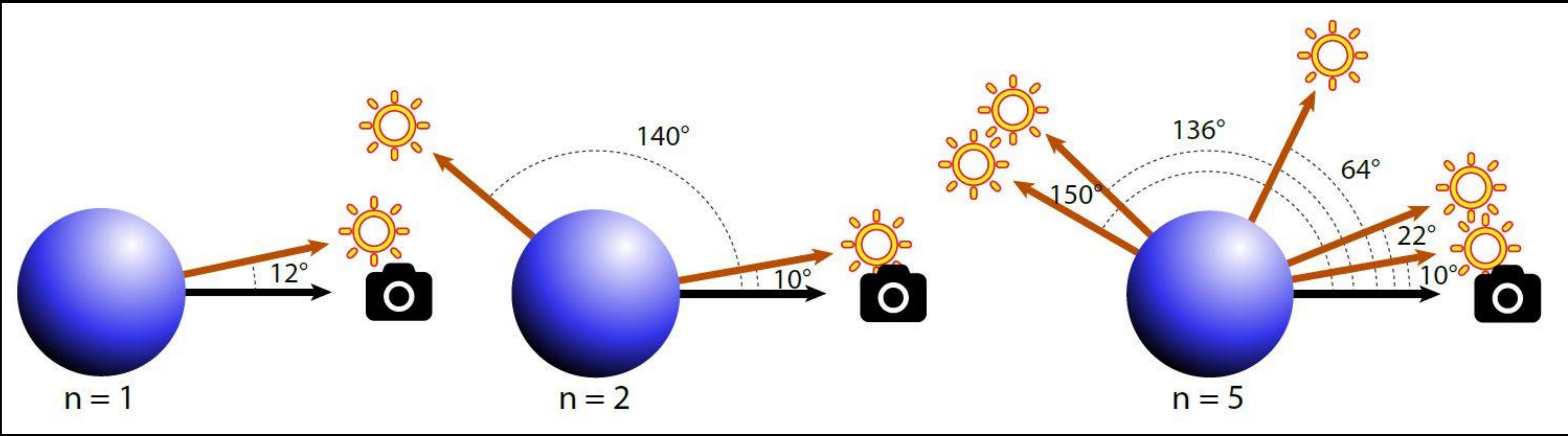
Gold paint 1.8%

Orange plastic 4.3%

Aluminum bronze 2.5%

BRDFs based on 800 samples

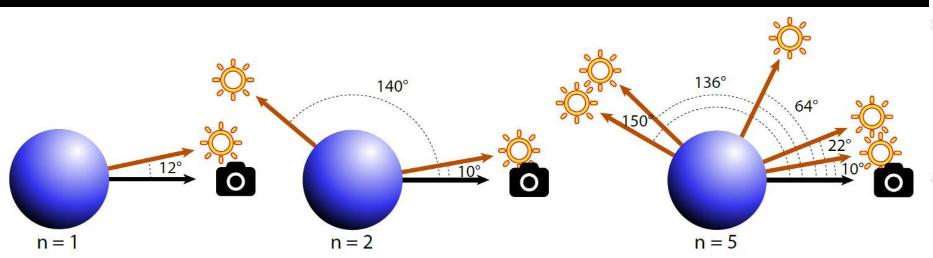
Optimal BRDF sampling [Neilson et al. 15]



- Up to 5 views sufficient for spherical samples
- Fitting based on projection to space spanned by 100 MERL BRDFs

Optimal BRDF sampling

[Neilson et al. 15]



Suggested minimal measurements

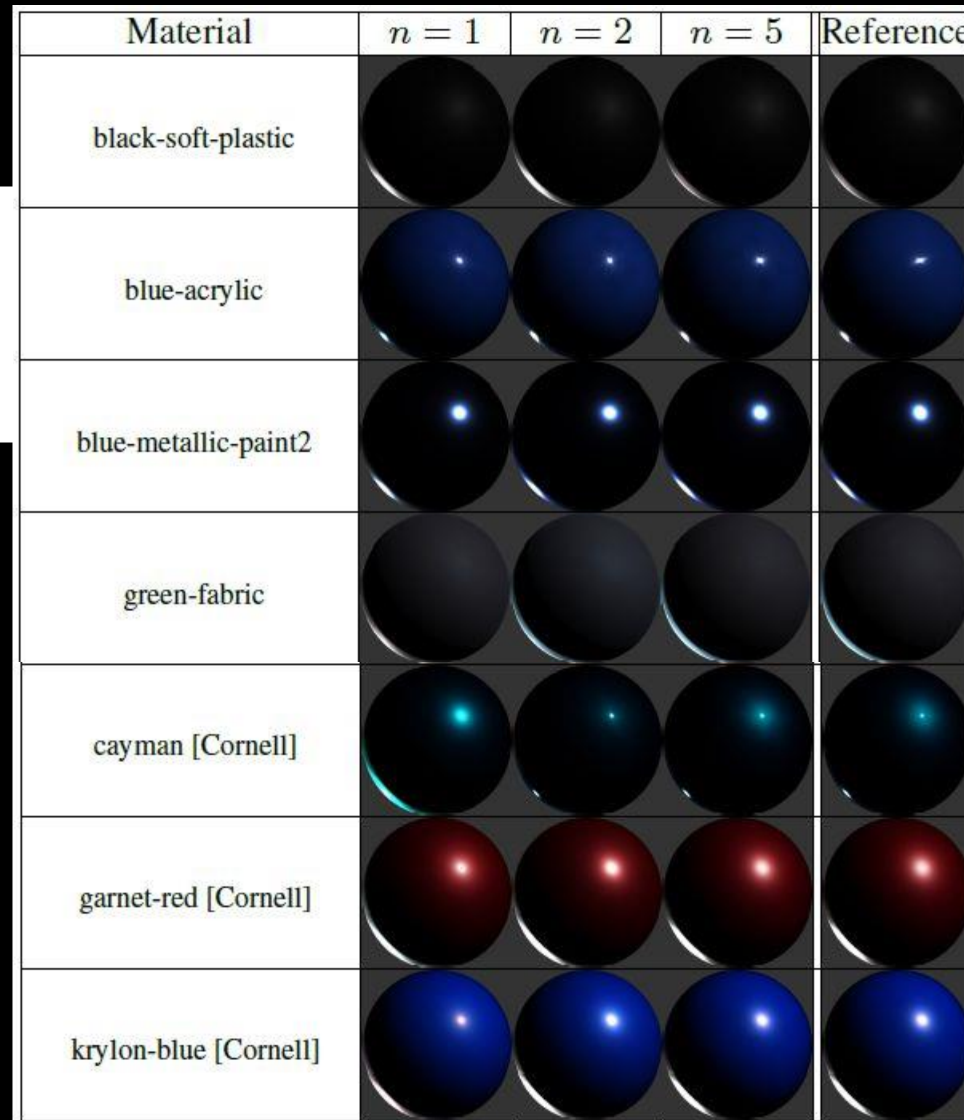
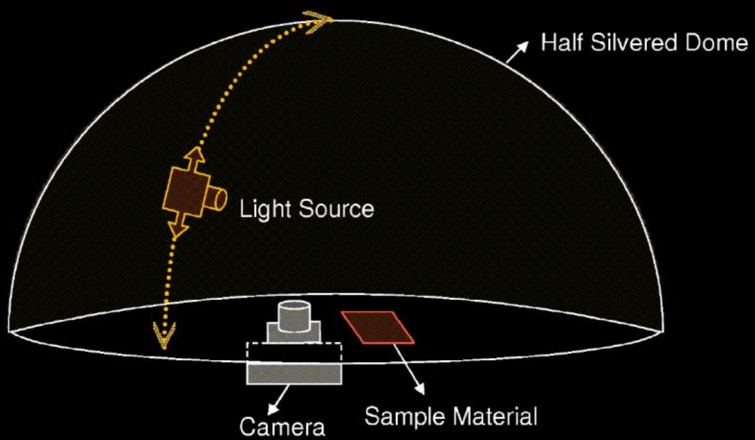
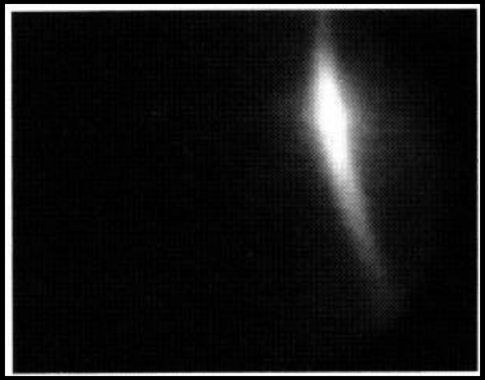


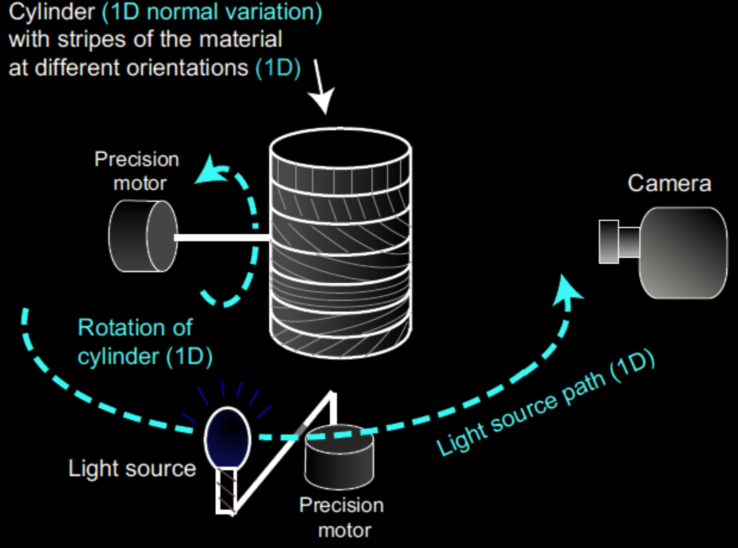
Image-based Measurements

Anisotropic

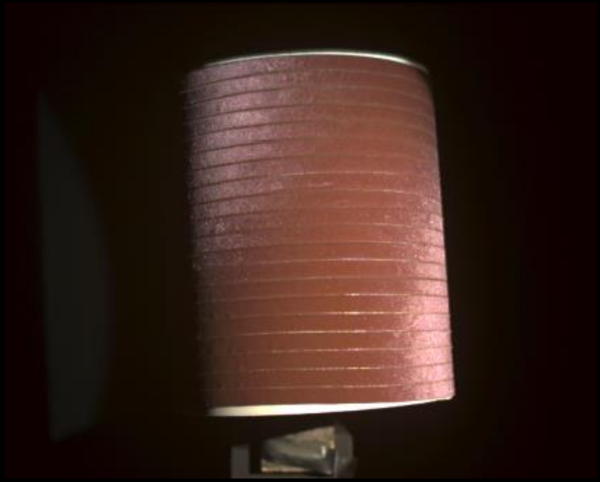


[Ward 92]



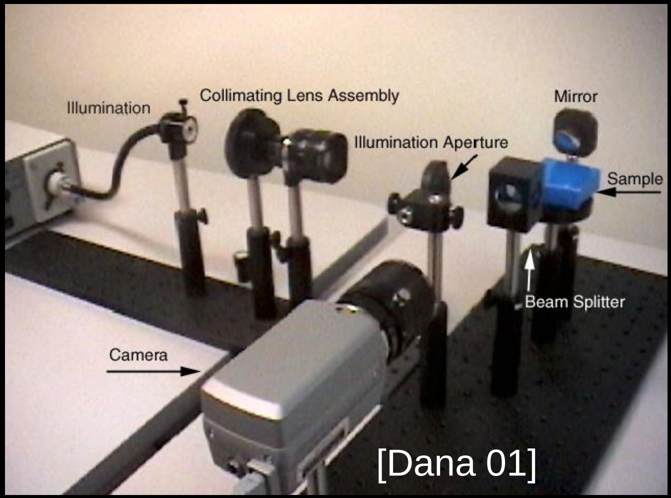


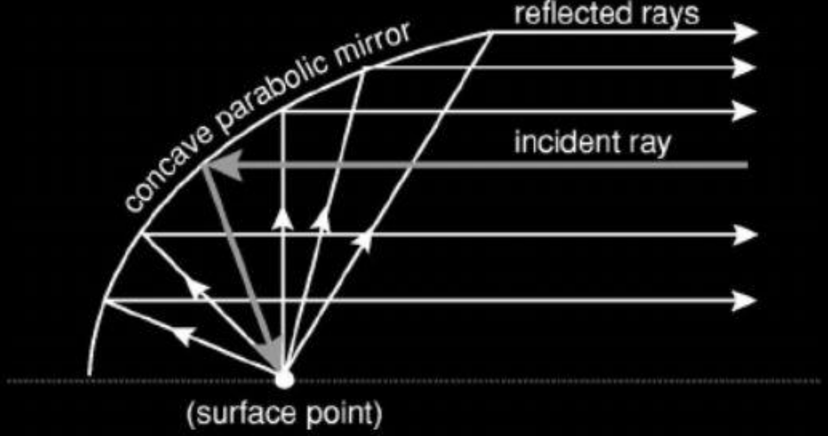
[Ngan et al. 05]

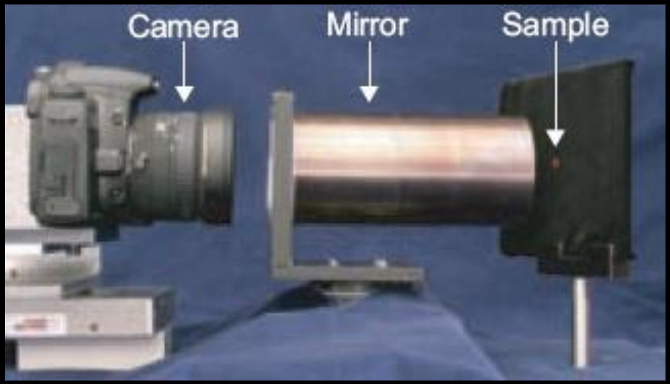


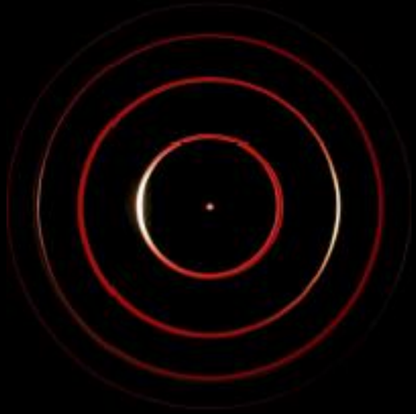
Catadioptric Measurements

Mirrors



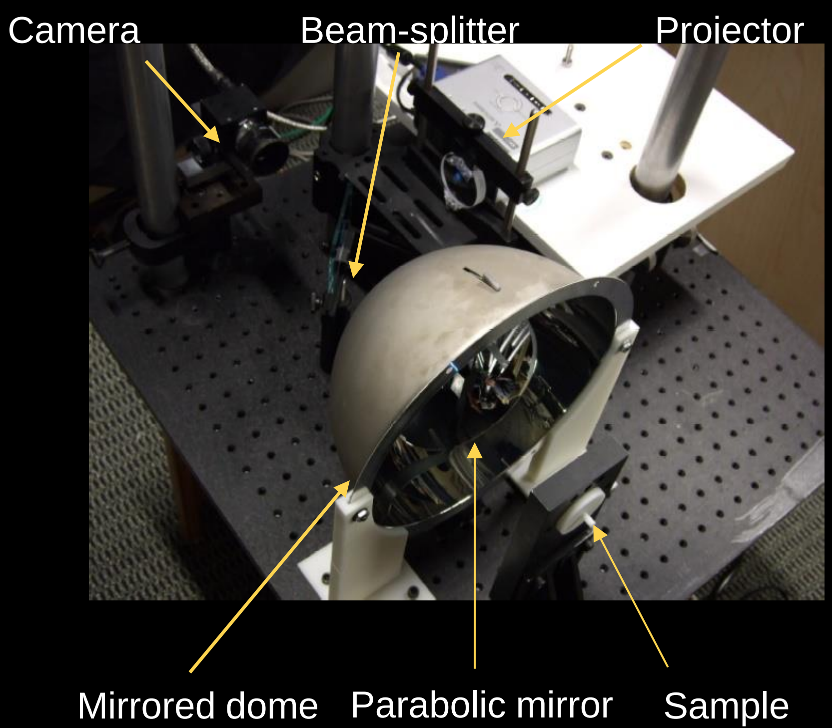




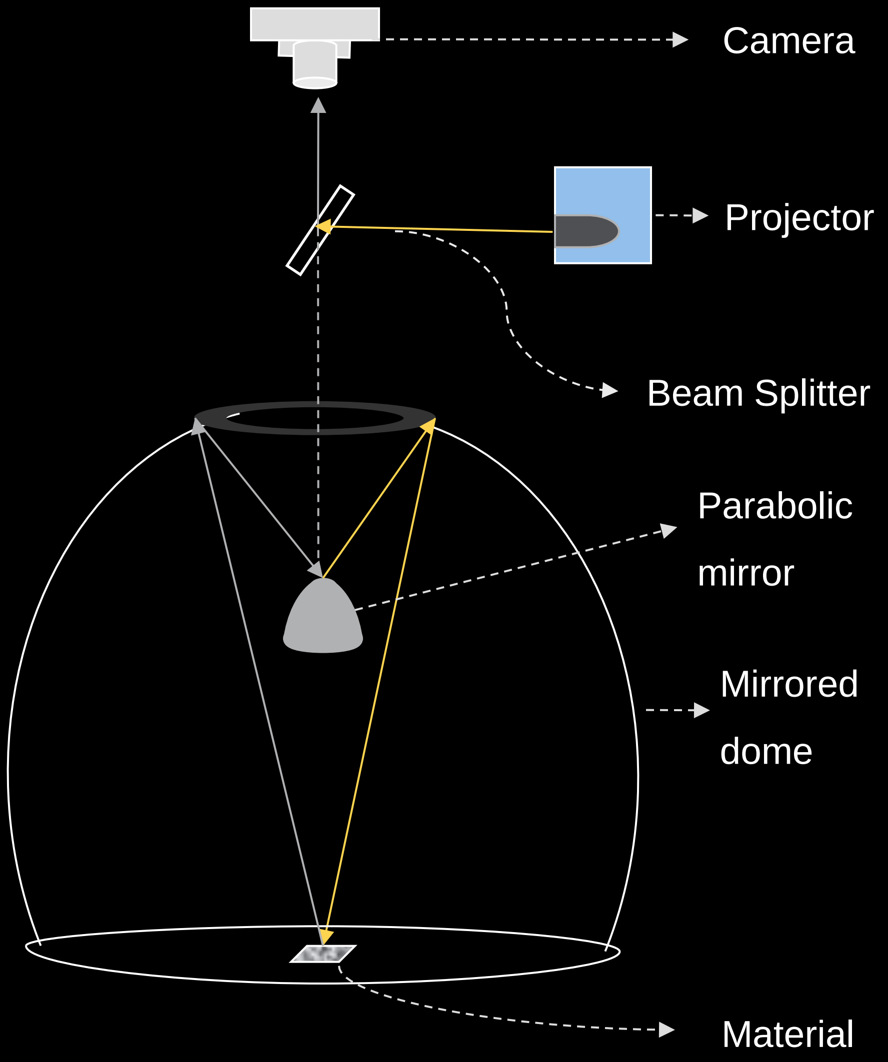


[Kuthirummal&Nayar 06]

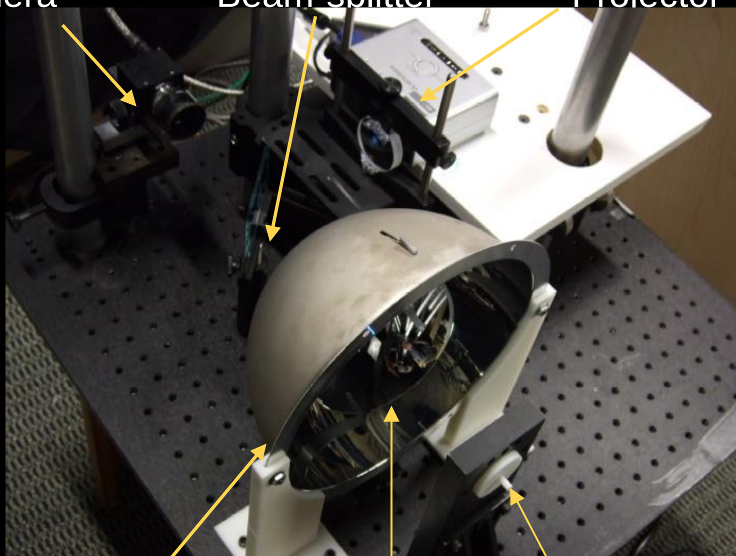
Catadioptric Measurements



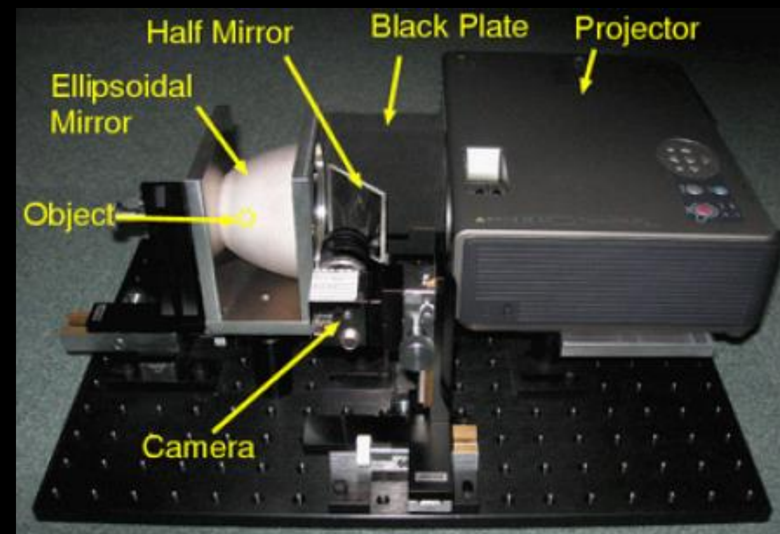
[Ghosh et al. 07]



Catadioptric Measurements



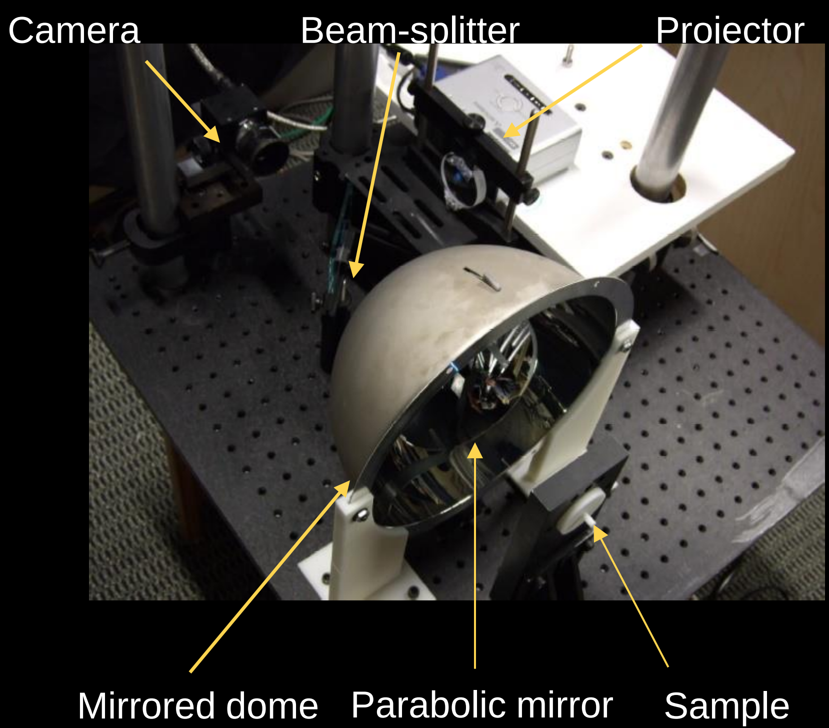
[Ghosh et al. 07]



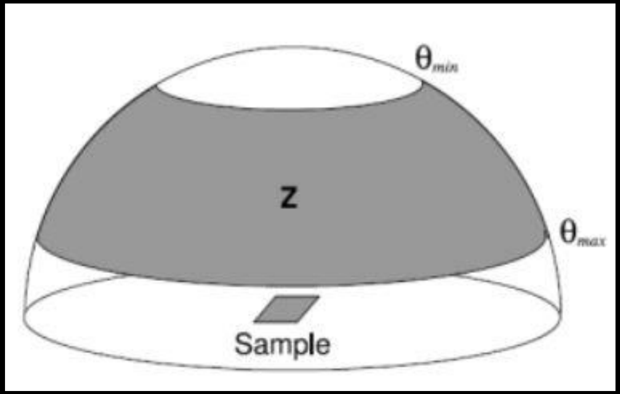
[Mukaigawa et al. 07]

- Mukaigawa et al. point sample the BRDF
- Ghosh et al. project basis functions

Basis Illumination



[Ghosh et al. 07]



Measurement Zone

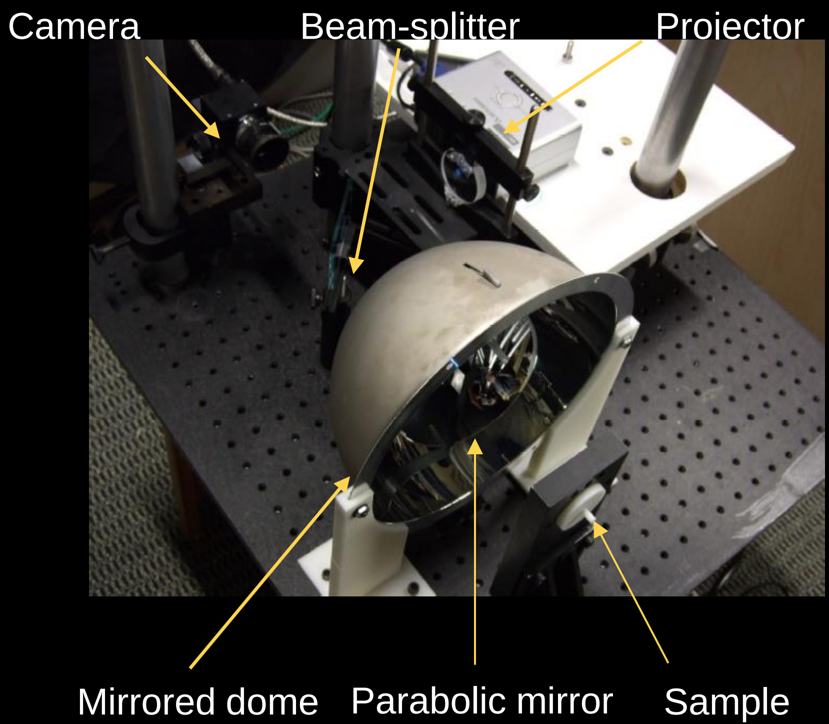
$$\hat{f}_r(\omega_i, \omega_o) = f_r(\omega_i, \omega_o) \cos\theta_i \approx \sum_k Z_k(\omega_i) z_k(\omega_o),$$

$$z_k(\omega_o) = \int_{\mathbf{Z}} Z_k(\omega_i) f_r(\omega_i, \omega_o) \cos\theta_i \, d\omega_i.$$

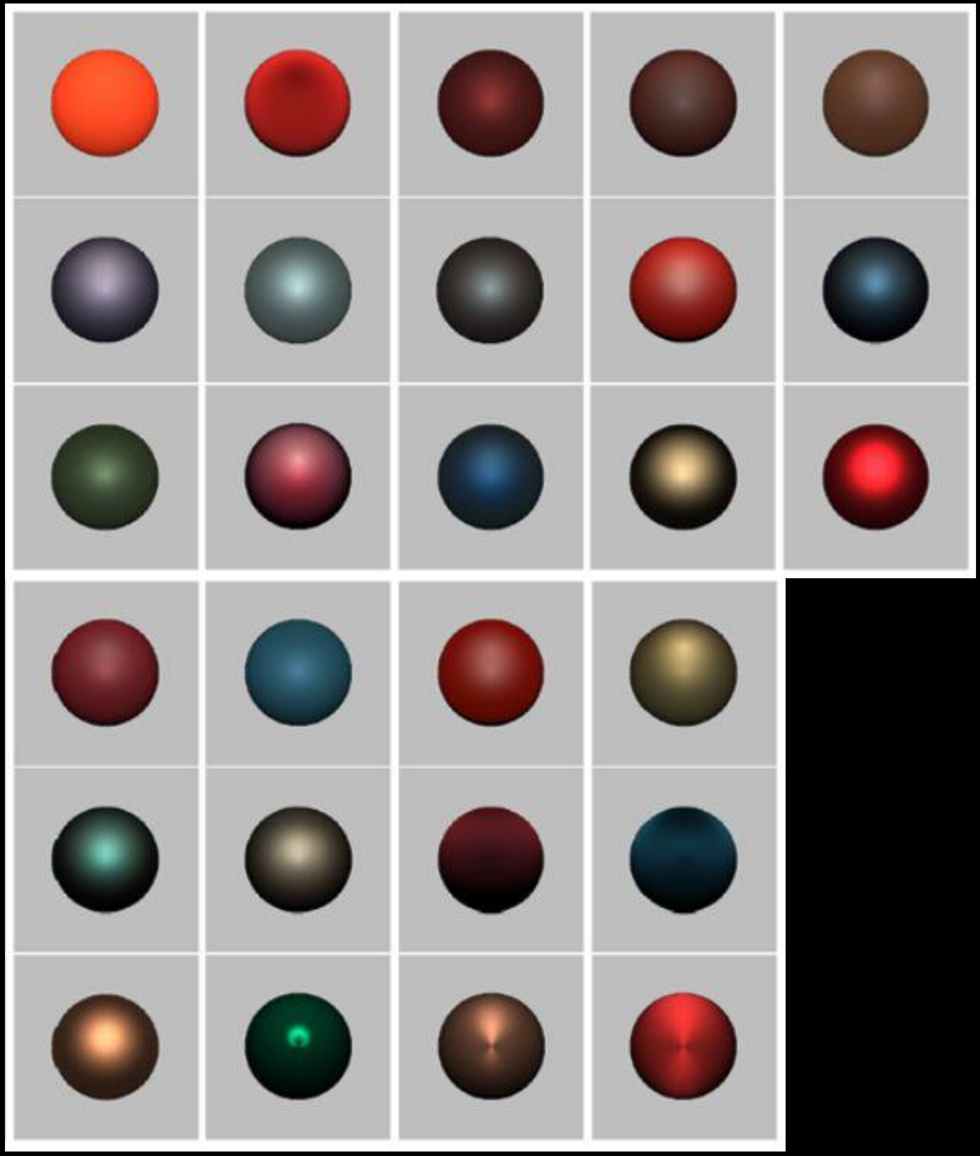
– Zonal basis functions (related to spherical harmonics)

– Coeffiecients of BRDF in the basis recorded

Basis Illumination



[Ghosh et al. 07]



- Zonal basis functions (related to spherical harmonics)
- Coeffiecients of BRDF in the basis recorded

SVBRDF (Spatially Varying BRDFs)

SVBRDF

•6D function (Surface position, incident, exitant)

•Planar surfaces

•Many independent surface points with different BRDFs

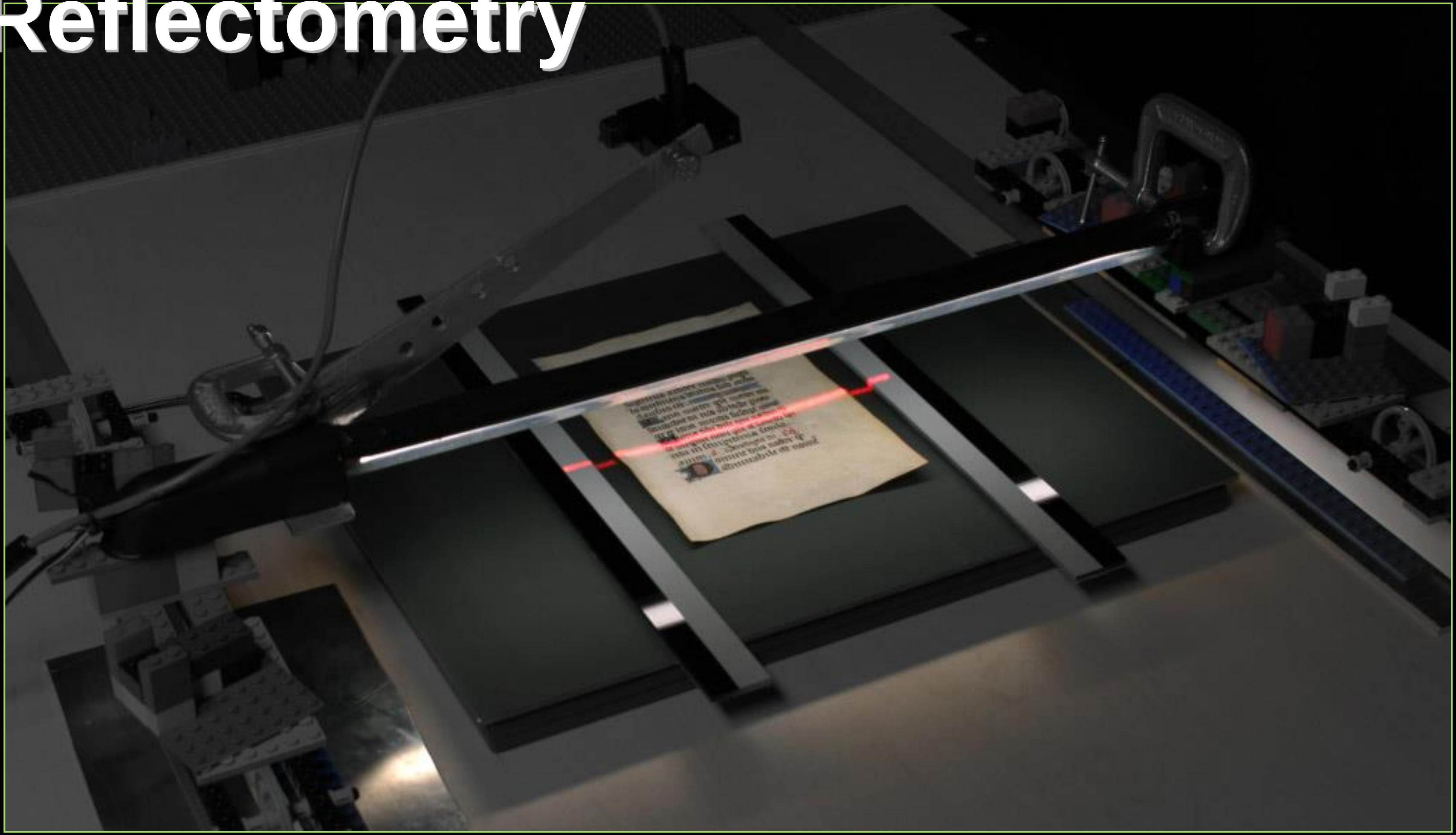
•Not a simple texture!

Question

•How to efficiently capture and model?

- Analytic
- Data-driven
- Statistical/Frequency domain modeling

Linear Light Source Reflectometry



Andrew Gardner, Chris Tchou, Tim Hawkins, and Paul Debevec, SIGGRAPH 2003

Linear Light Source Reflectometry

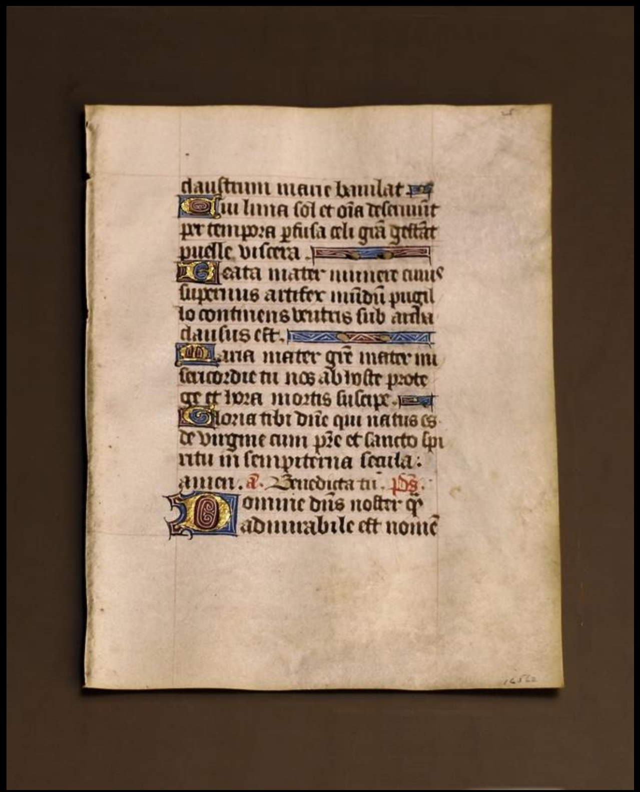
Linear light source

+

+

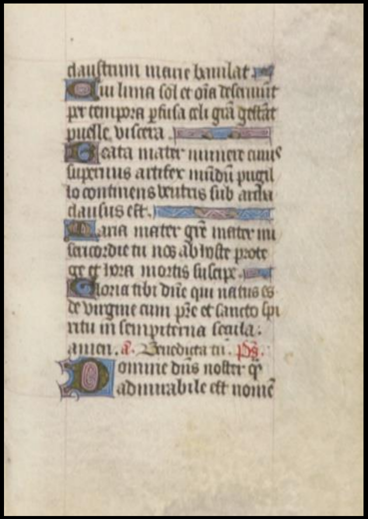
Legos

=

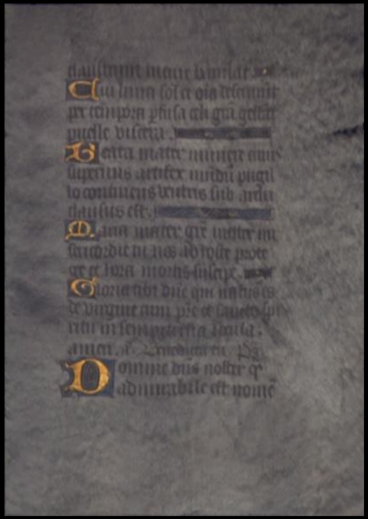


SVBRDF sample

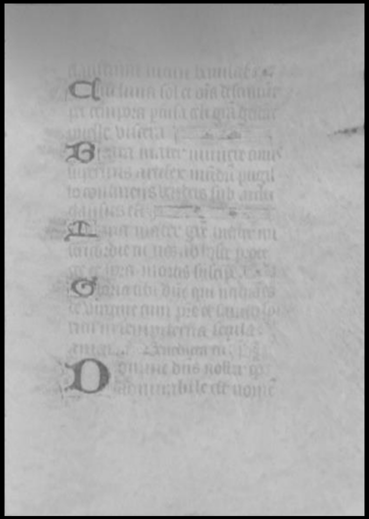
SVBRDF Parameters



Diffuse Intensity

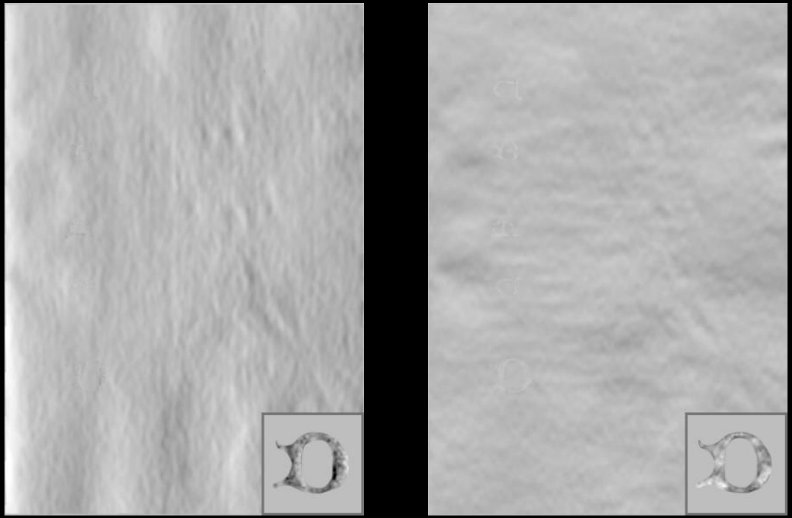


Specular Intensity

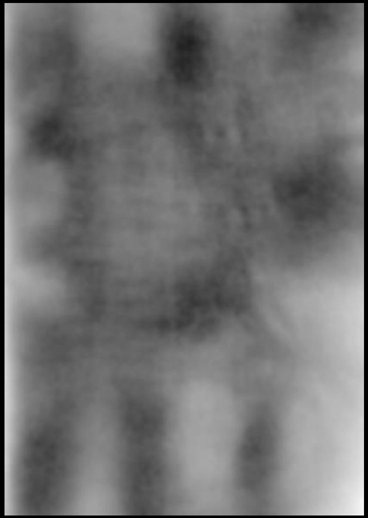


Specular Roughness

Translucency

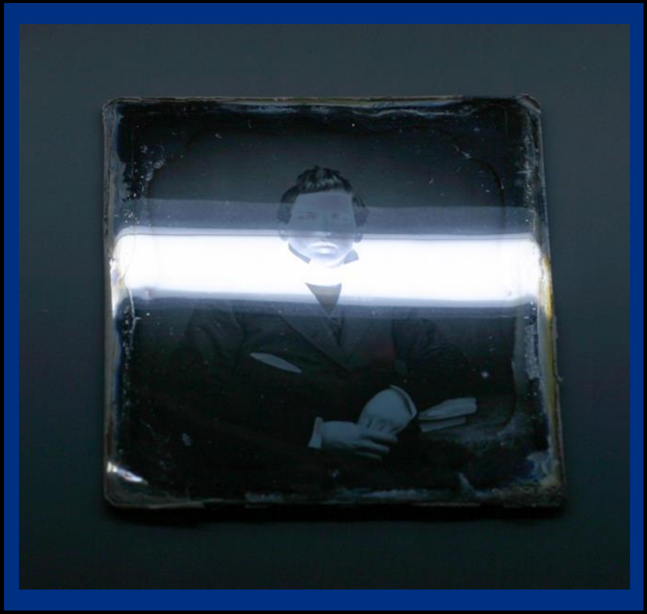


Normals (X & Y gradients)



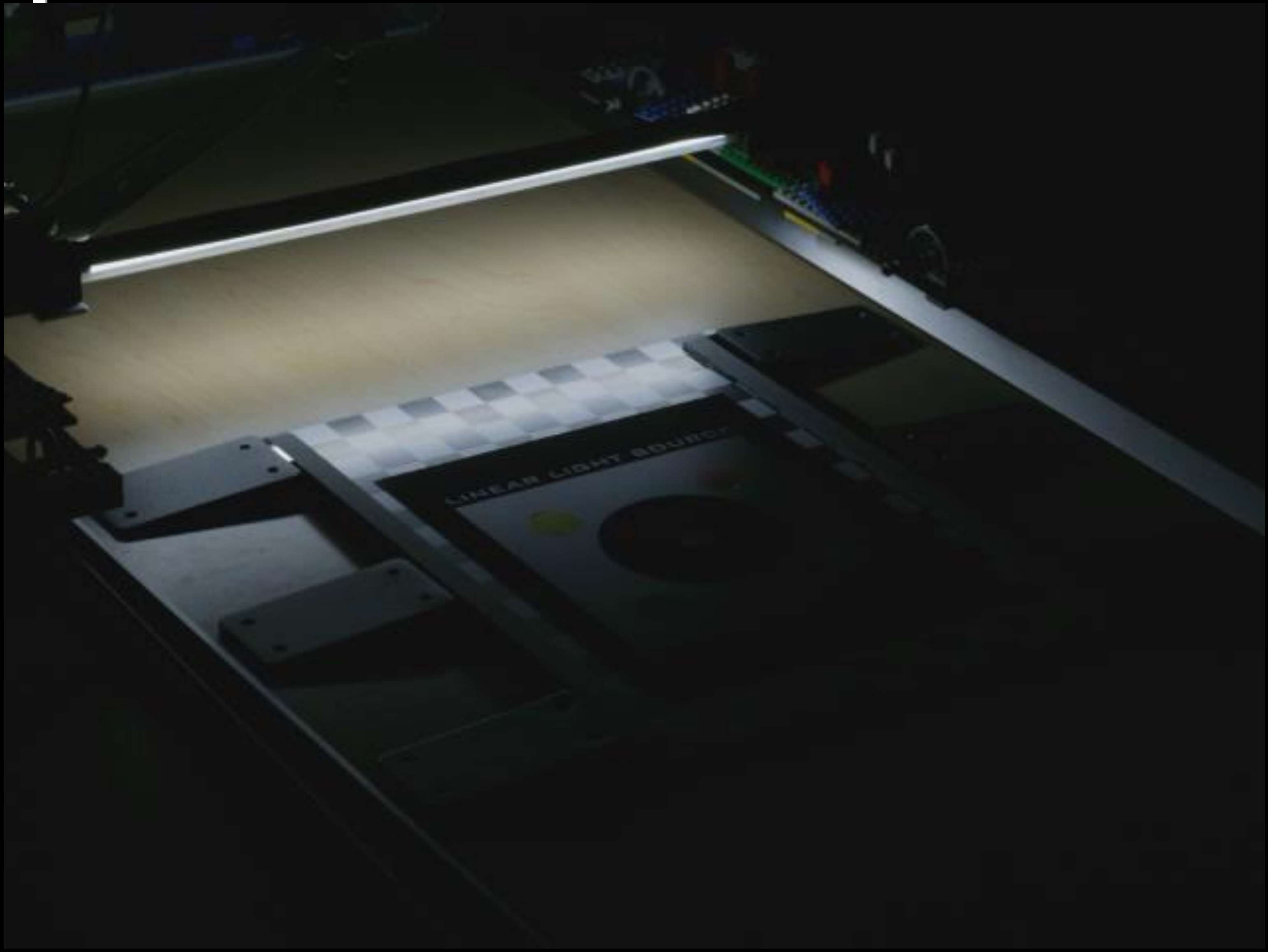
Displacement

Motivation: Linear Light Source



- Fewer images needed to cover planar samples with linear light source
- Dynamic range compression compared to point light source
  - can be photographed with single exposure instead of HDR
- Simple machinery of linear 1D translation to cover entire sample

Capture



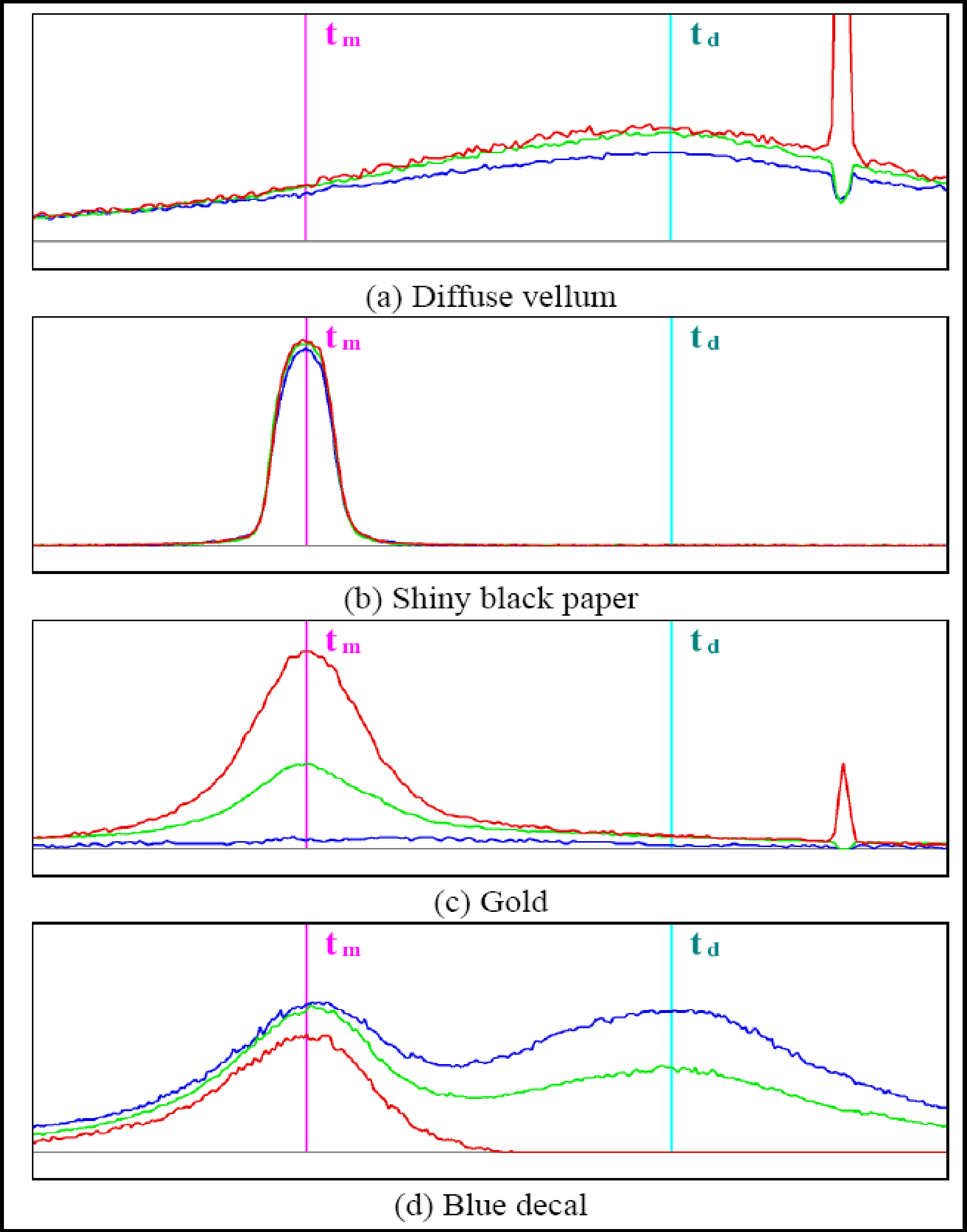
Reflectance trace for each pixel

X-axis: time (light motion)

Y-axis: reflectance

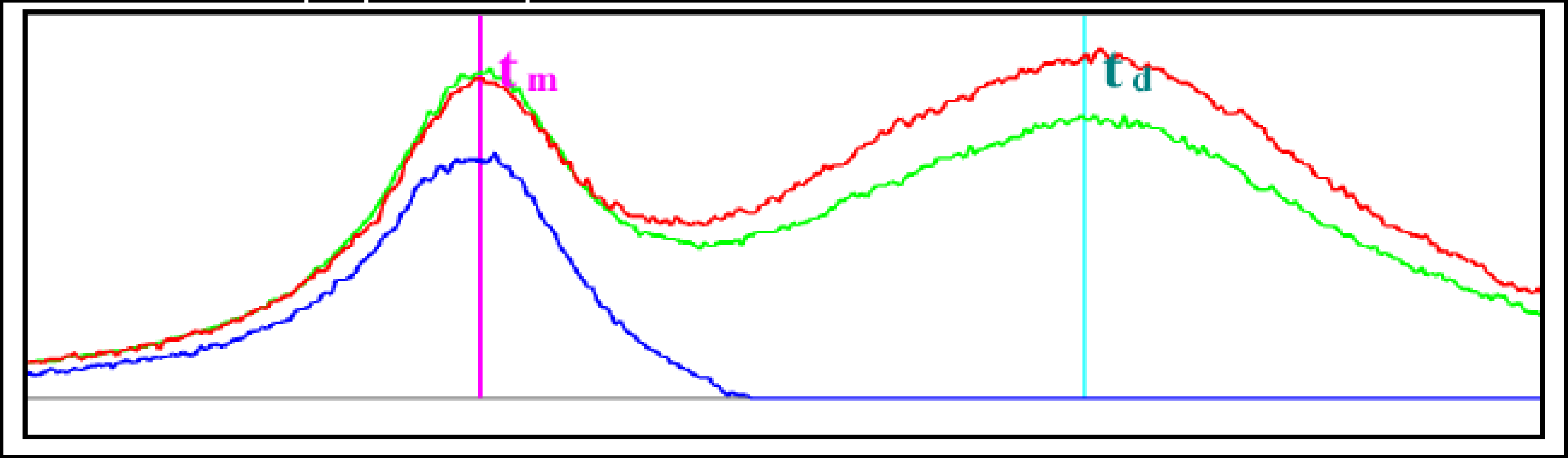
Diffuse peak td coincides with light aligned with surface normal

Specular peak tm coincides with light aligned with mirror reflection



BRDF Fitting

1. Fit diffuse
2. Subtract diffuse
3. Estimate mean and variance of specular
4. Look-up specular parameters



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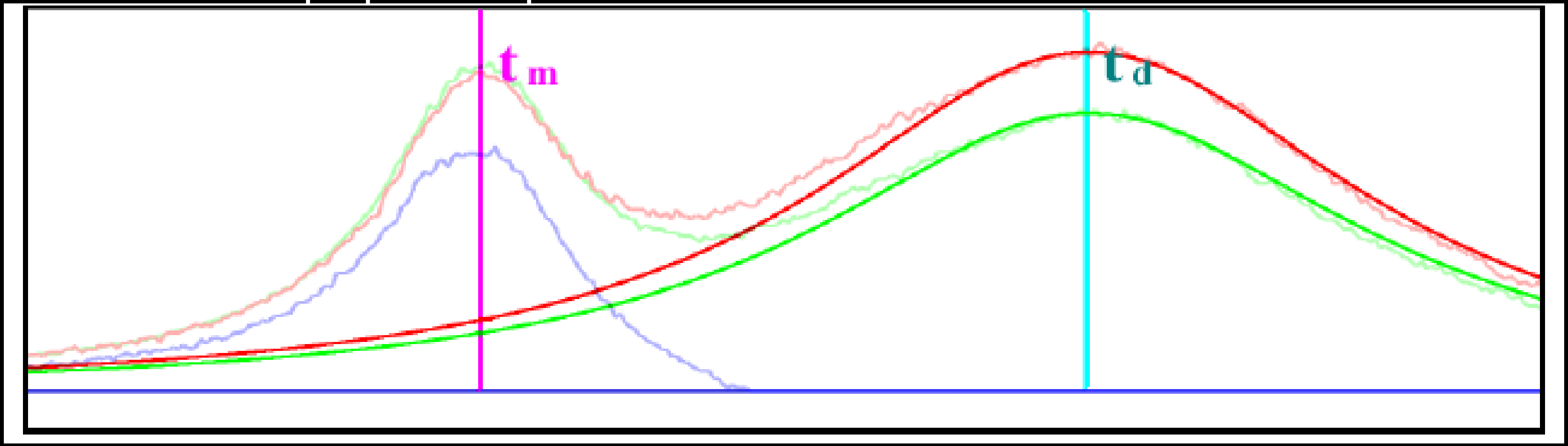

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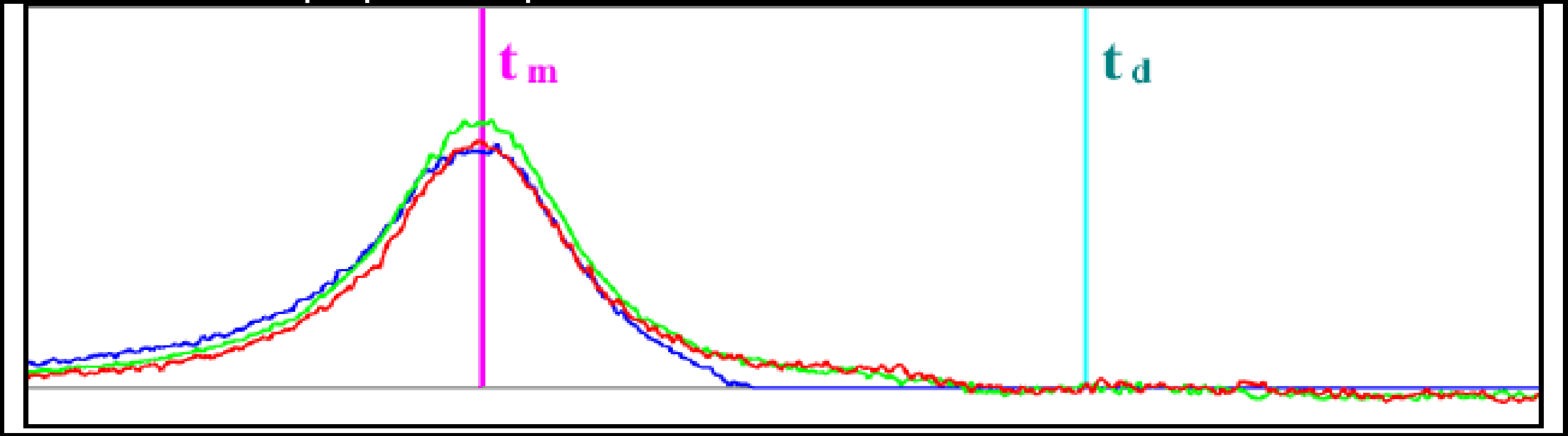

BRDF Fitting

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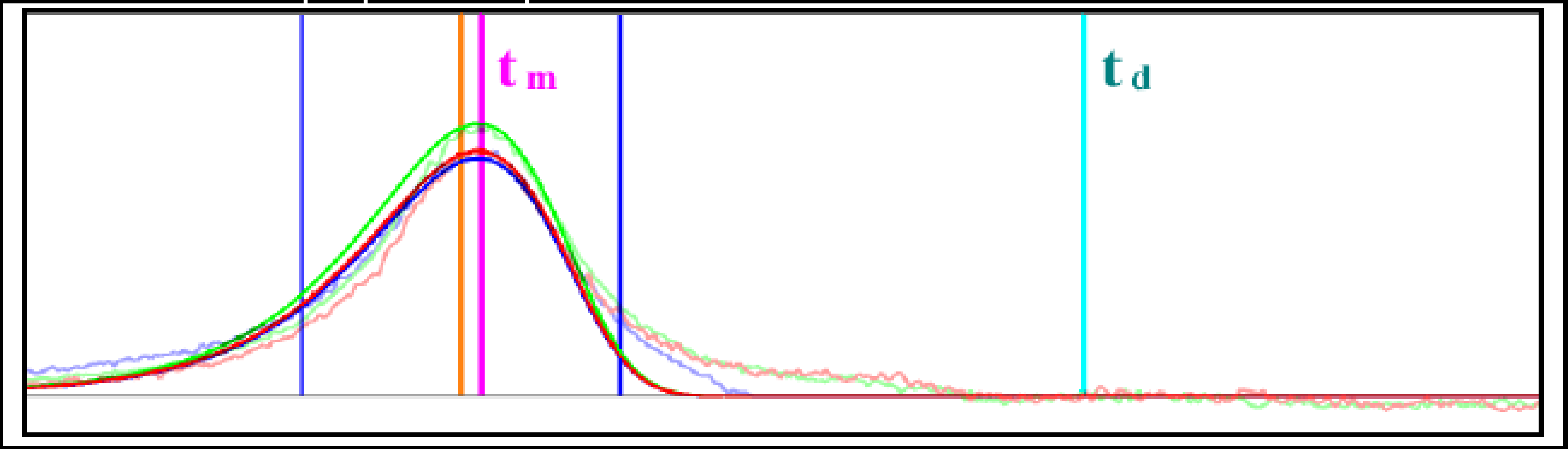
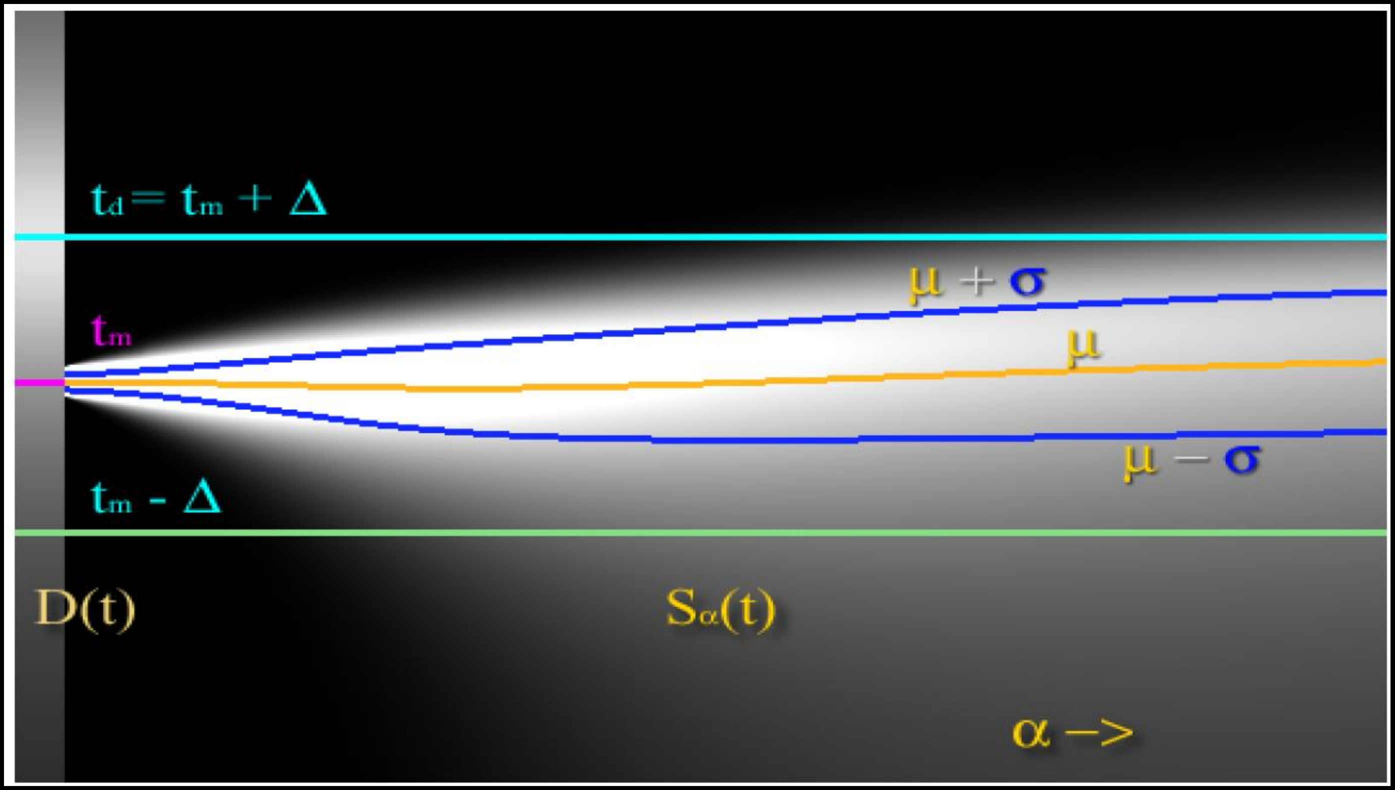
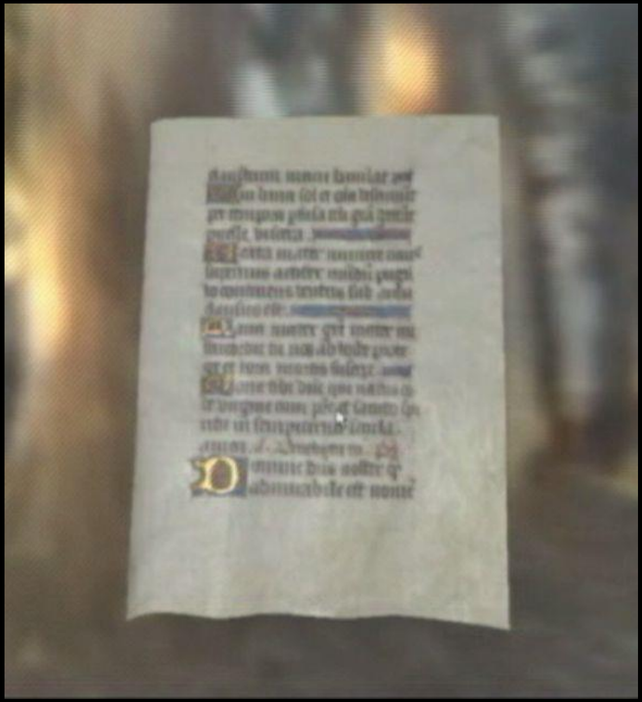


BRDF Fitting

1. Fit diffuse
2. Subtract diffuse
3. Estimate mean and variance of specular



Results



Pocket Reflectometry

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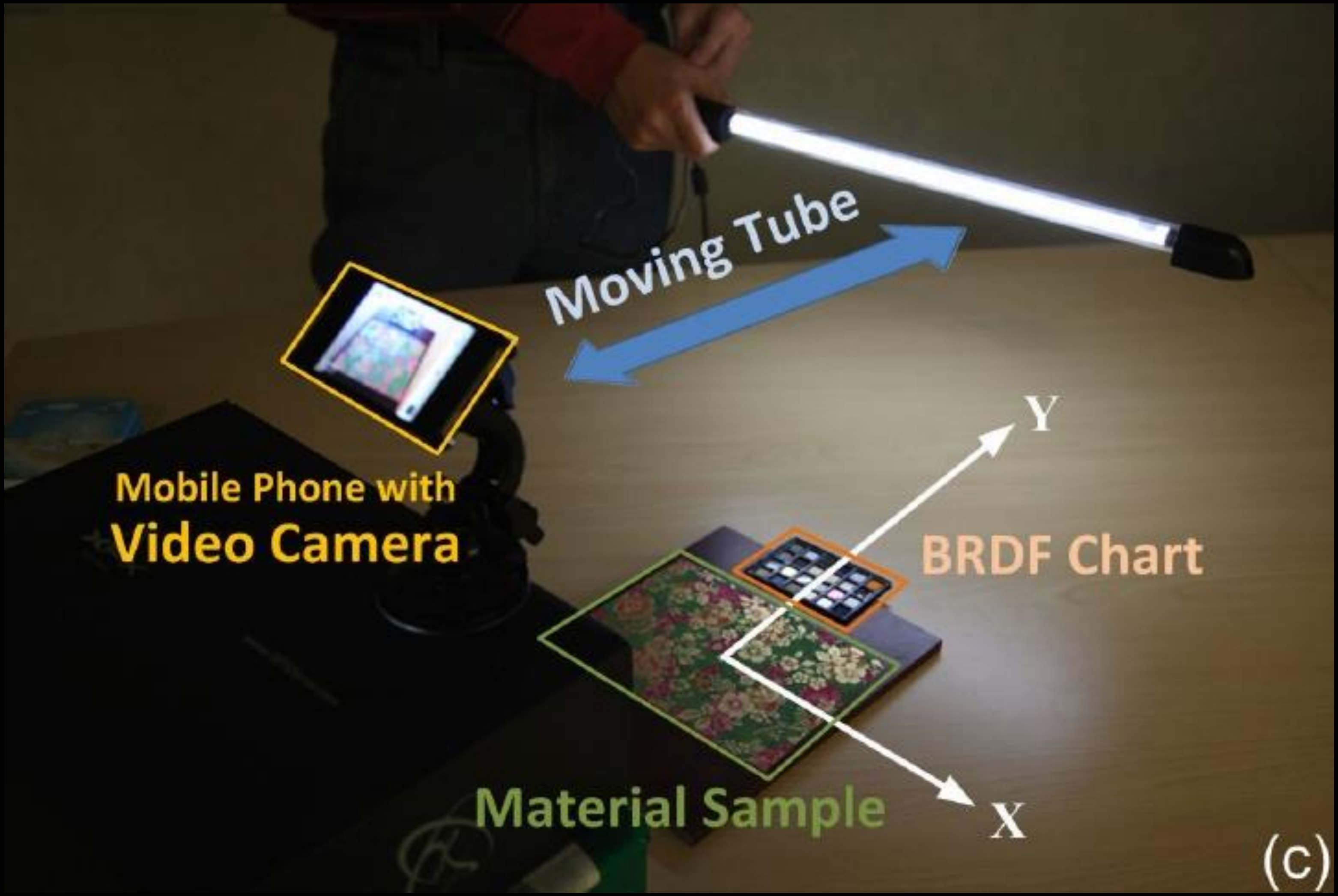
Ren et al. SIGGRAPH 2011

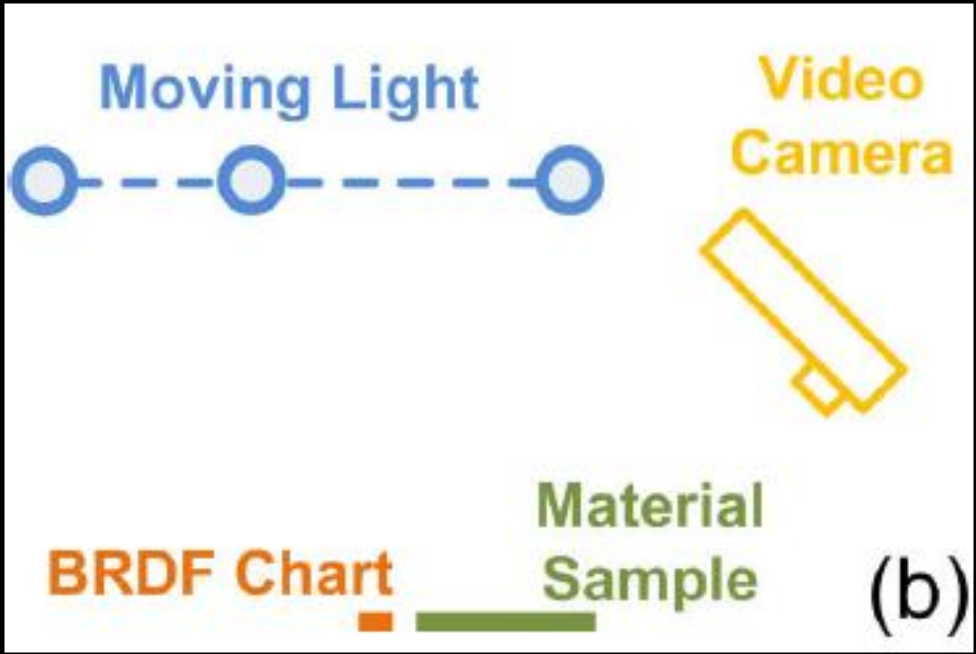
Pocket Reflectometry



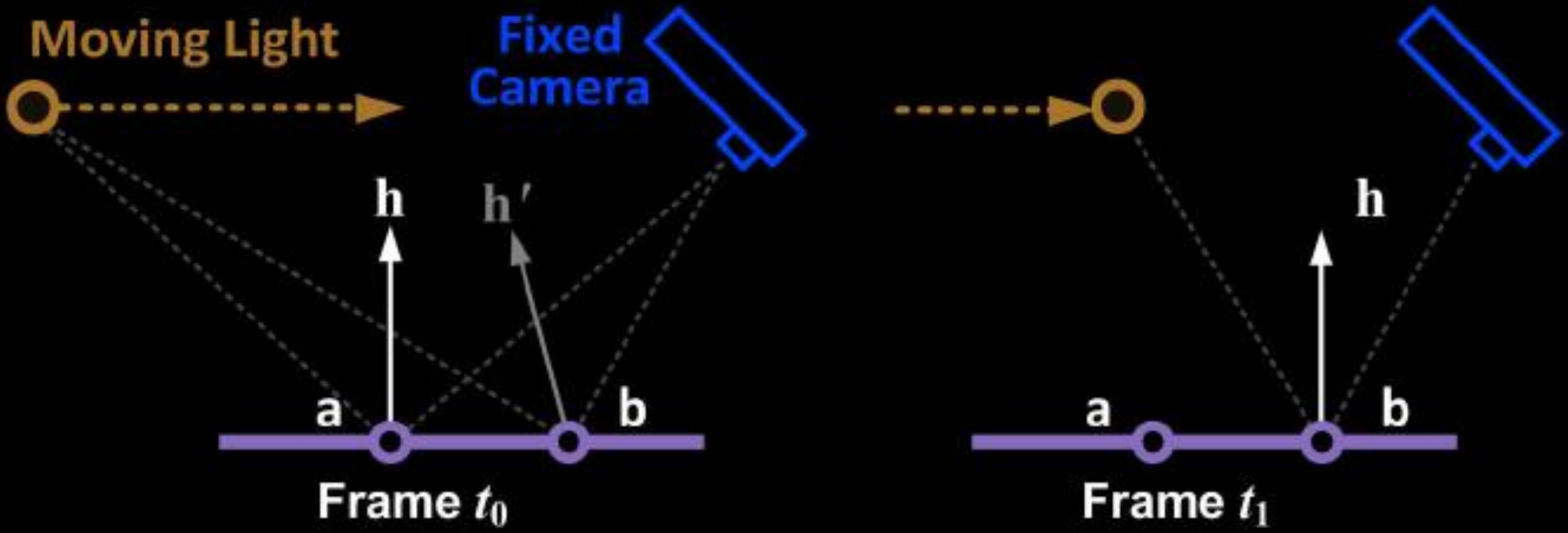
BRDF chart

plaster	sliver paint	rubber	polished acrylic	aluminium	fluorescent paint
matte tape	black paper	polished resin	bronze	bronze metallic paint	acrylic
plastic	brass	coated metallic paint	polyethylene	red metallic paint	alumina
80% Spectralon	leather	matte golden paint	alum-bronze	tinfoil	lactoprene

Pocket Reflectometry

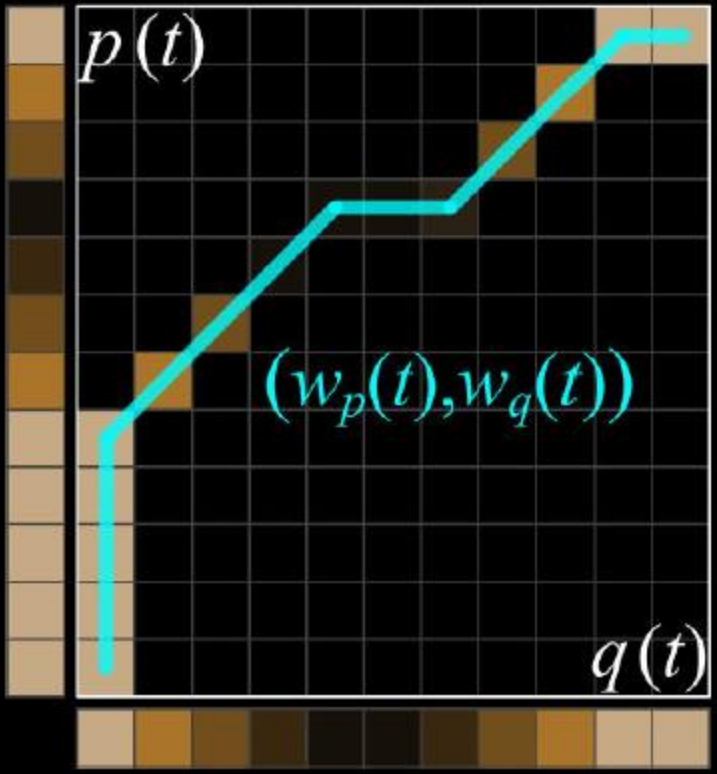


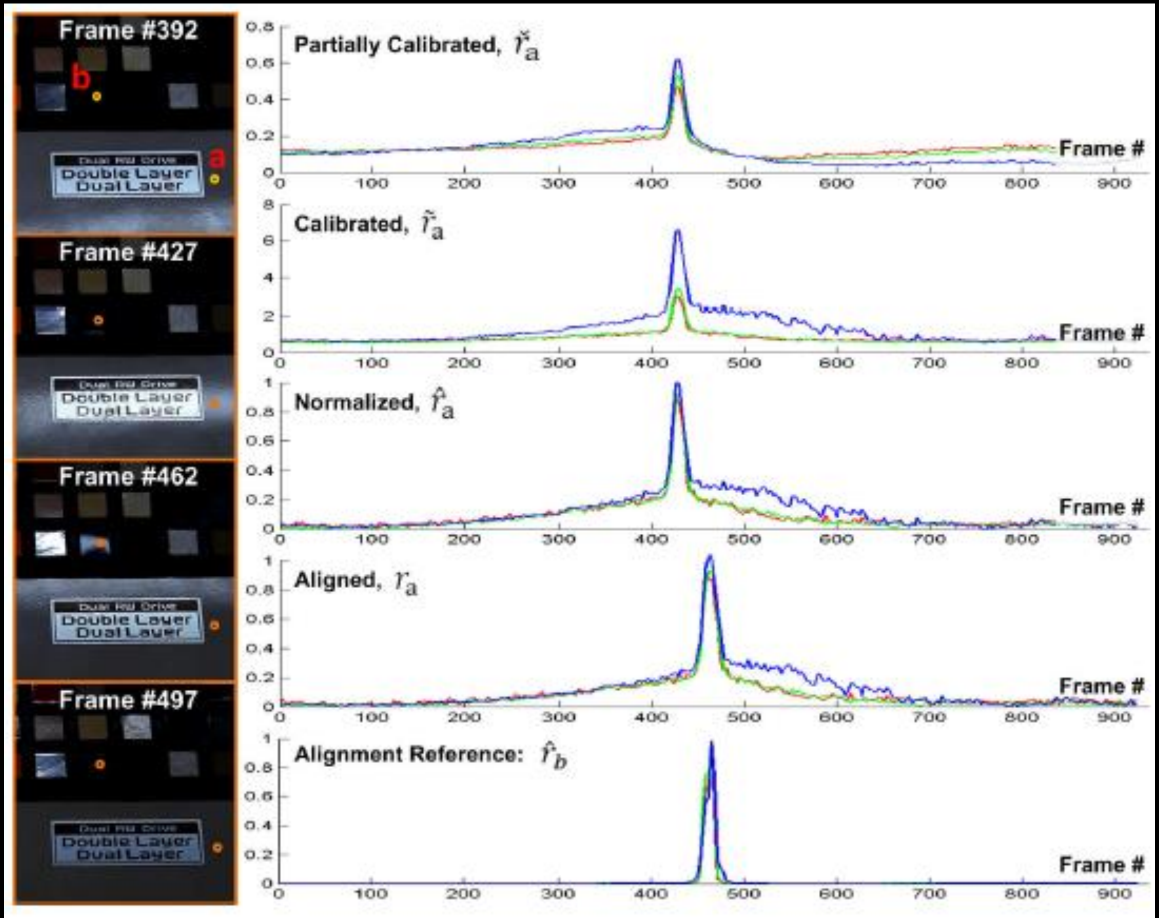
Time-shift compensation



- Different surface points will have their peaks at different time (frame)
- Reflectance trace of BRDF chart cannot be directly compared with sample

Dynamic time warping





- Alignment of reflectance traces of BRDF chart with sample

Reflectance estimation from chart

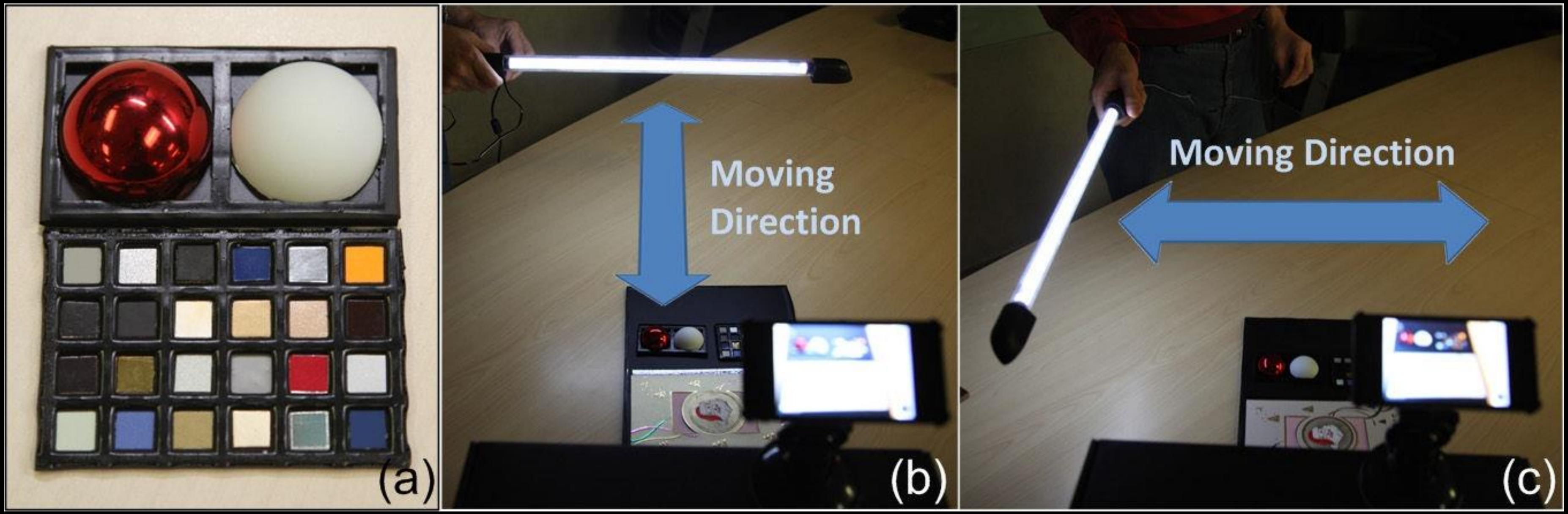
$$\mathbf{r} = d\,\mathbf{a} + s\,\mathbf{b},$$

$$a(t) = \int_{\Omega^+} L_t(\mathbf{i})\,\alpha(\mathbf{i},\mathbf{o})\,(\mathbf{n}\cdot\mathbf{i})\,\mathrm{d}\mathbf{i}, \quad b(t) = \int_{\Omega^+} L_t(\mathbf{i})\,\beta(\mathbf{i},\mathbf{o})\,(\mathbf{n}\cdot\mathbf{i})\,\mathrm{d}\mathbf{i},$$

$$\min_{u_0, u_1, \cdots, u_k} \left\| \mathbf{r} - u_0\,\mathbf{a} - \sum_{j=1}^{k} u_j\,\mathbf{b}_j \right\|, \quad u_j \geq 0, \;\; \mathbf{b}_j \in \Phi(\mathbf{r})$$

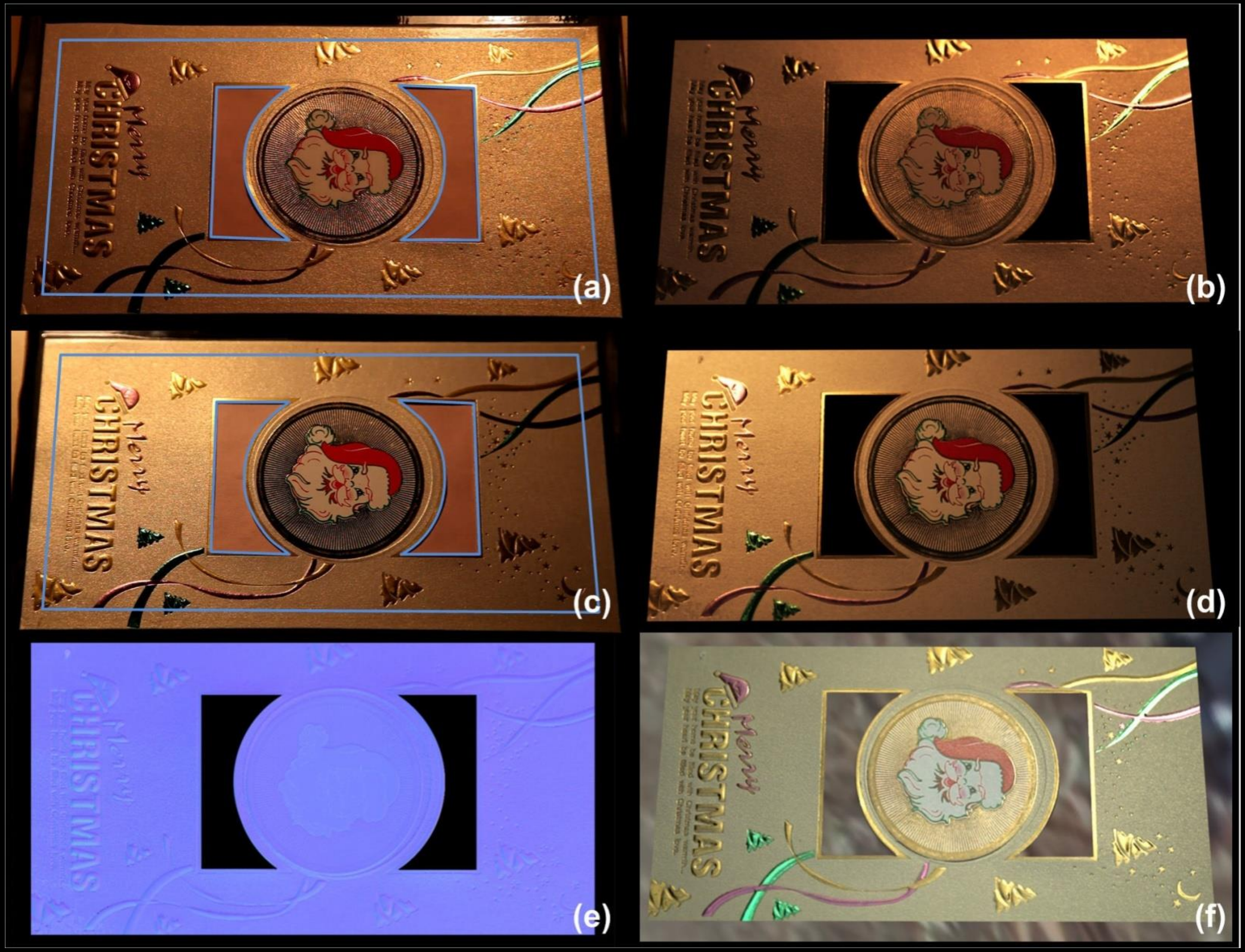
- a diffuse BRDF with albedo d
- b specular BRDF with parameters s
- Instead of direction estimation of s, estimate a linear combination of k exemplar BRDFs in BRDF chart

Bumpy surface estimation

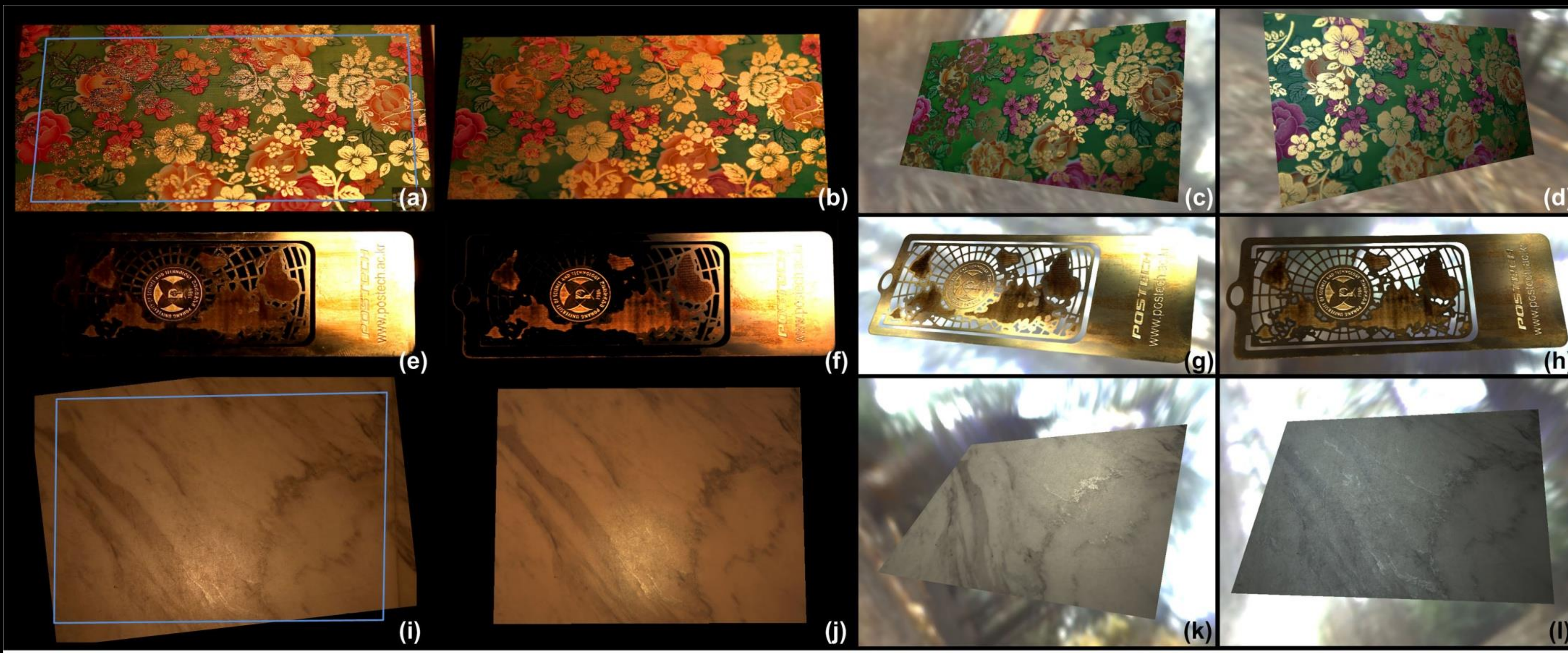


- Compute surface normal as intersection of two orthogonal passes of light source to estimate X & Y components of surface normals
- Assumption mostly flat surface, so no need to estimate z component

Bumpy surface results



Flat surface results

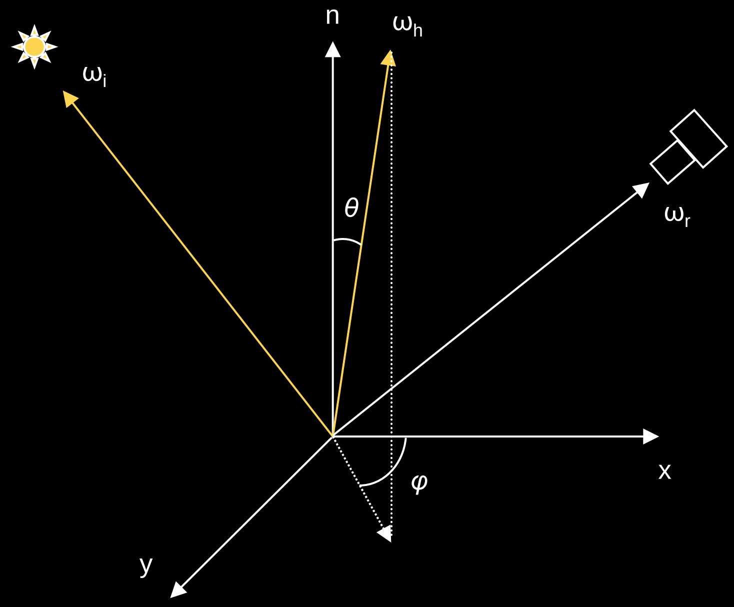


Real Photo in Incandescent Bulb | Rendering Result in Incandescent Bulb | Rendering Results in Natural Environmental Lighting

Measure and fit

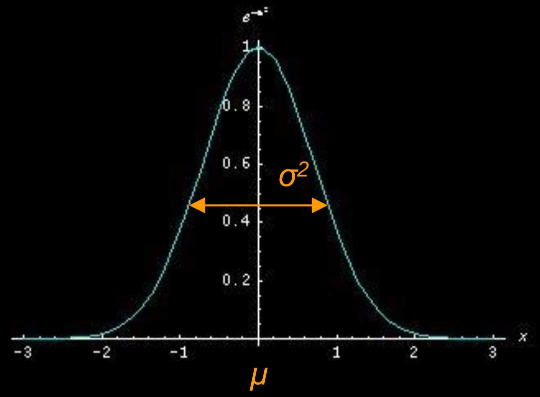
- Analytic BRDF models
  - albedo
  - specular roughness
  - normal and tangent directions

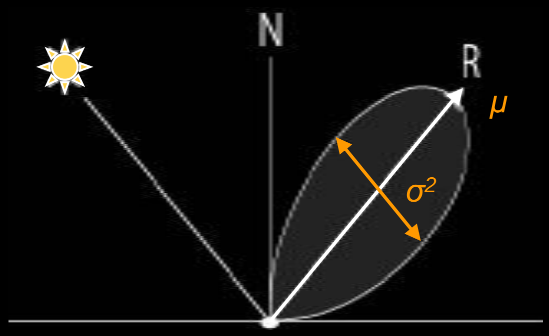
- Is DIRECT estimate possible?



2^{nd} order statistics of reflectance [Ghosh et al. 09]

- Specular reflection
  - measure of variance σ^2 about mean μ
  - reflection vector and specular roughness
  - computational illumination for optical measurement of reflectance statistics!





0^{th}, 1^{st} & 2^{nd} moments

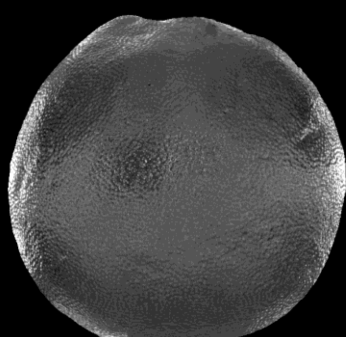
- In 1D, the moments of f(x):
  - total energy *α*
  - mean *μ*
  - variance σ^2

$$
\begin{aligned}
\alpha &= \int \mathbf{f}(x)\,dx = L_0, \\
\mu &= \int x \frac{\mathbf{f}(x)}{\alpha}\,dx, \\
&= \frac{1}{\alpha}\int x\,\mathbf{f}(x)\,dx = \frac{L_1}{L_0}, \\
\sigma^2 &= \int (x-\mu)^2 \frac{\mathbf{f}(x)}{\alpha}\,dx, \\
&= \frac{L_2}{L_0} - \frac{L_1^2}{L_0^2}.
\end{aligned}
$$

0^{th} spherical moment

parallel

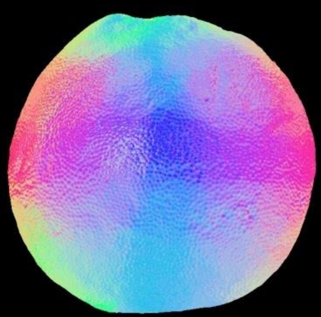
cross



$$L_0 = \int_{\Omega} \mathbf{f}(\vec{\omega})\, d\vec{\omega},$$

α

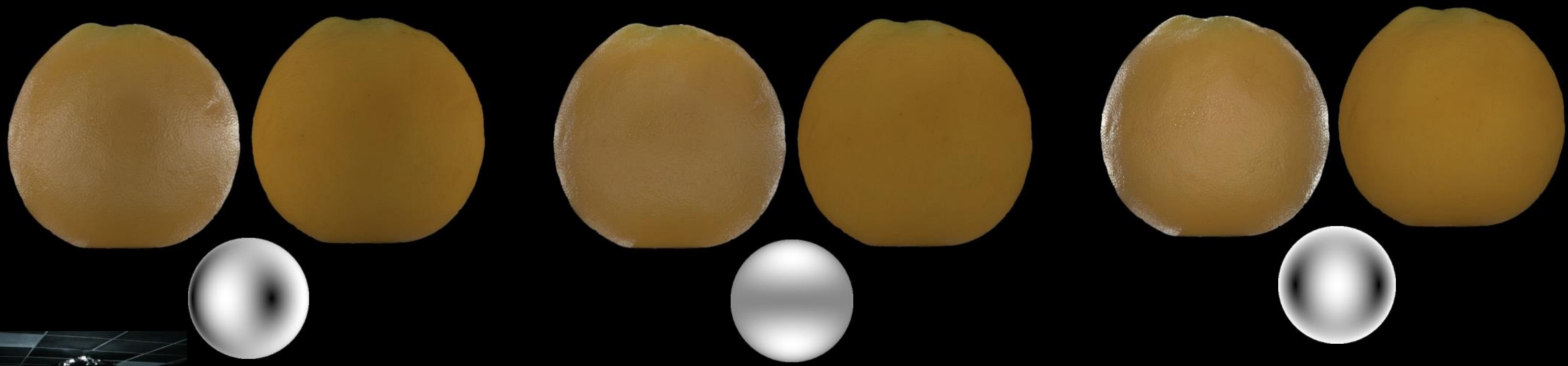
1st spherical moment

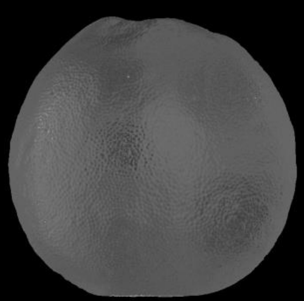


$$L_1 = \int_\Omega \vec{\omega}\, \mathbf{f}(\vec{\omega})\, d\vec{\omega},$$

μ

2nd spherical moment



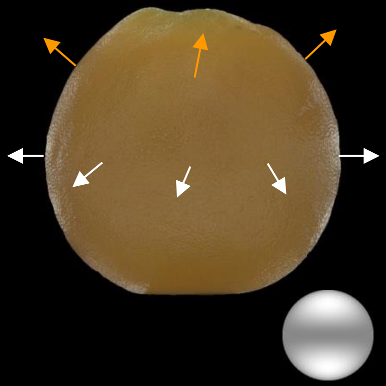


$$L_2 = \int_{\Omega} \vec{\omega}\vec{\omega}^T \, \mathbf{f}(\vec{\omega}) \, d\vec{\omega},$$

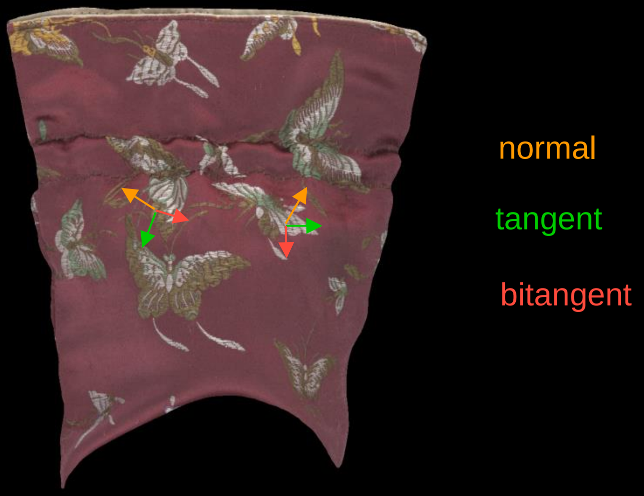
σ^2

Need to compute statistics in local shading frame!

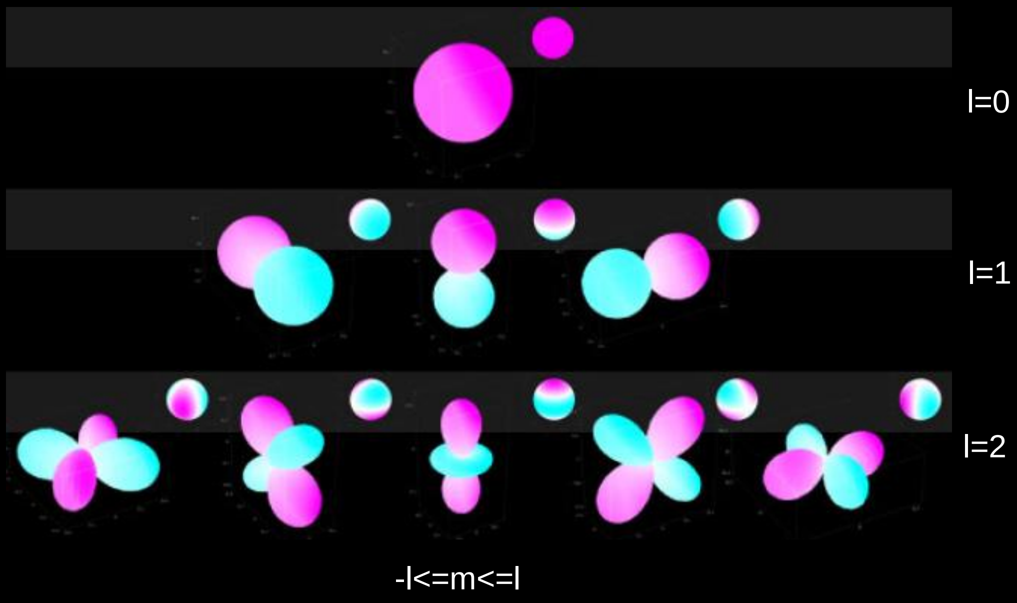
- Isotropic material

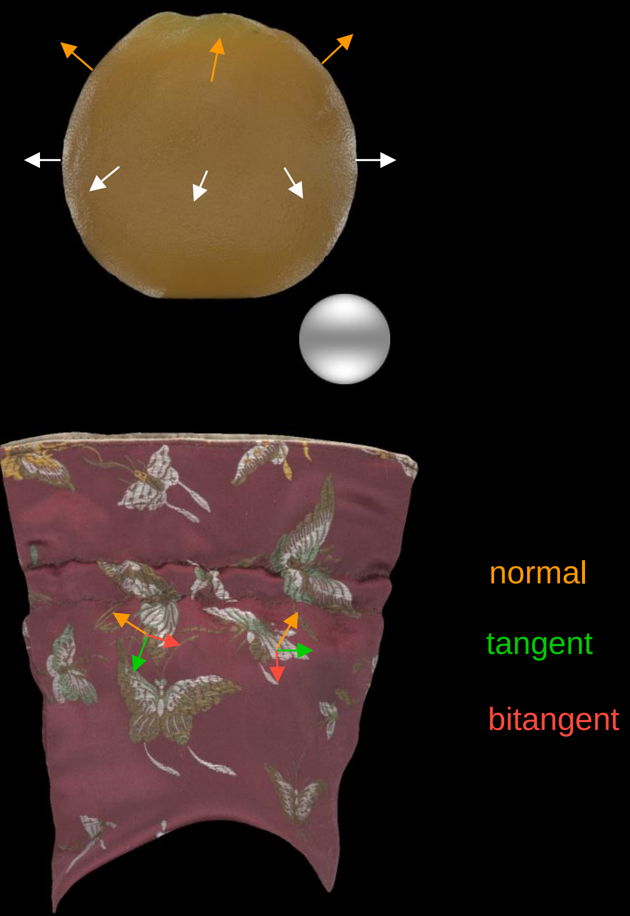


- Anisotropic material



Spherical harmonics





- Steerable spherical basis
  - SH basis can be rotated over the 3D sphere
- Capture reflectance with fixed SH patterns
  - Computation steering in post-process for rotations

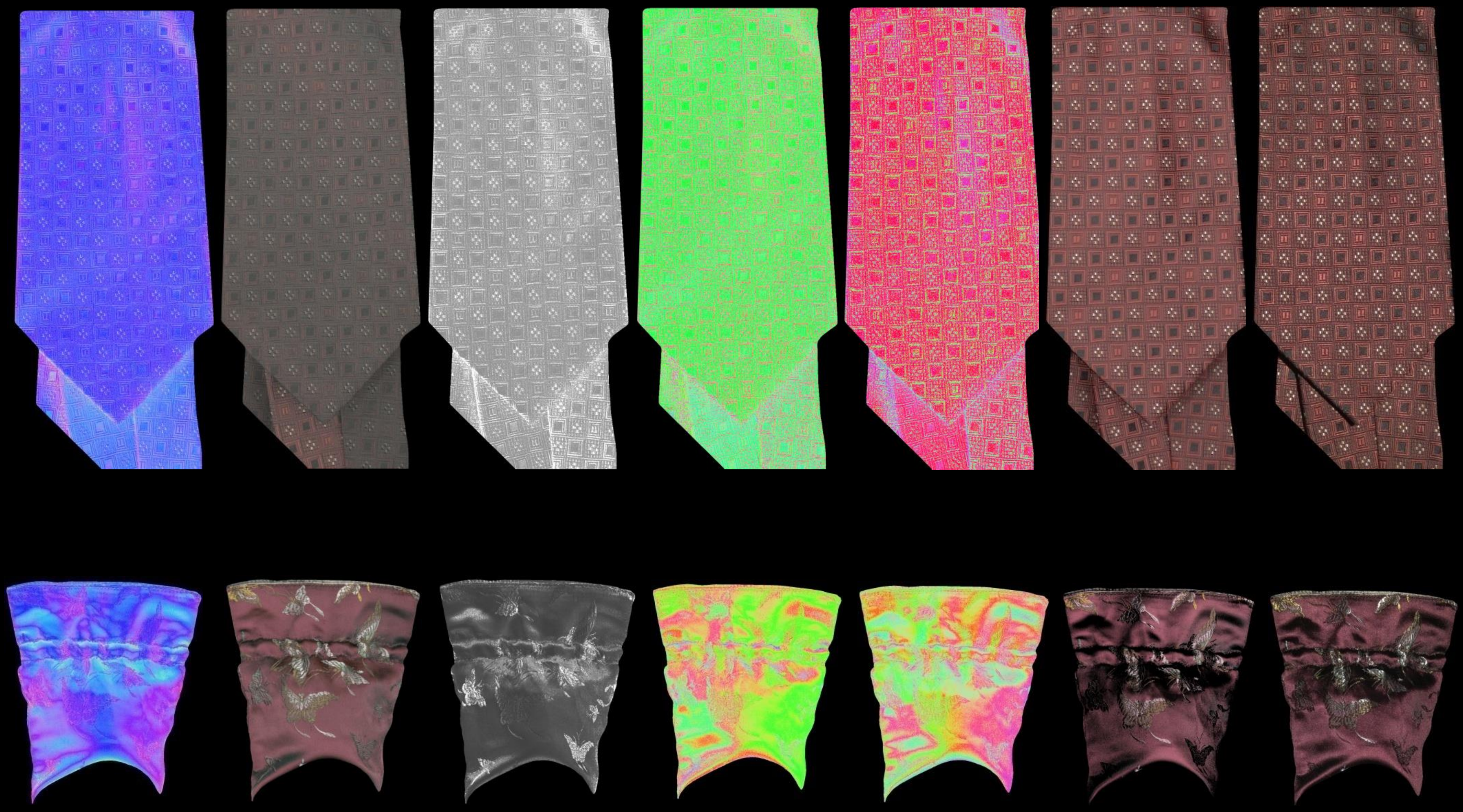
Spherical harmonics

- Anisotropic material
  - σ_x^2 and σ_y^2

Isotropic reflectance

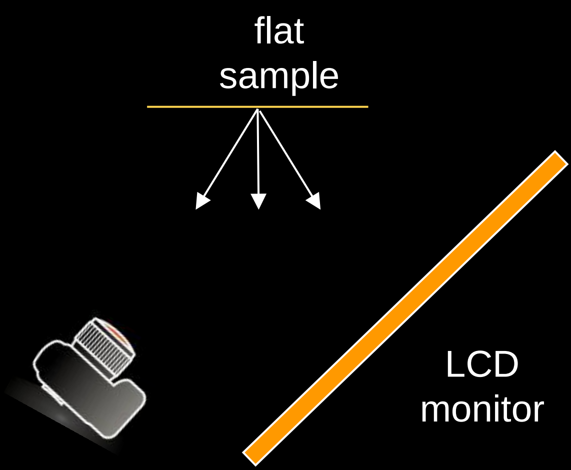
spec. normal spec. albedo spec. roughness rendering photograph

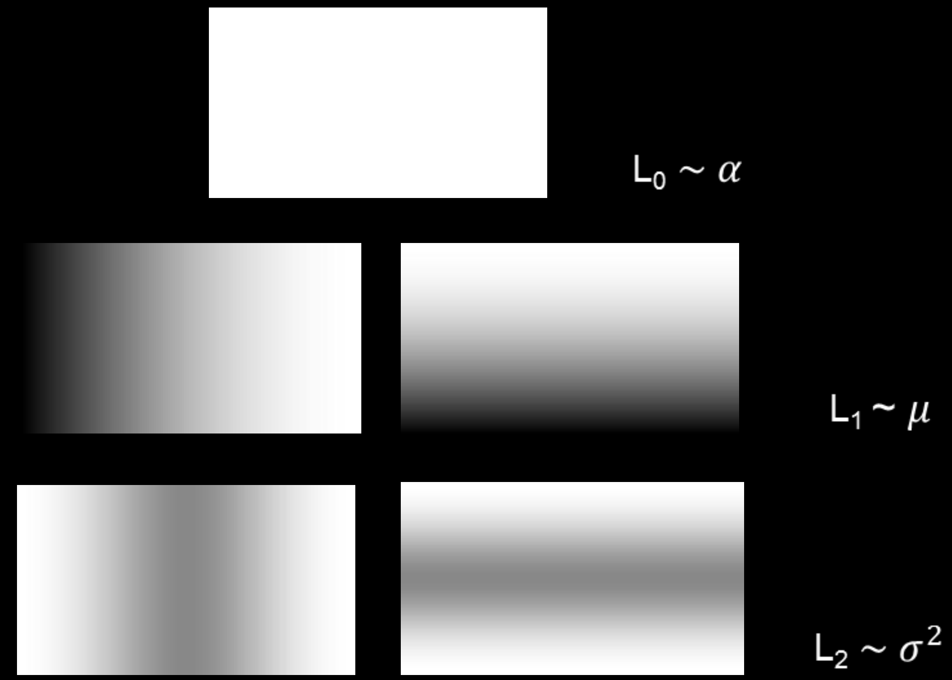
Anisotropic reflectance



spec. normal | spec. albedo | anisotropy (σ_x/σ_y) | tangent | bitangent | rendering | photograph

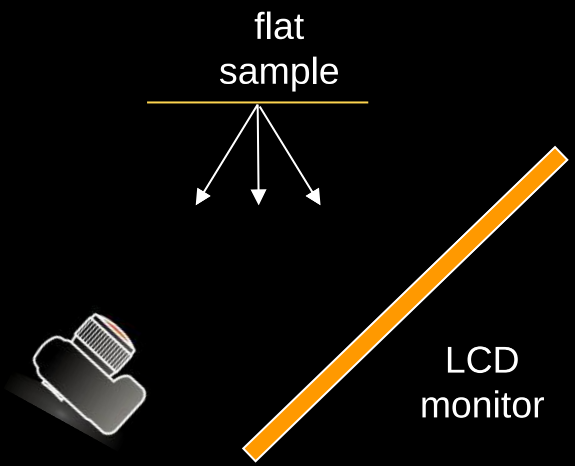
Flat sample



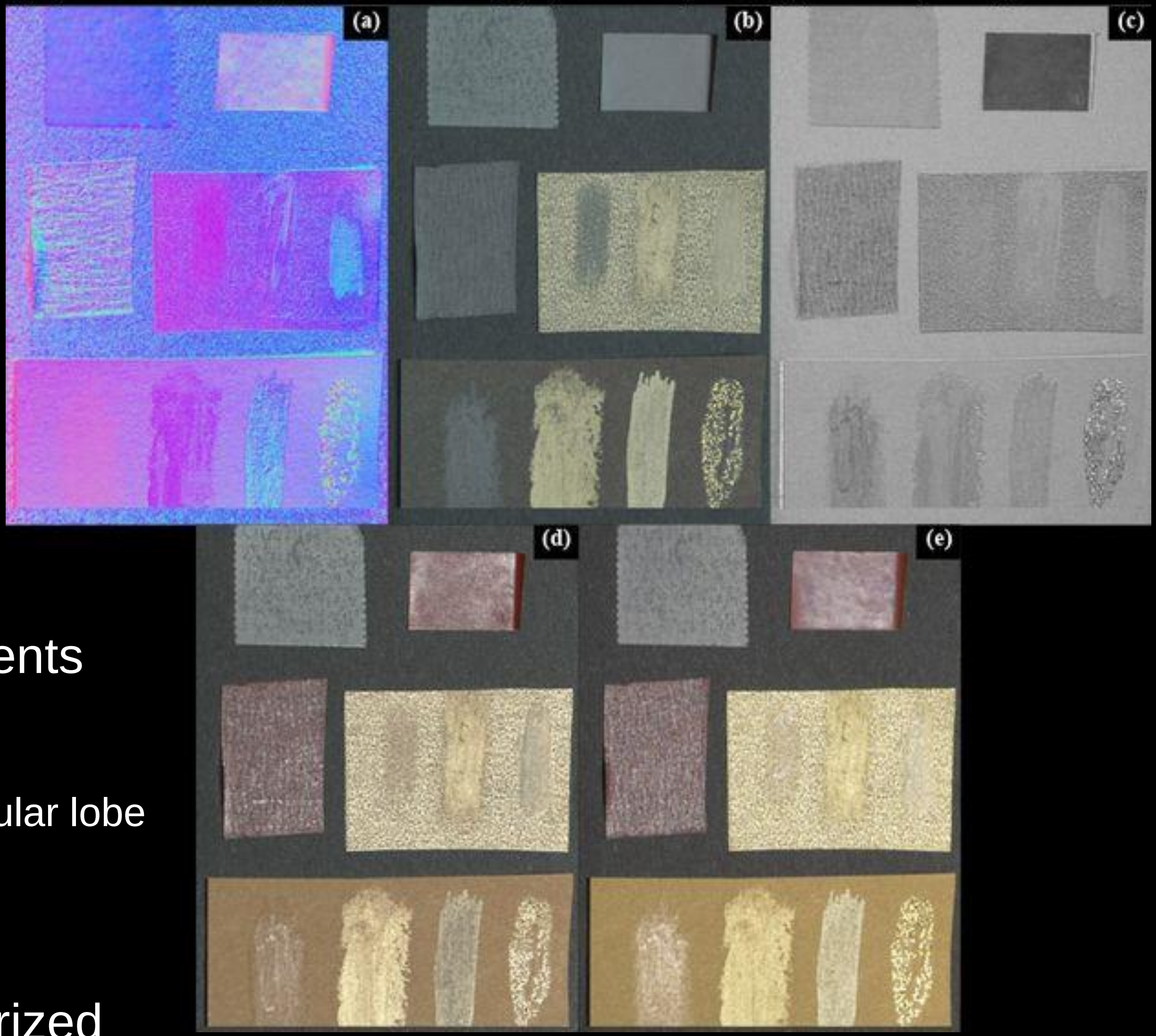


- Project 2nd order gradients from LCD screen
  - Sufficient to cover specular lobe of flat samples
- Screen is already polarized
  - Diffuse specular separation

Flat sample



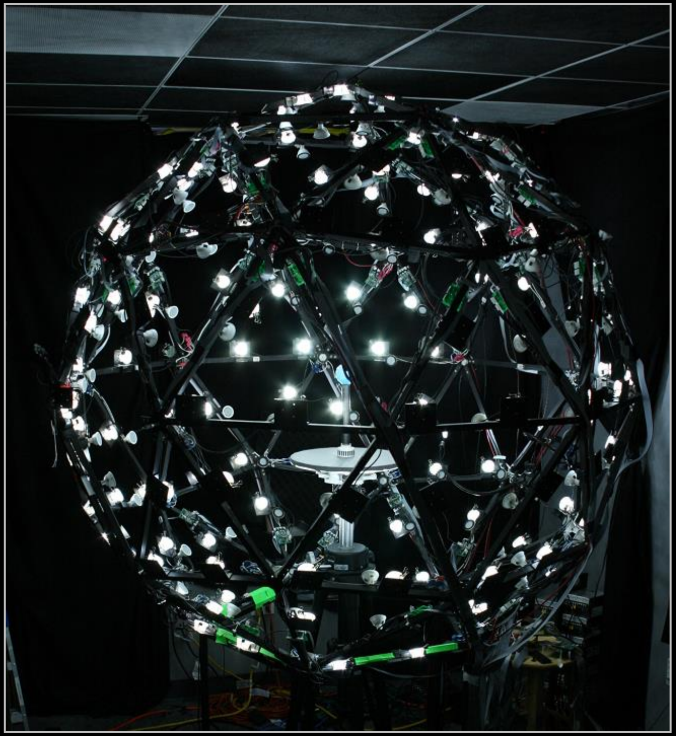
(a) specular normals, (b) specular albedo, (c) specular roughness, (d) rendering and (e)

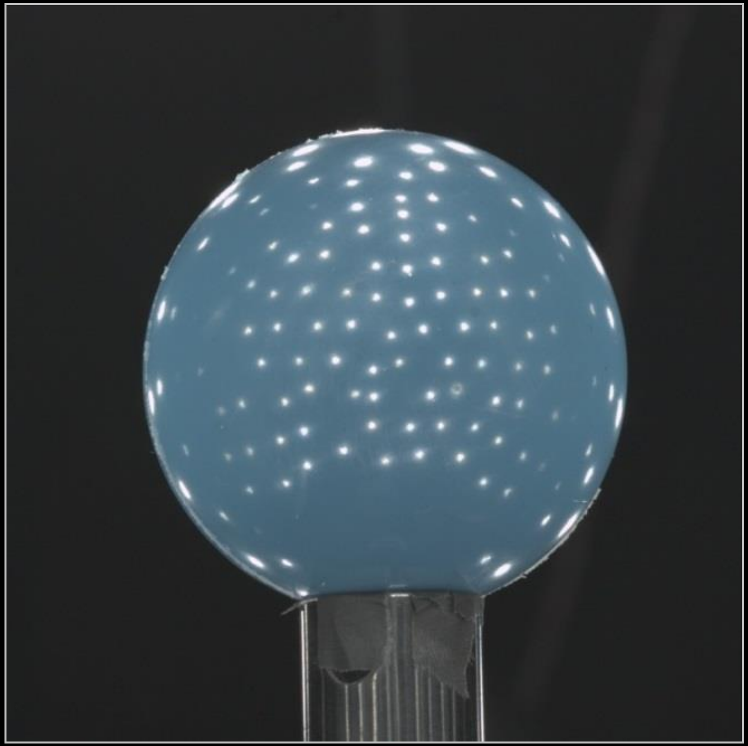


- Project 2nd order gradients from LCD screen
  - Sufficient to cover specular lobe of flat samples
- Screen is already polarized
  - Diffuse specular separation

Specular materials!

Specular materials!

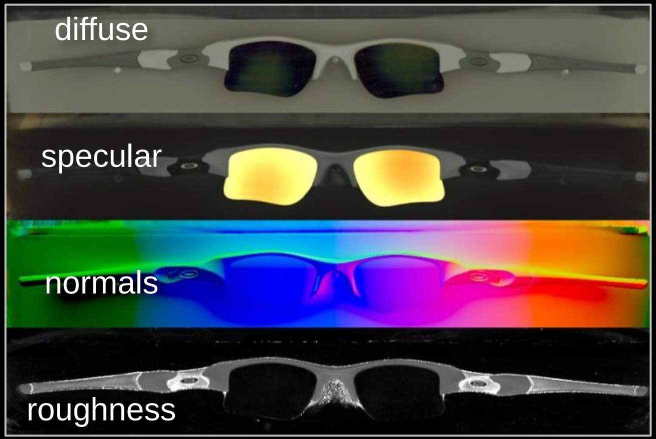


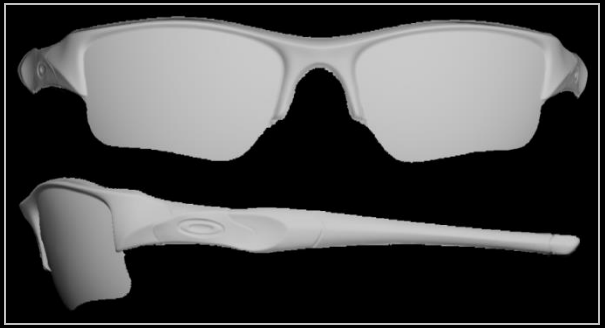


LED sphere

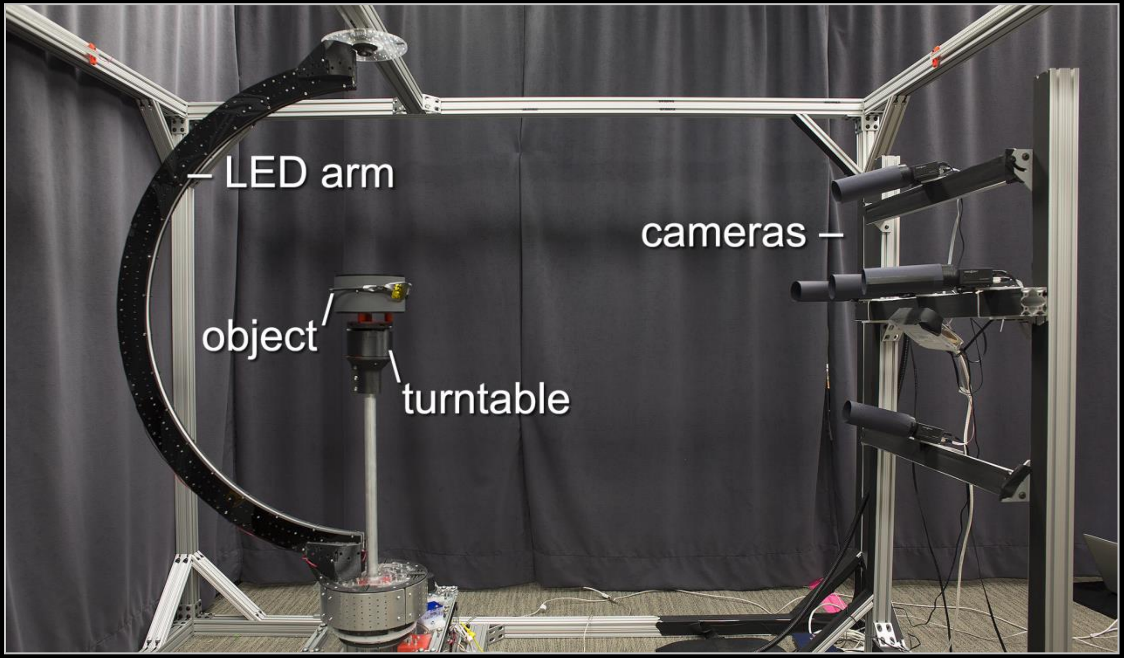
Continuous spherical harmonic illumination

[Tunwattanpong et al. 2013]



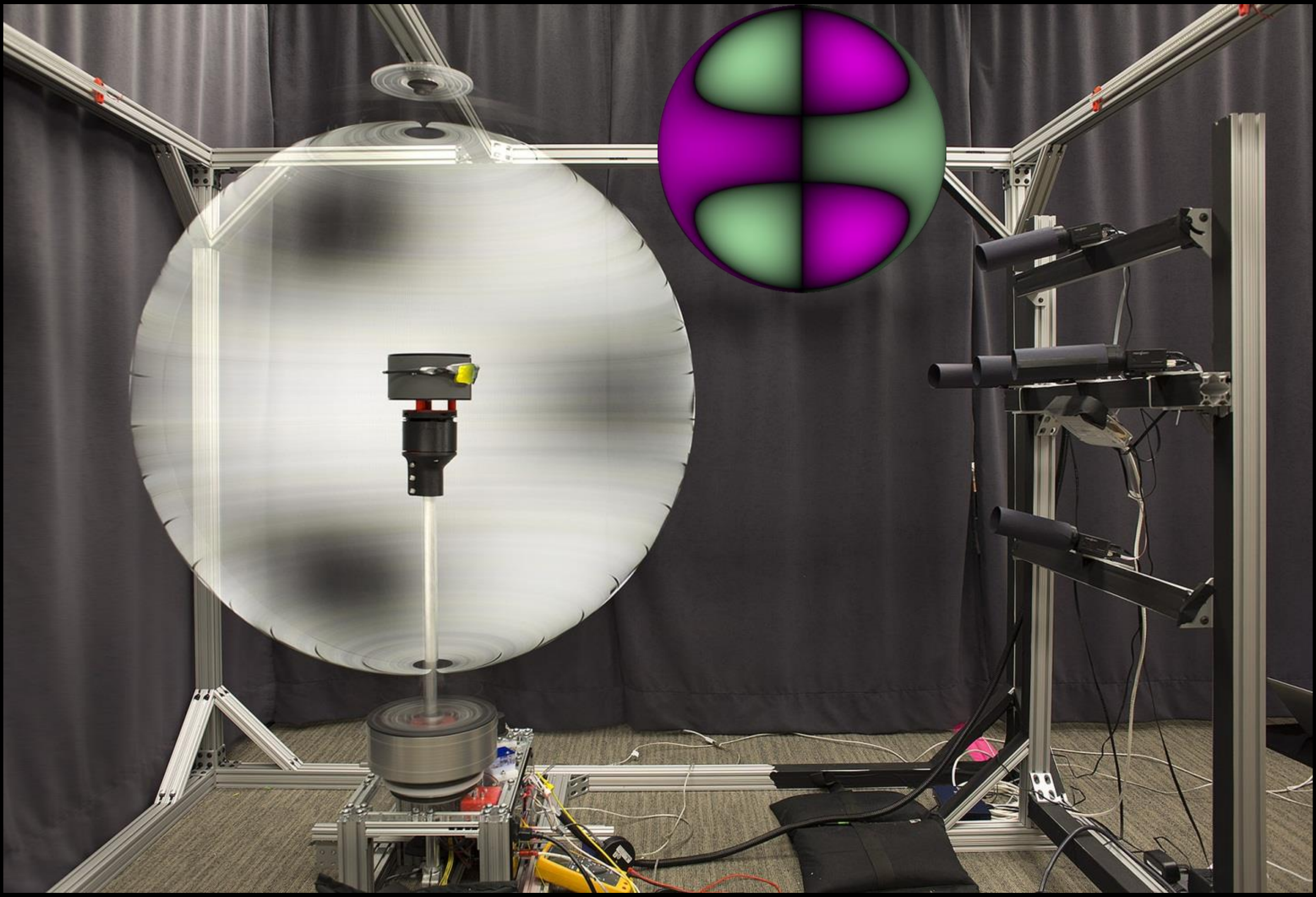


Hardware setup

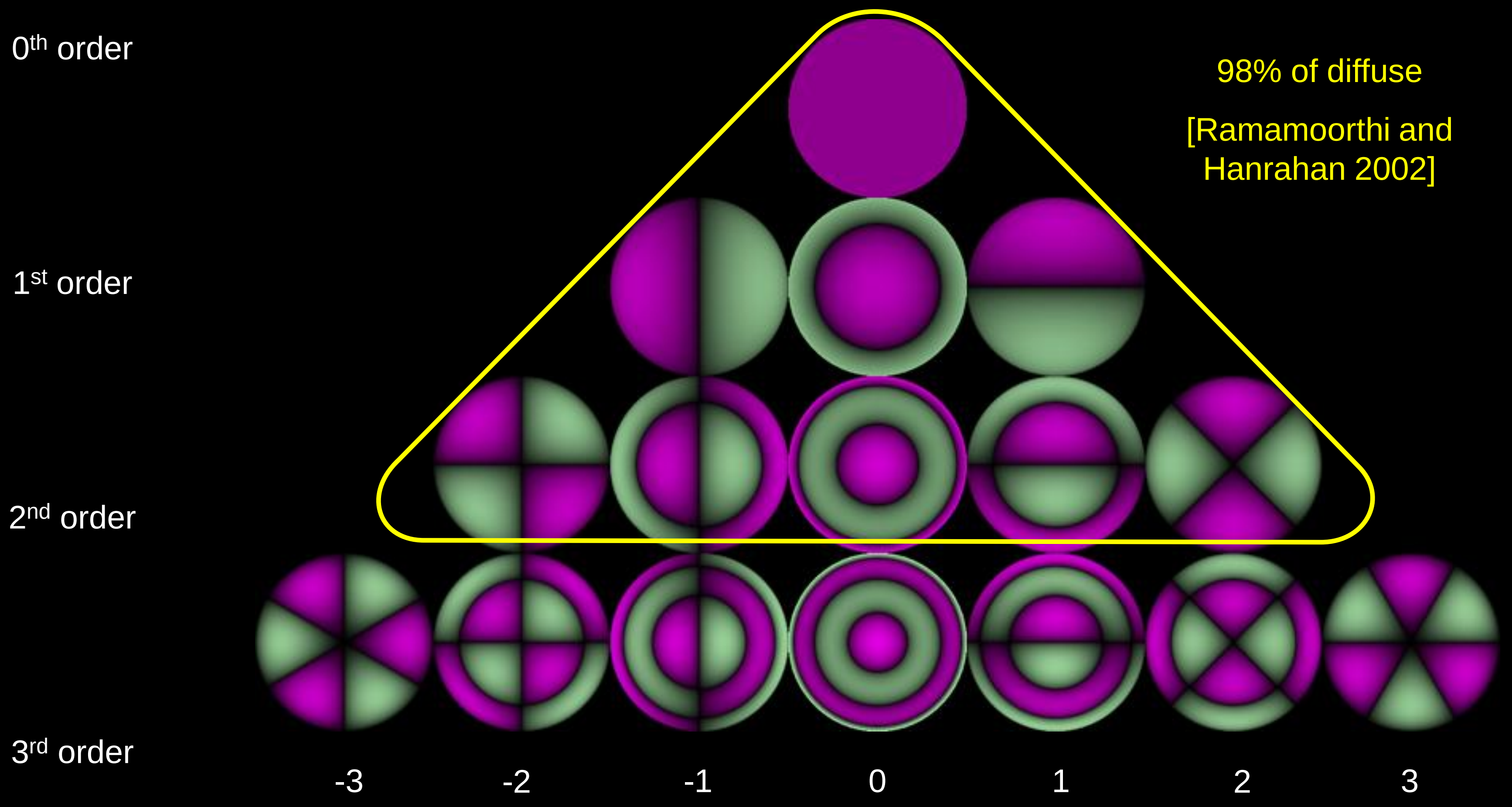


continuous illumination

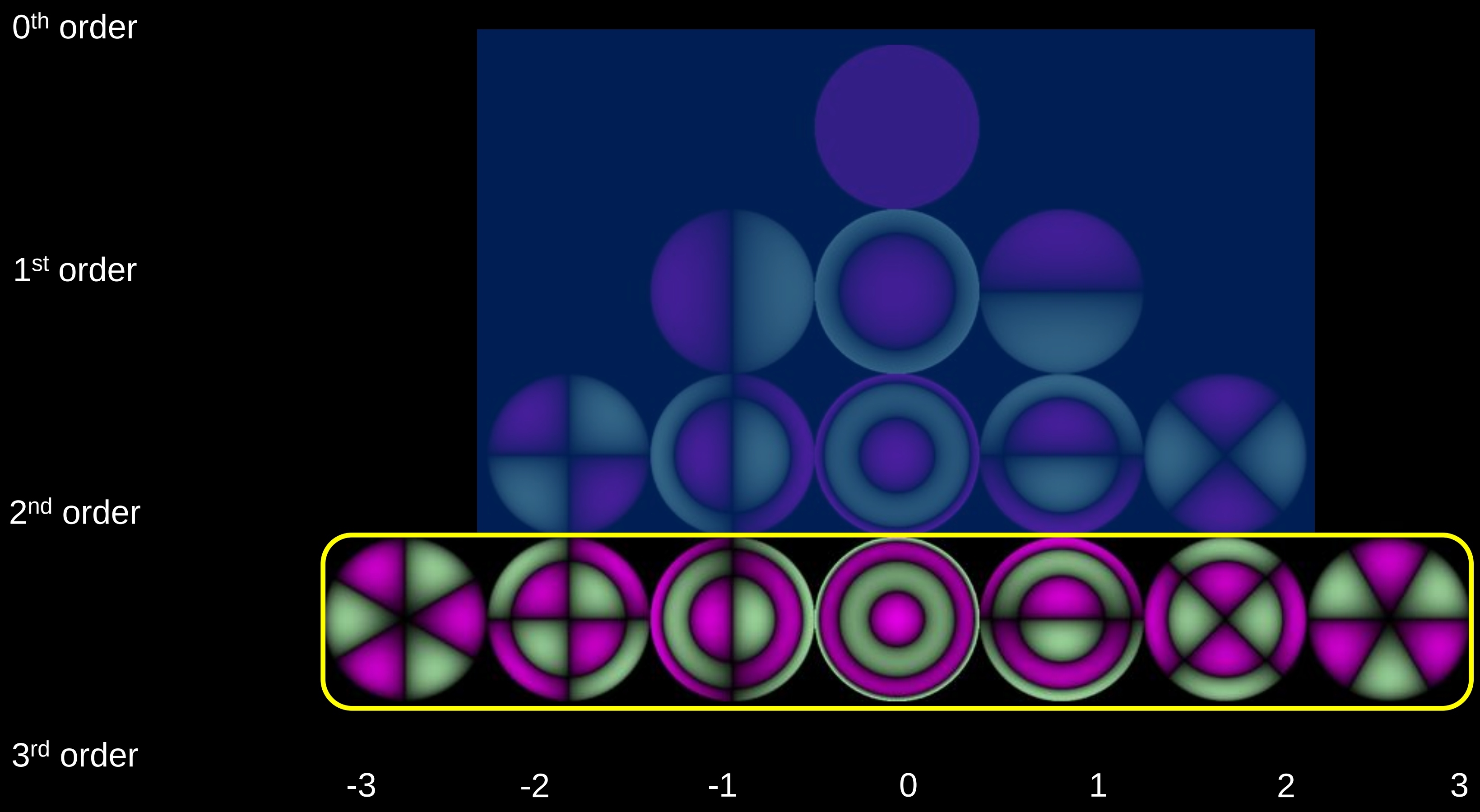
SH illumination



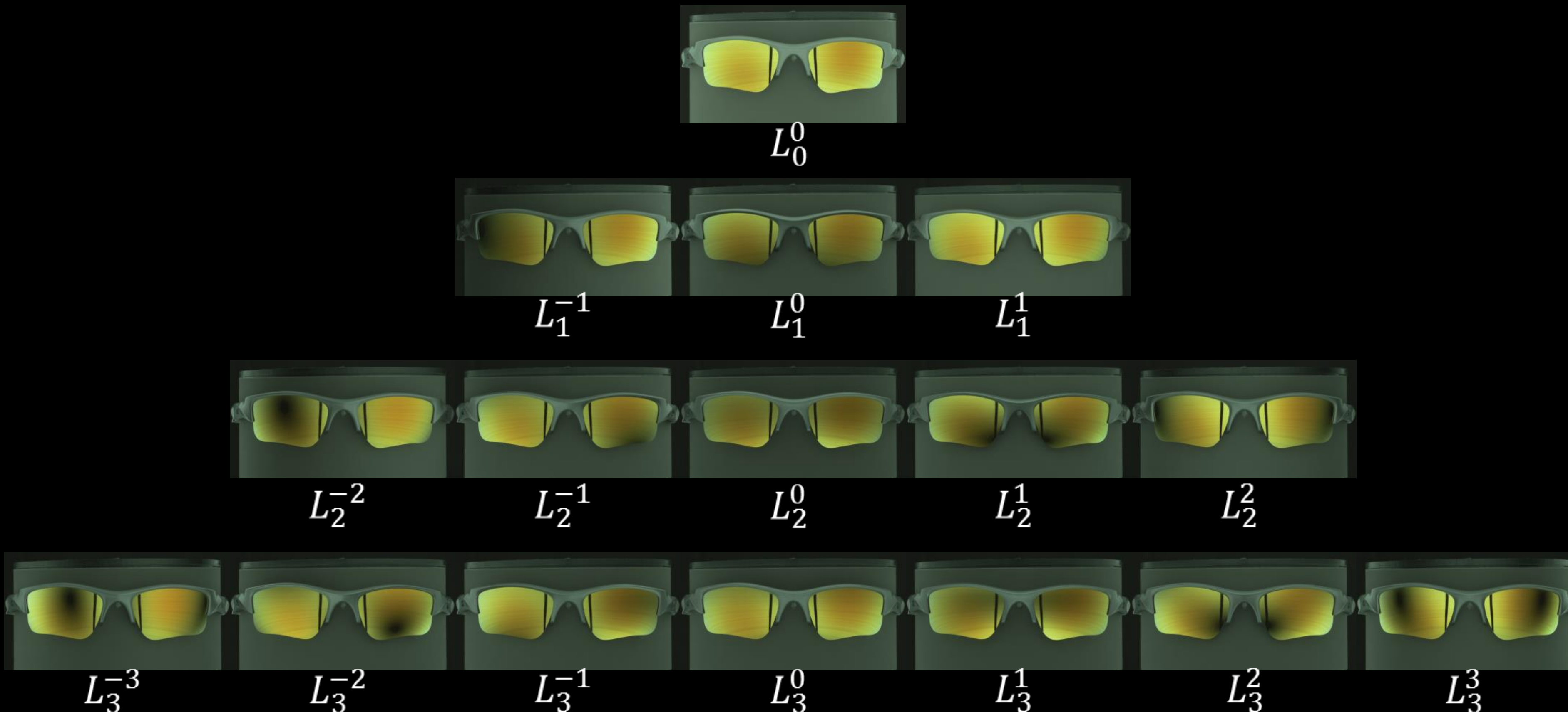
Diffuse-specular separation



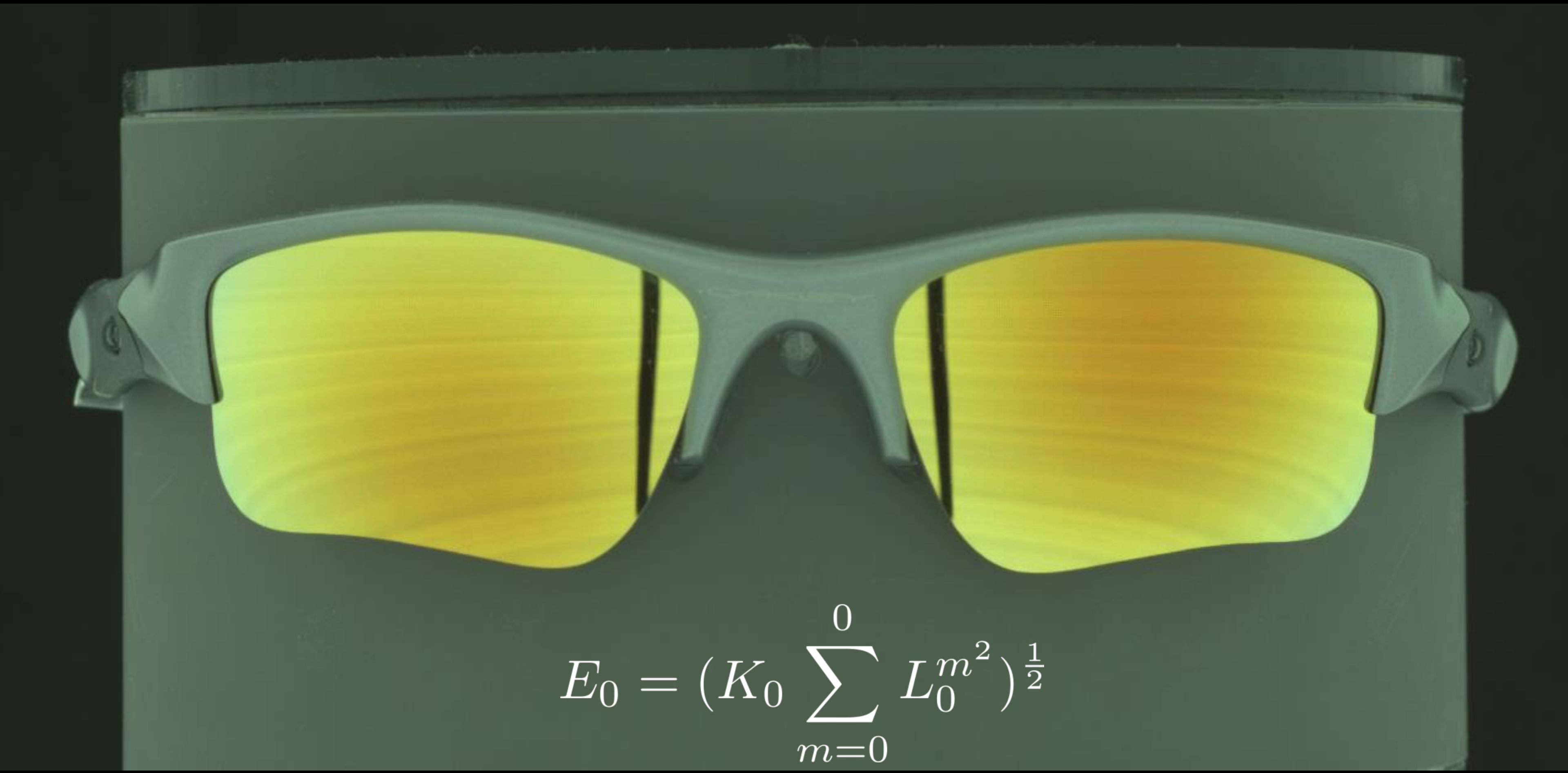
Specular response only!



Diffuse-specular separation

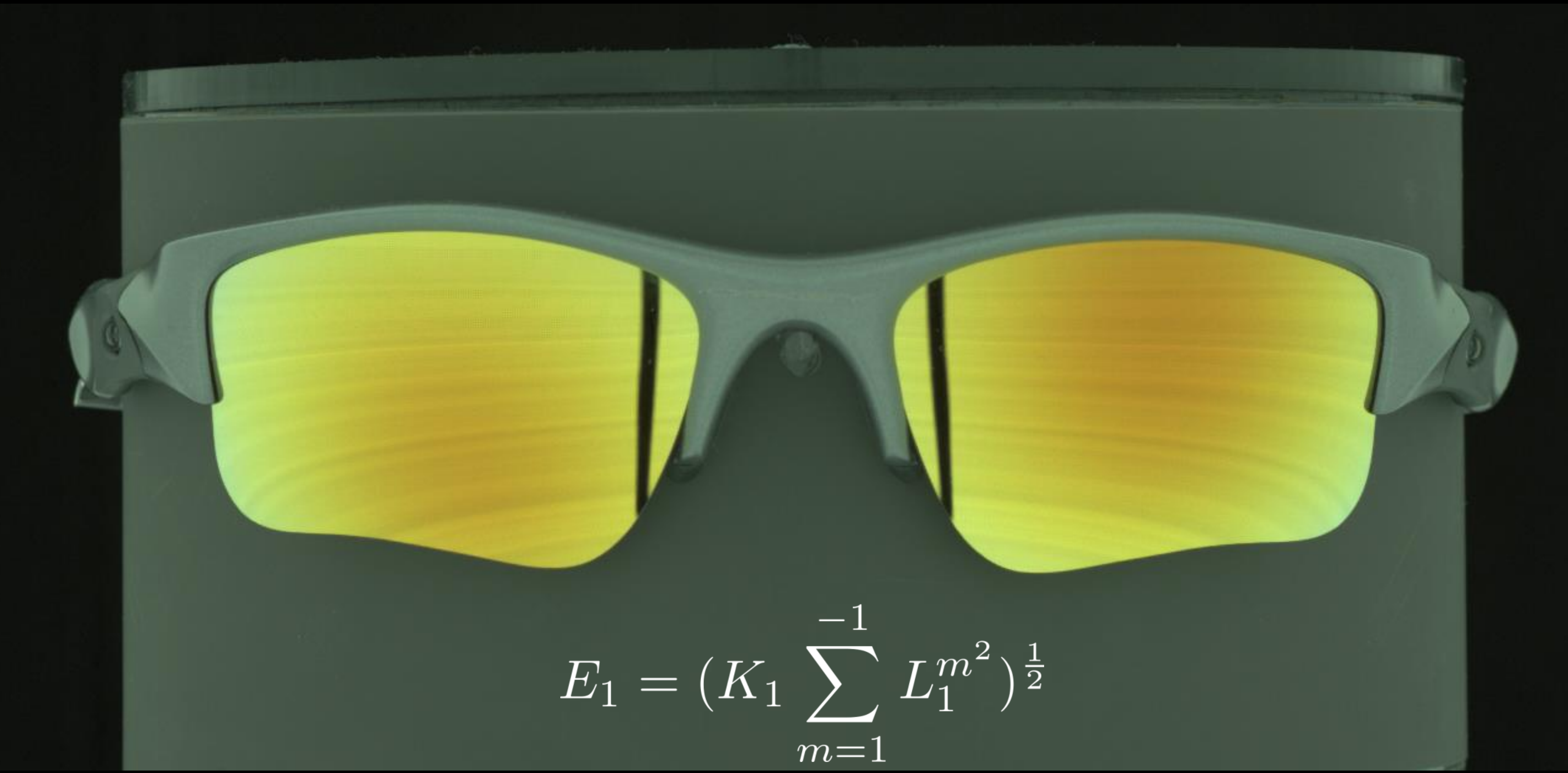


0^{th} order energy



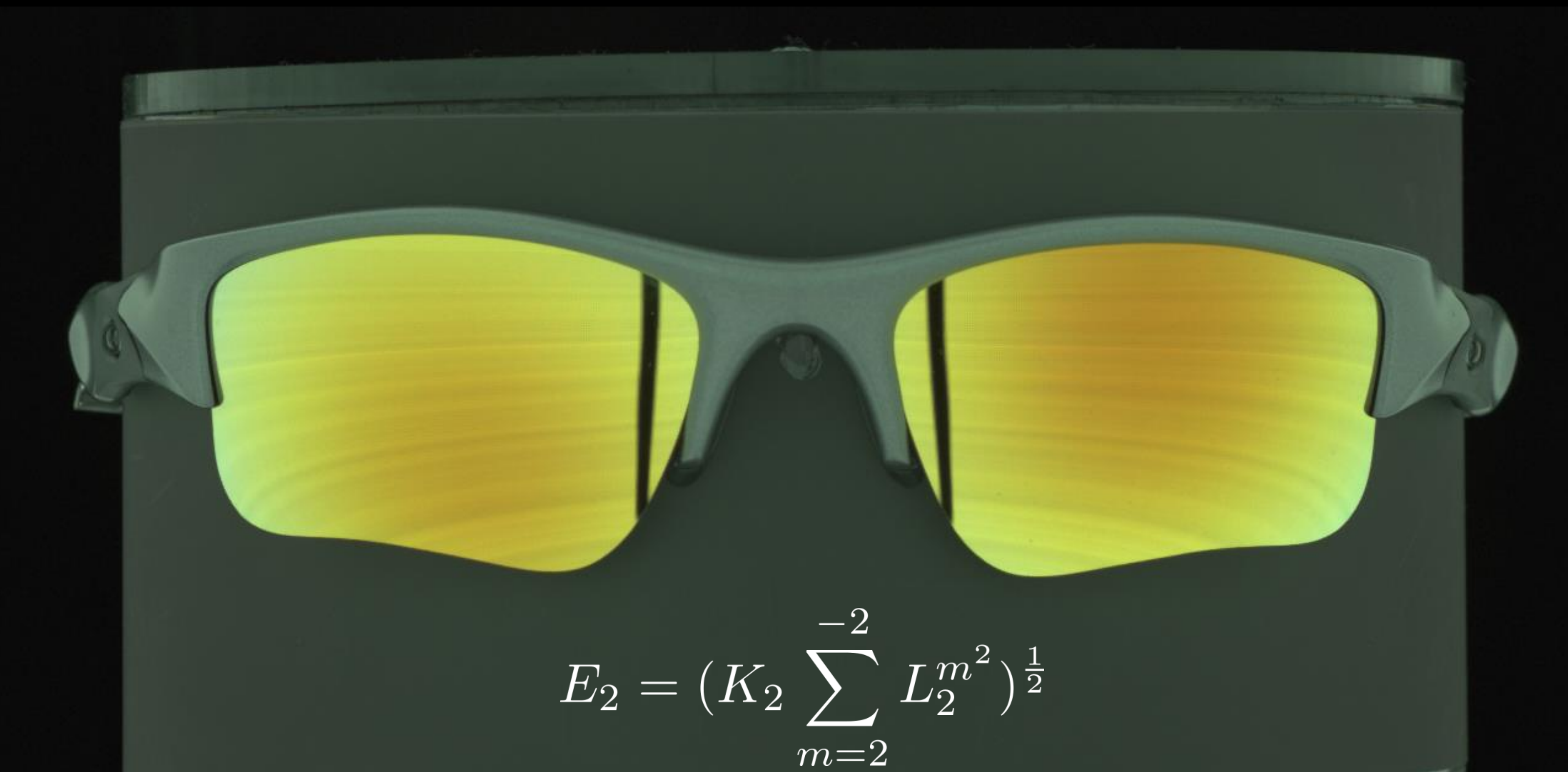
$$E_0 = (K_0 \sum_{m=0}^{0} L_0^{m^2})^{\frac{1}{2}}$$

1st order energy



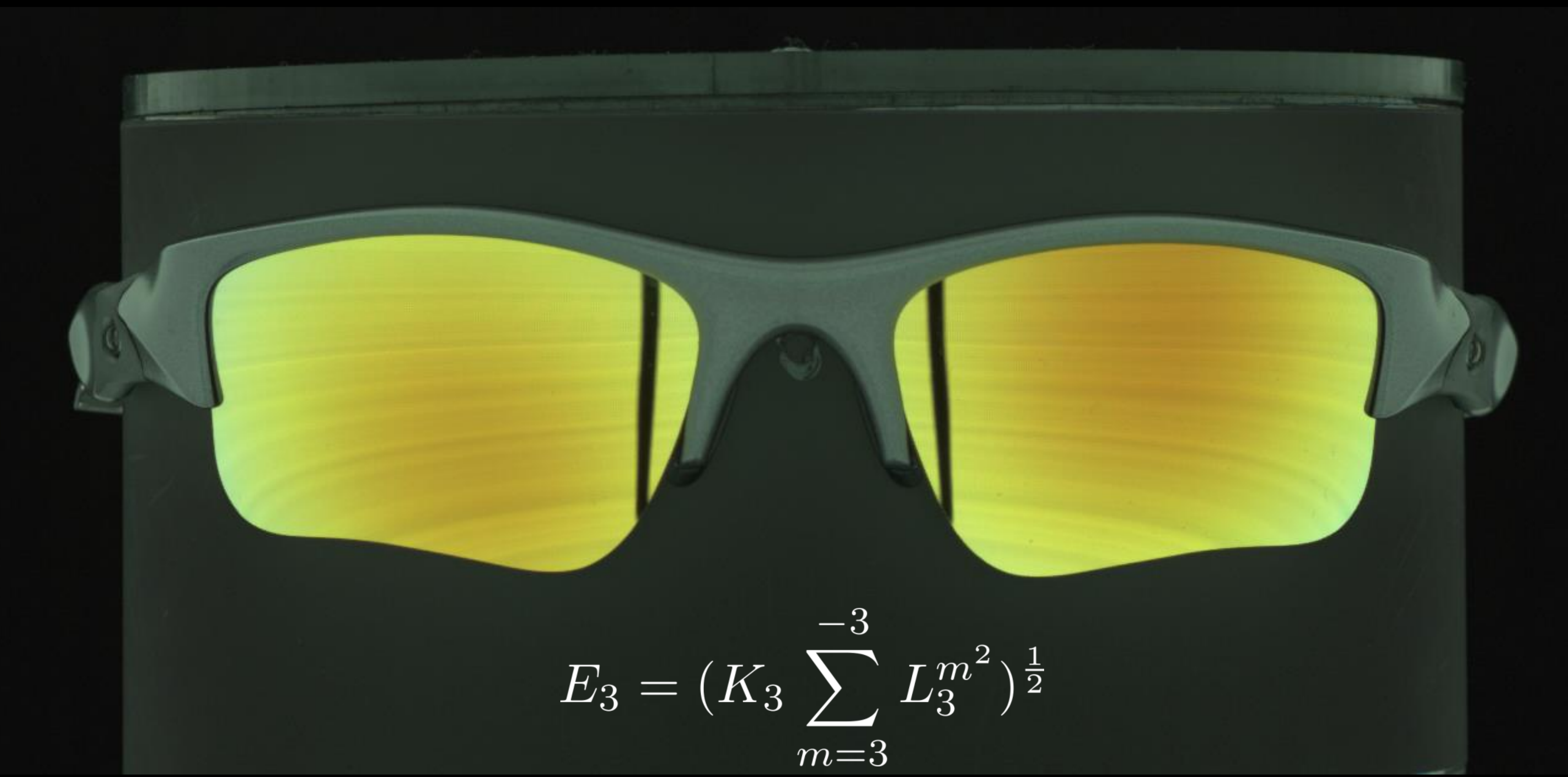
$$E_1 = (K_1 \sum_{m=1}^{-1} L_1^{m^2})^{\frac{1}{2}}$$

2nd order energy



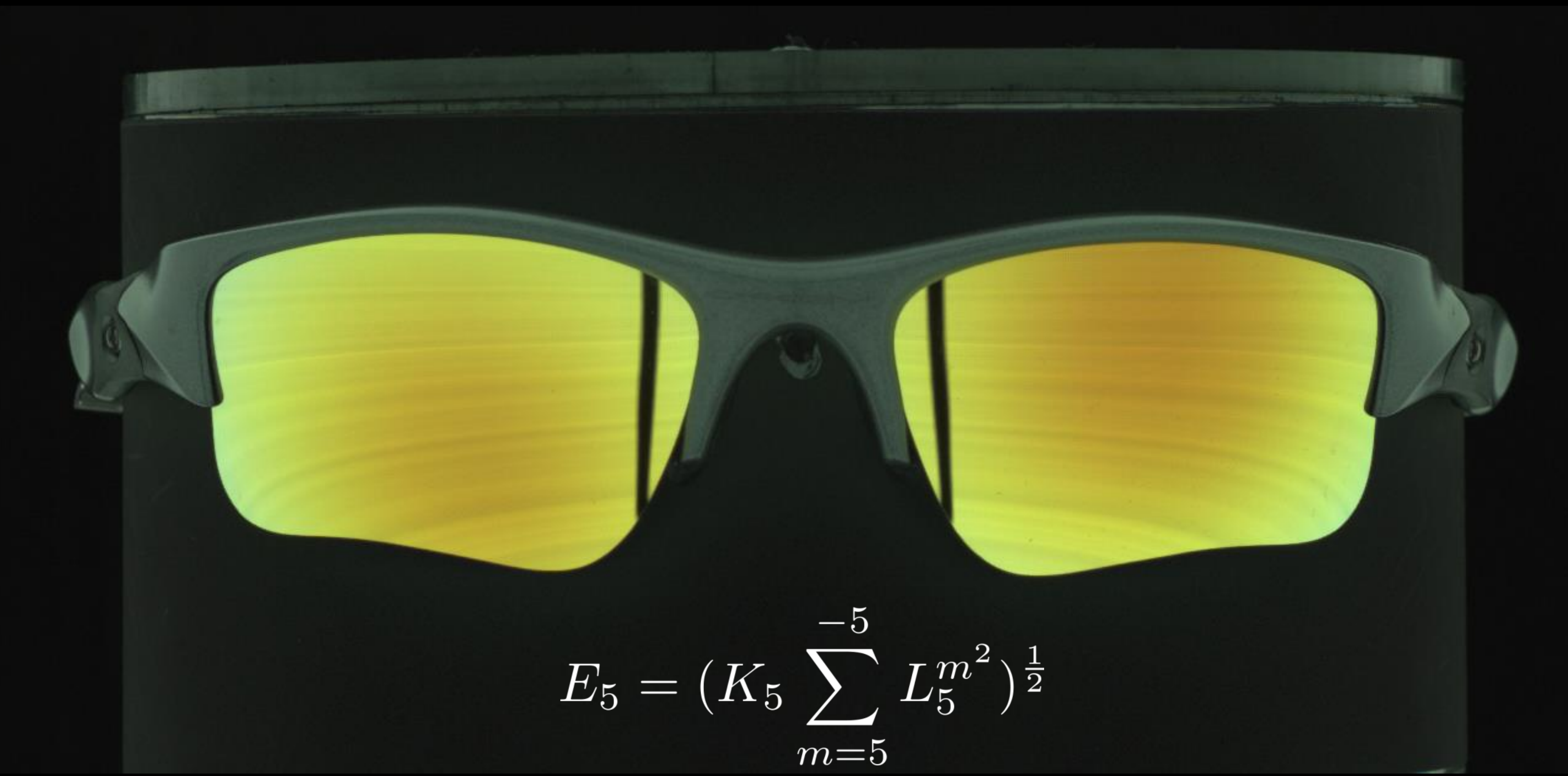
$$E_2 = (K_2 \sum_{m=2}^{-2} L_2^{m^2})^{\frac{1}{2}}$$

3rd order energy!



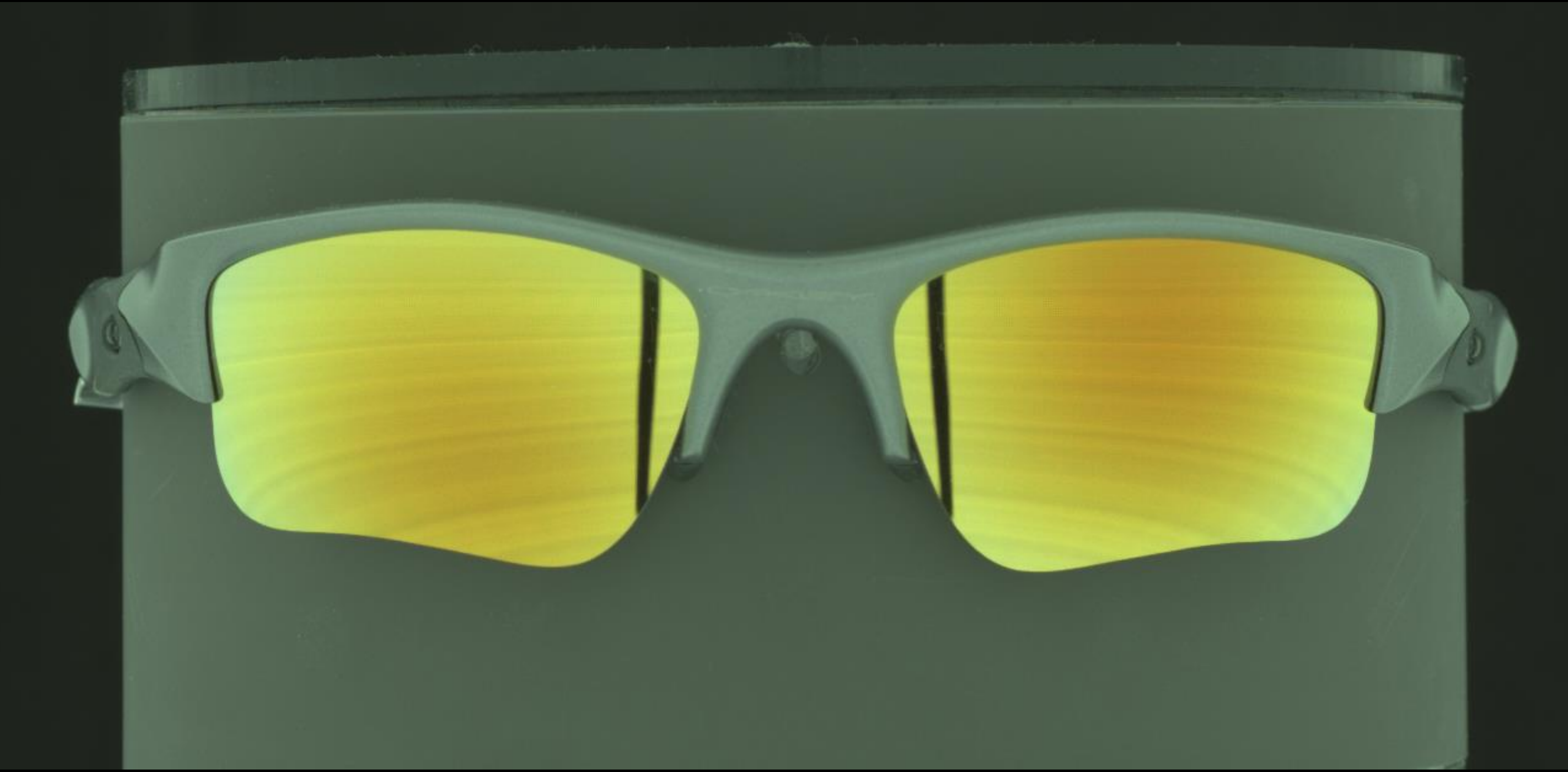
$$E_3 = (K_3 \sum_{m=3}^{-3} L_3^{m^2})^{\frac{1}{2}}$$

5^{th} order energy!



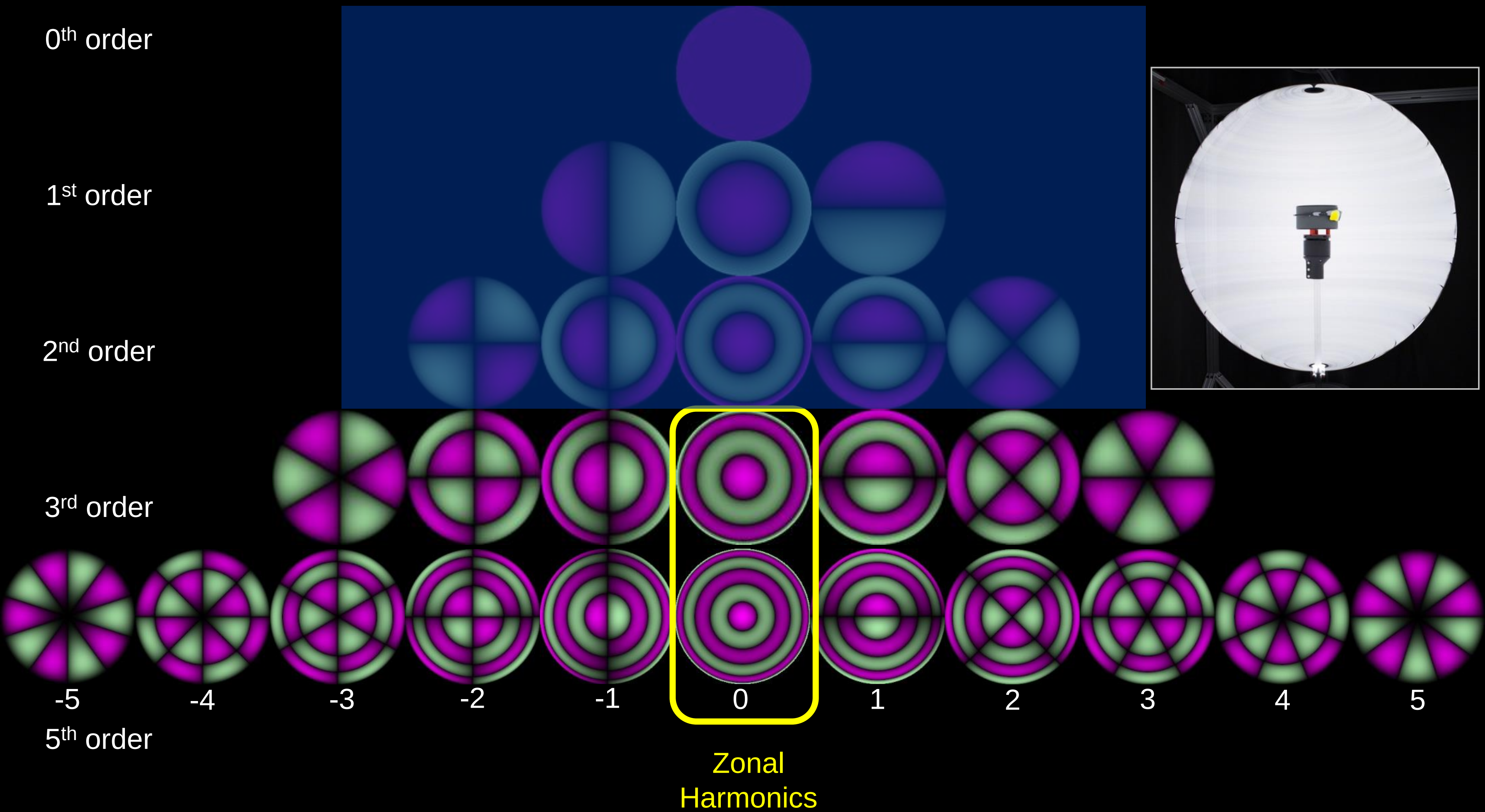
$$E_5 = (K_5 \sum_{m=5}^{-5} L_5^{m^2})^{\frac{1}{2}}$$

Constant illumination

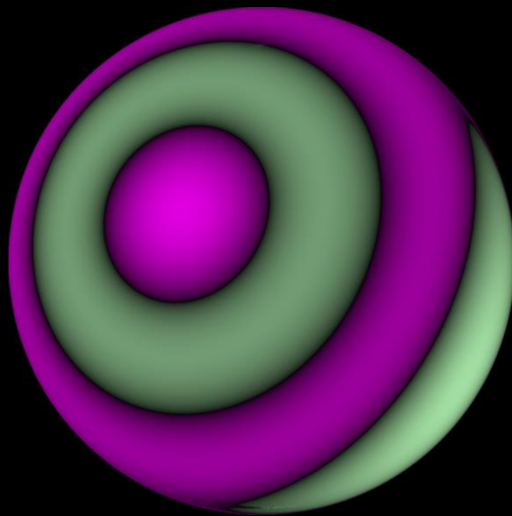


Diffuse albedo

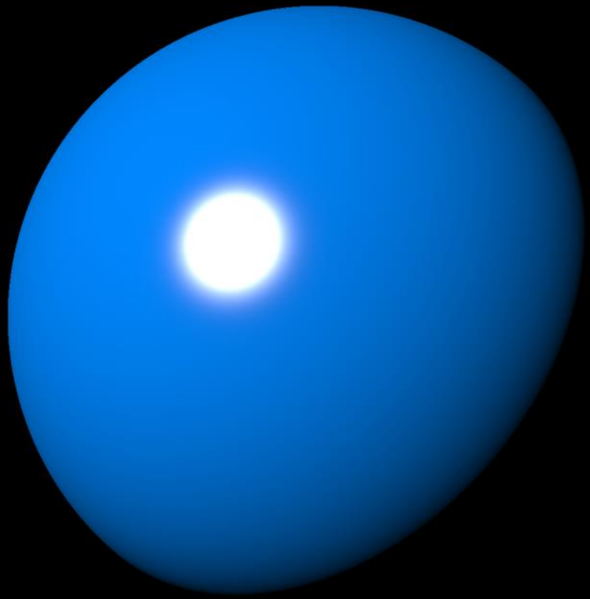
Reflectometry from SH



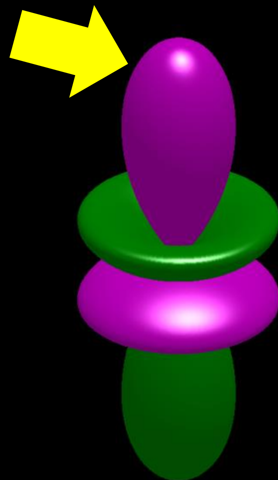
3rd order Zonal



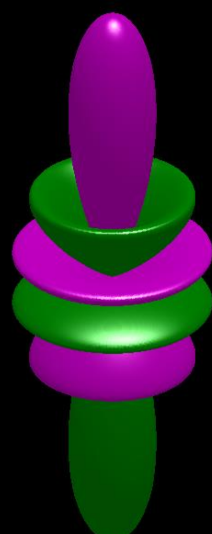
5th order Zonal

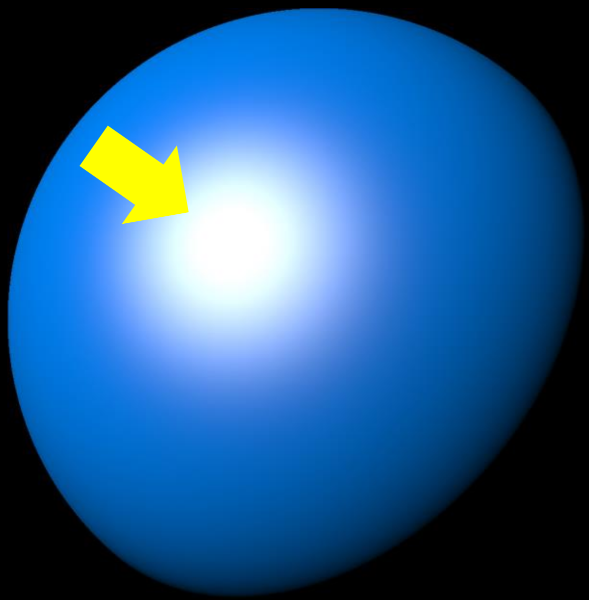


3rd order Zonal

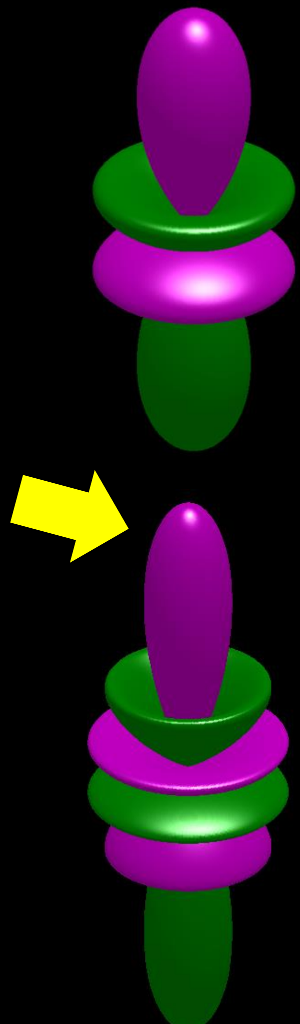


5th order Zonal

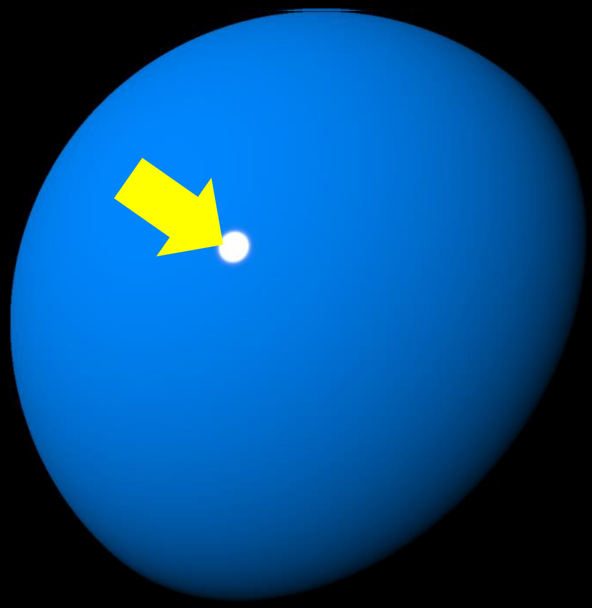




3rd order Zonal



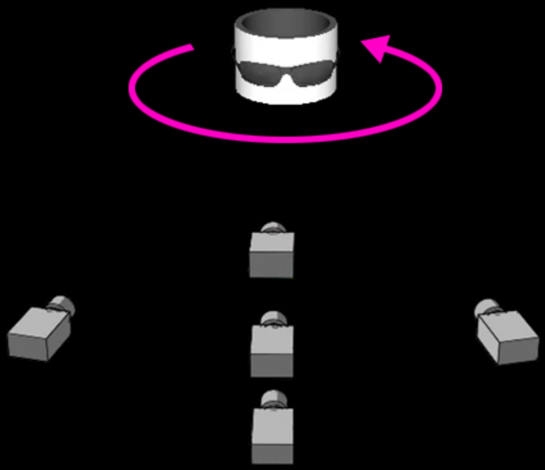
5th order Zonal



Specular roughness

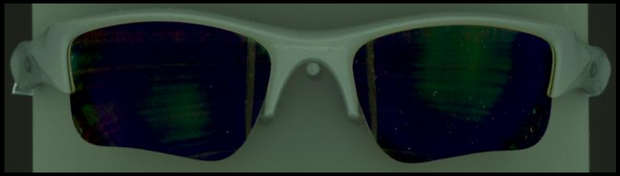
Stereo reconstruction

diffuse albedo | specular albedo | reflection vector



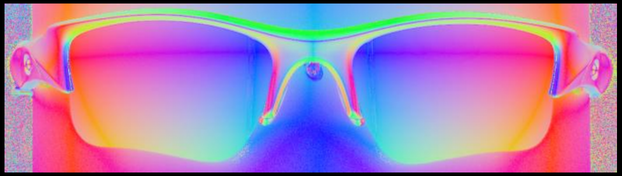
5 cameras = 5 views

Stereo reconstruction

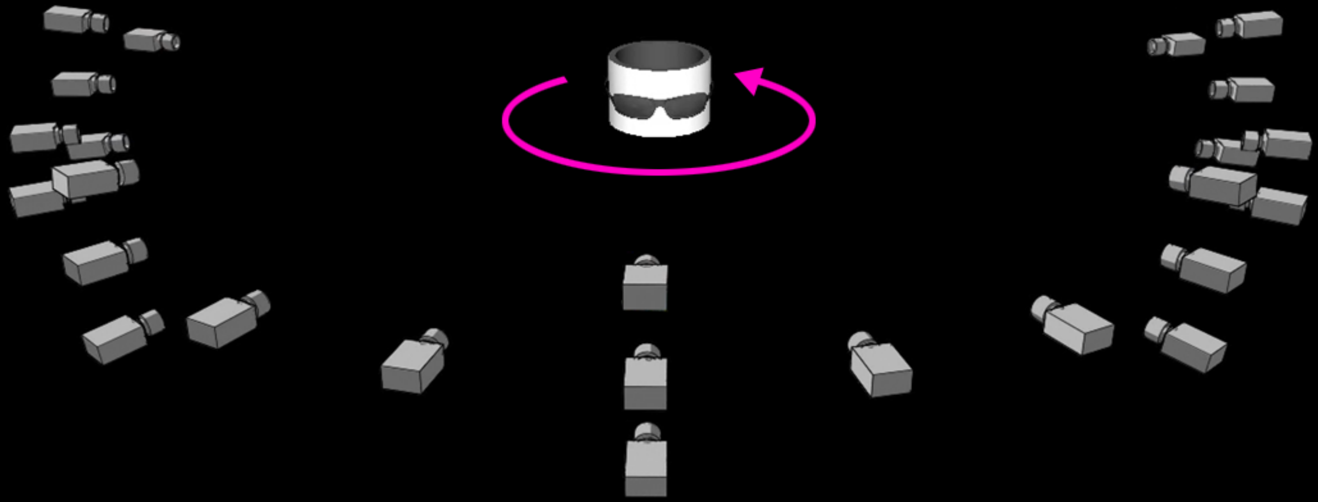


diffuse albedo

specular albedo



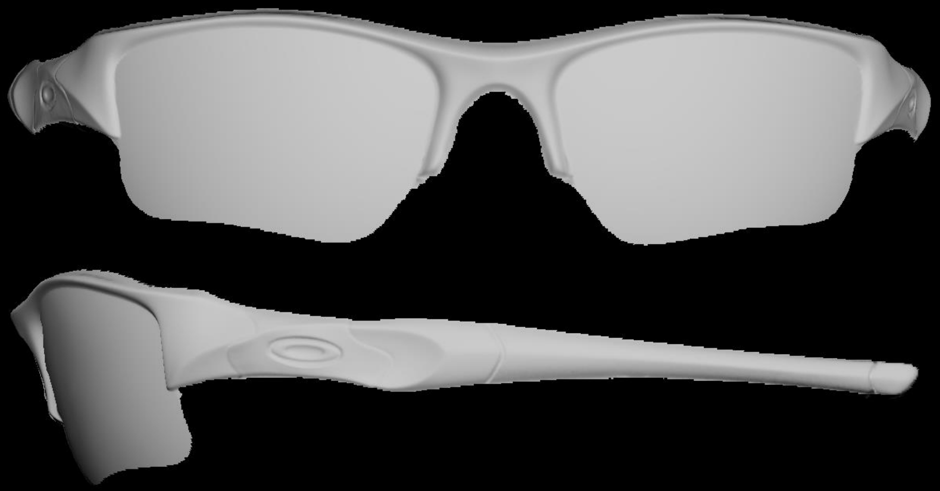
reflection vector



5 cameras × 5 rotations = 25 views

Stereo reconstruction

photograph



reconstructed geometry

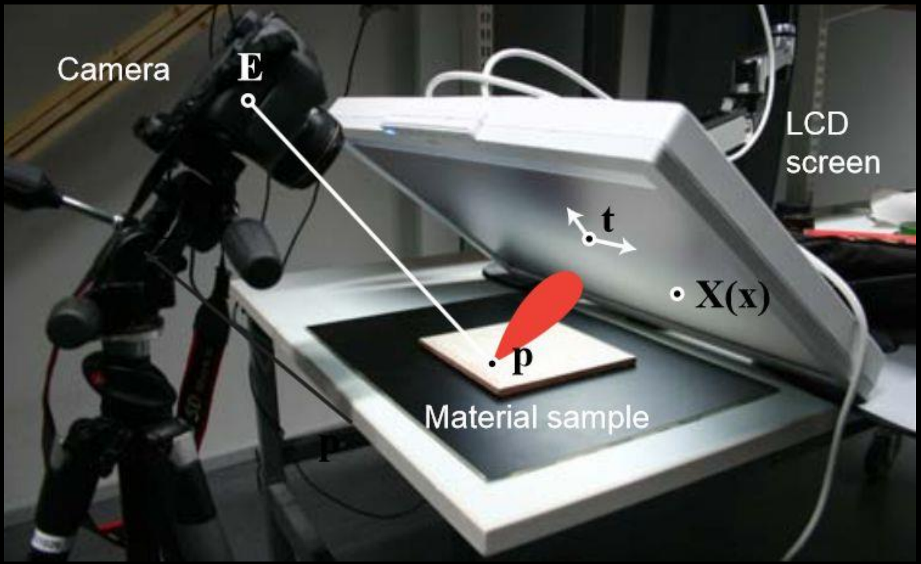
Rendering with geometry & reflectance

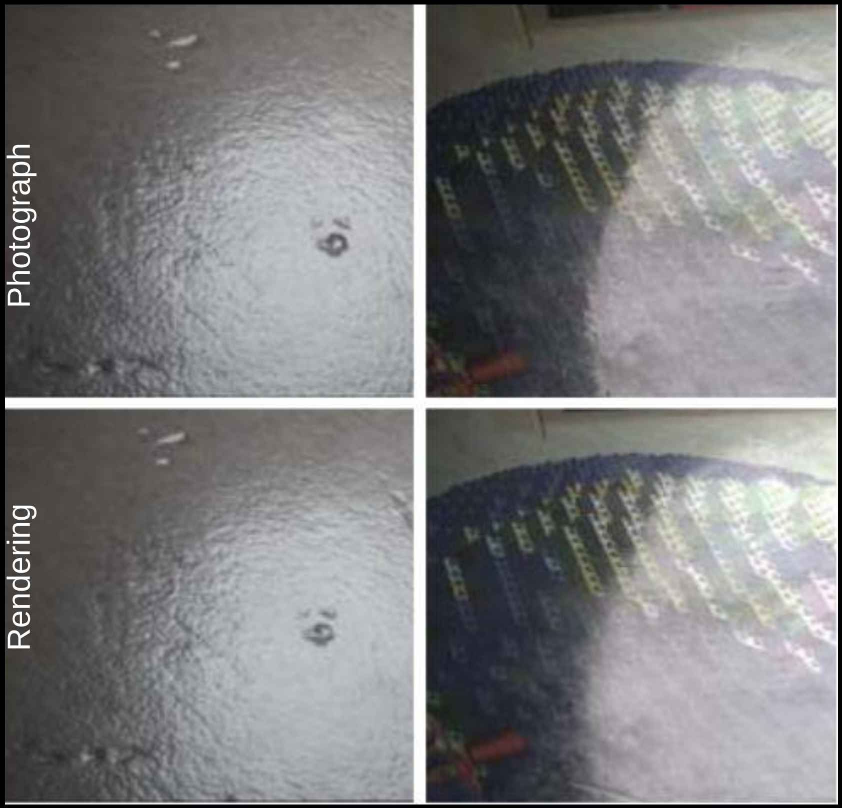
Validation

rendering

photograph

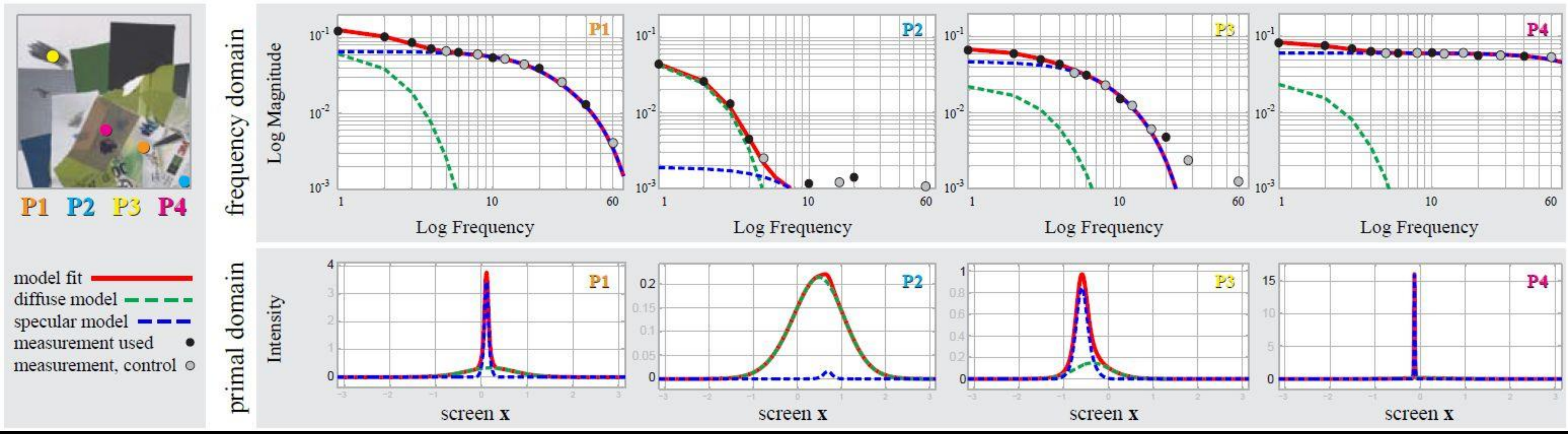
Fourier basis measurement [Aitalla et al. 2013]





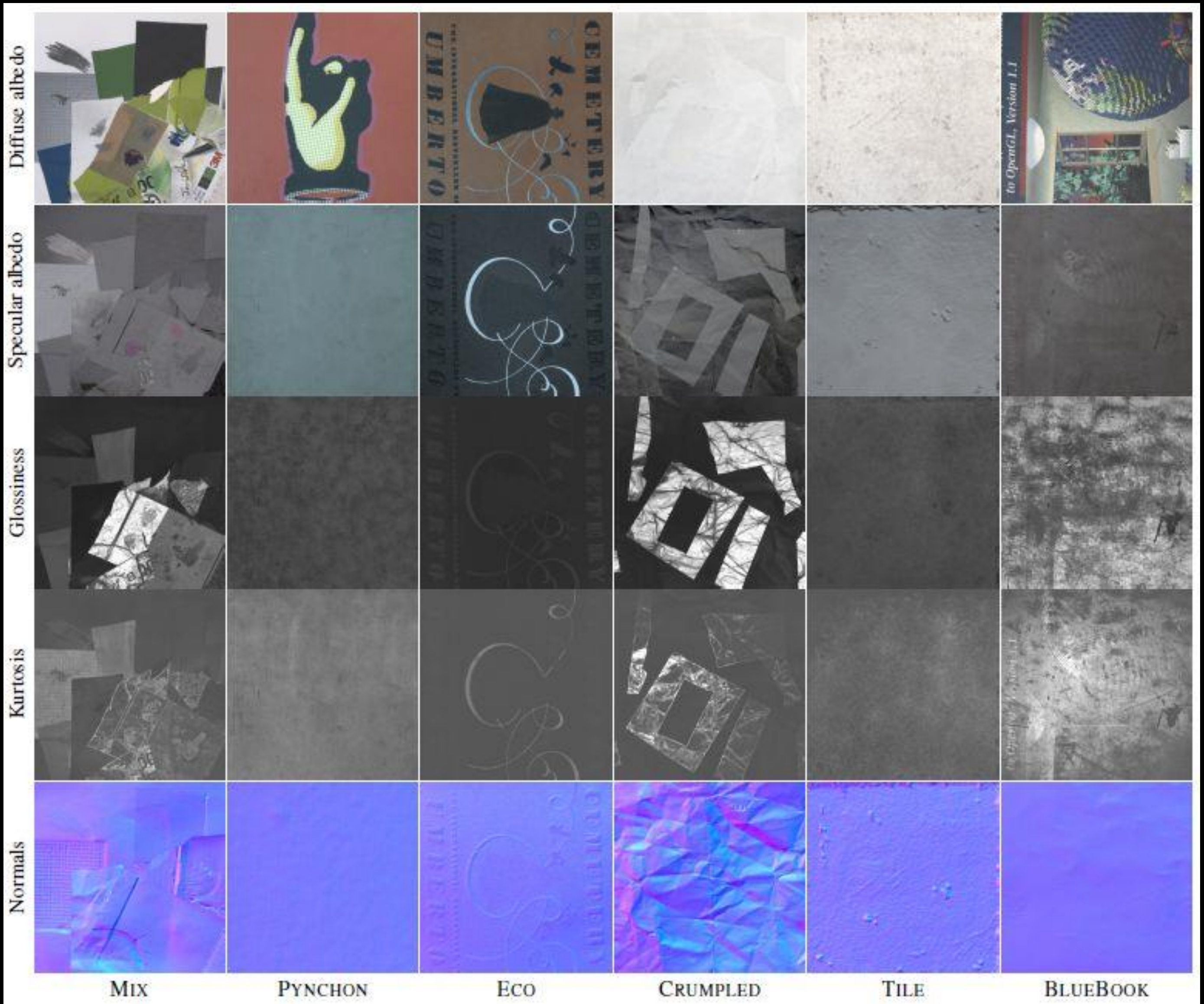
- Fourier basis illumination
  - Spectrum decay measure of glossiness

Fourier basis measurement [Aitalla et al. 2013]



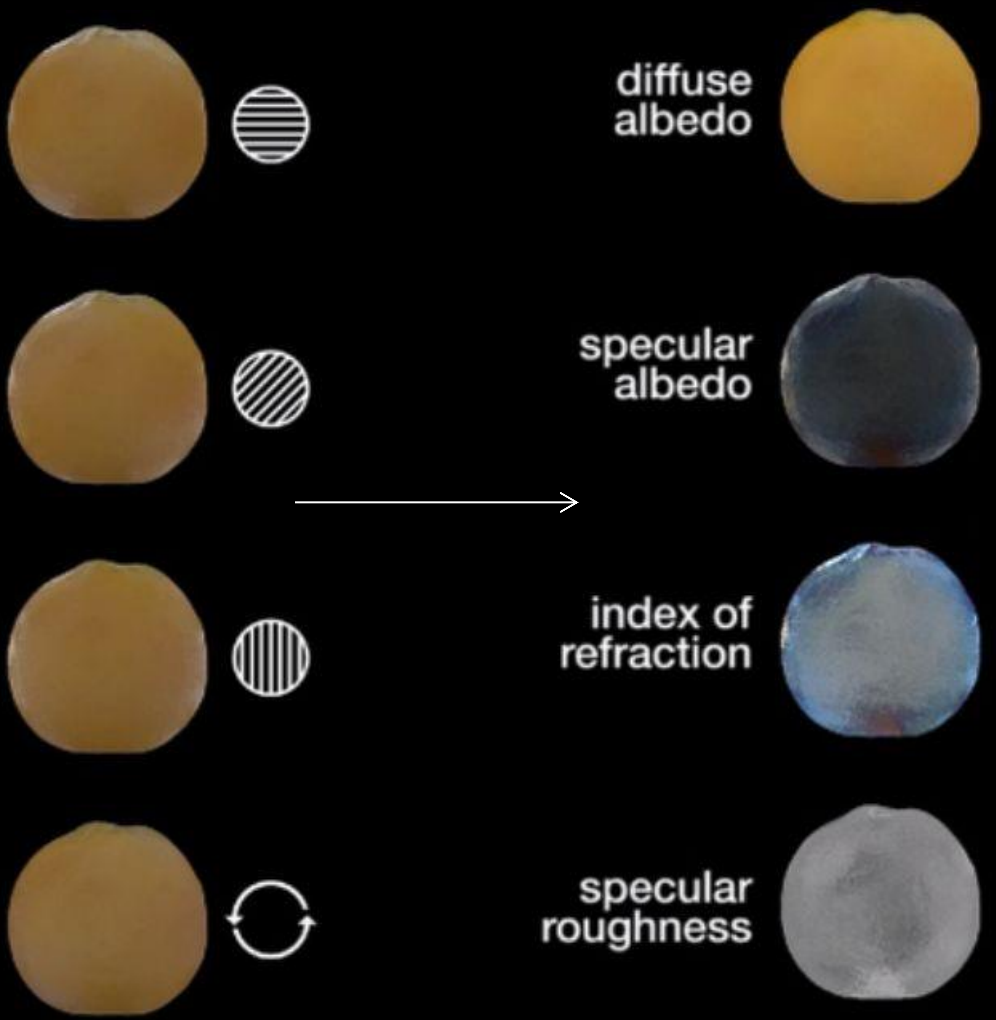
- Fourier basis illumination
  - Spectrum decay measure of glossiness
  - Surface normal inferred from position (phase of Fourier basis) on screen

Fourier basis measurement [Aitalla et al. 2013]



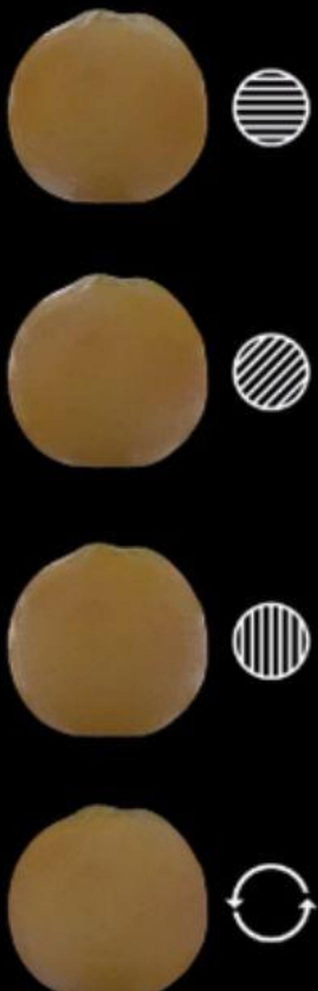
Polarization imaging reflectometry [Ghosh et al. 2010]

- Constant uniform illumination!
  - Circularly polarized
- Measurement of Stokes parameters



Polarization imaging reflectometry [Ghosh et al. 2010]

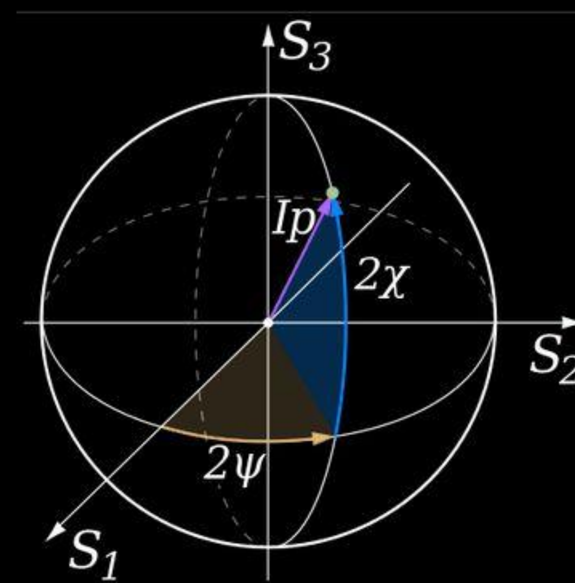
- Stokes parameters



$$
\begin{aligned}
S_0 &= I \\
S_1 &= Ip\cos 2\psi \cos 2\chi \\
S_2 &= Ip\sin 2\psi \cos 2\chi \\
S_3 &= Ip\sin 2\chi
\end{aligned}
$$

$$\begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

Right-hand circularly polarized



Poincare sphere

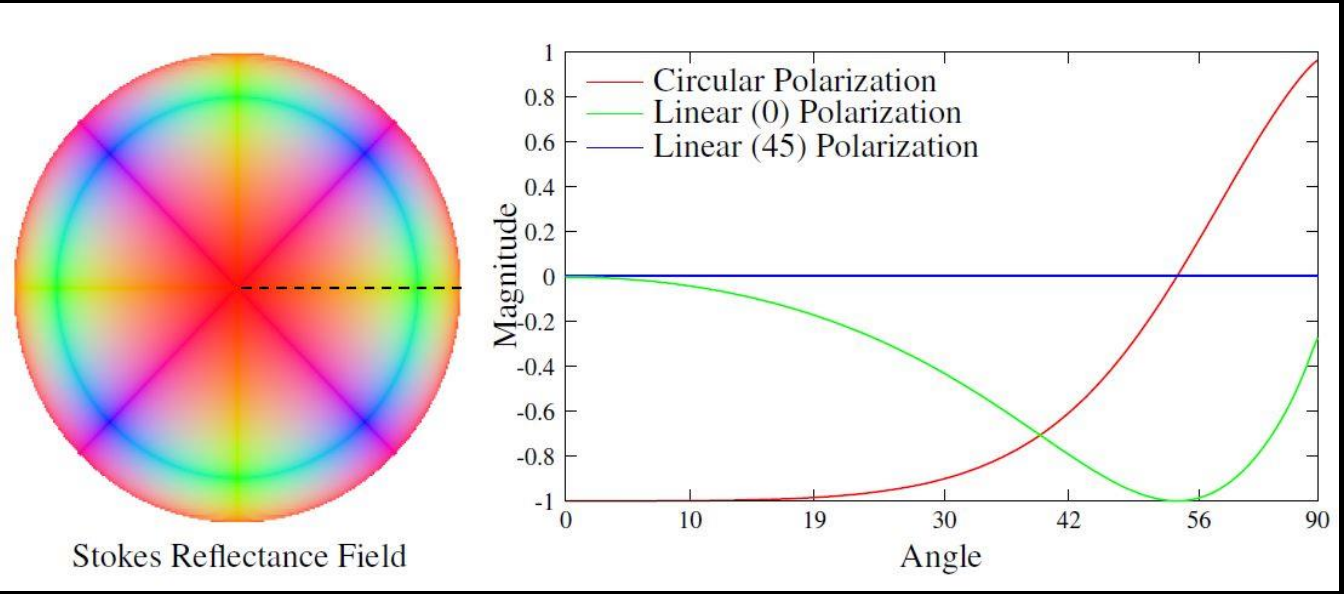
Polarization imaging reflectometry [Ghosh et al. 2010]

- Stokes reflectance field
  - Mueller calculus

$$\mathbf{s}' = \mathbf{C}(\phi)\mathbf{D}(\delta;\mathbf{n})\mathbf{R}(\theta;\mathbf{n})\mathbf{C}(-\phi)\mathbf{s}$$

$$\mathbf{C} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\phi & -\sin 2\phi & 0 \\ 0 & \sin 2\phi & \cos 2\phi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

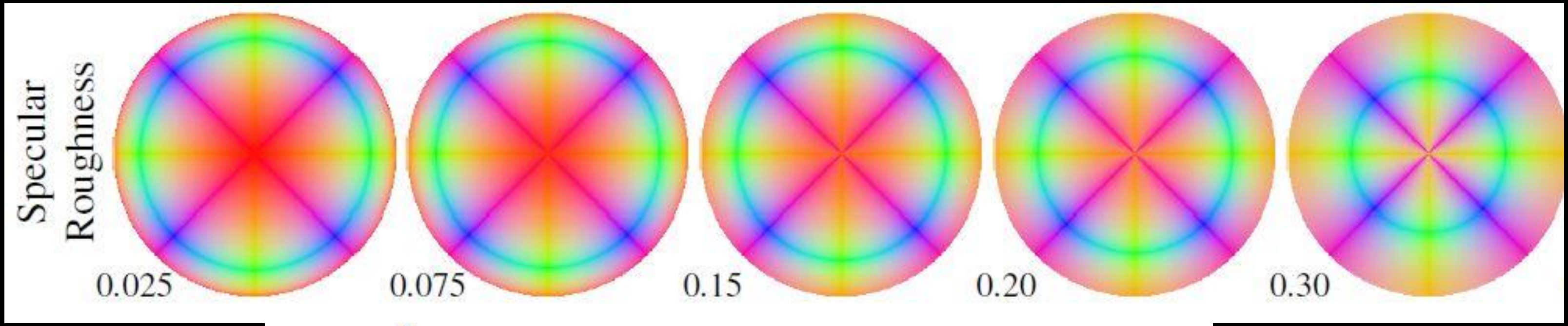
$$\mathbf{R} = \begin{pmatrix} \frac{\mathbf{R}_\parallel + \mathbf{R}_\perp}{2} & \frac{\mathbf{R}_\parallel - \mathbf{R}_\perp}{2} & 0 & 0 \\ \frac{\mathbf{R}_\parallel - \mathbf{R}_\perp}{2} & \frac{\mathbf{R}_\parallel + \mathbf{R}_\perp}{2} & 0 & 0 \\ 0 & 0 & \sqrt{\mathbf{R}_\parallel \mathbf{R}_\perp} & 0 \\ 0 & 0 & 0 & \sqrt{\mathbf{R}_\parallel \mathbf{R}_\perp} \end{pmatrix}$$

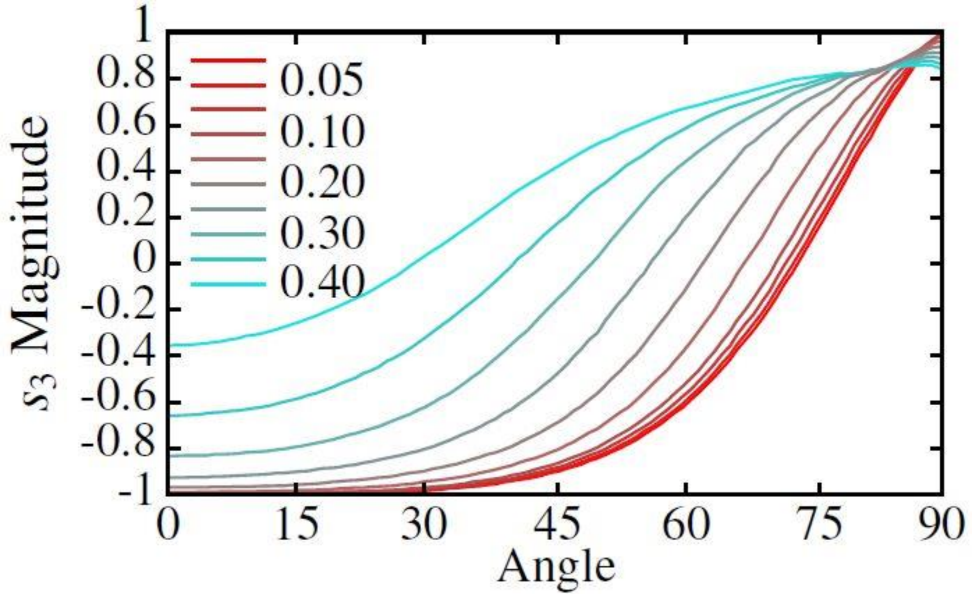


Polarization imaging reflectometry [Ghosh et al. 2010]

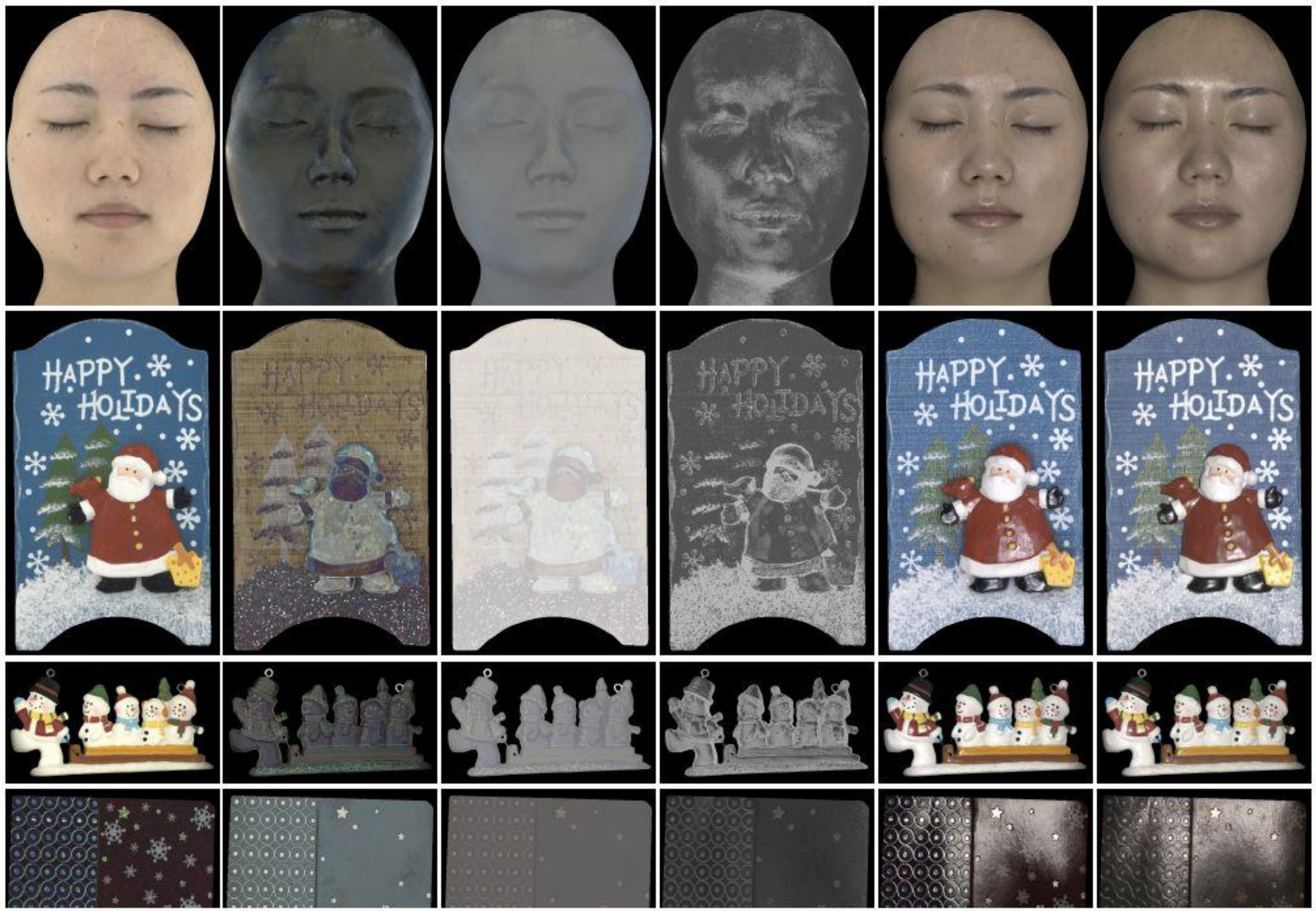
- Stokes reflectance field
  - Mueller calculus

$$\mathbf{s}' = \mathbf{C}(\phi)\mathbf{D}(\delta;\mathbf{n})\mathbf{R}(\theta;\mathbf{n})\mathbf{C}(-\phi)\mathbf{s}$$





Polarization imaging reflectometry [Ghosh et al. 2010]



(a) diffuse albedo (b) specular albedo (c) index of refraction (d) specular roughness (e) rendering (f) photograph

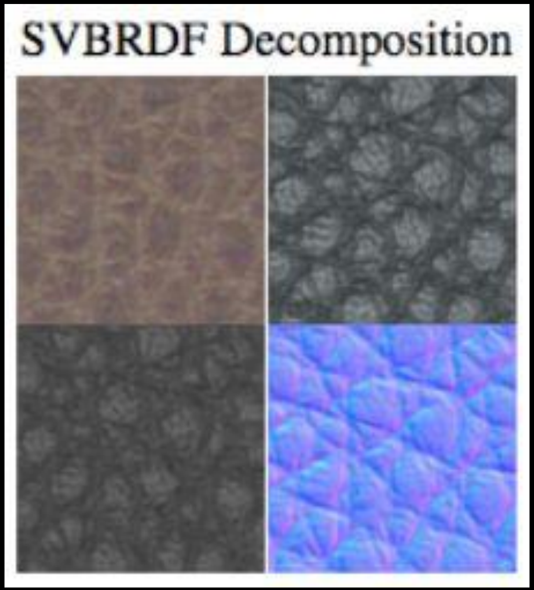
Polarization imaging reflectometry [Ghosh et al. 2010]

Mobile camera-flash measurements!

Stationary materials [Aittala et al. 15]

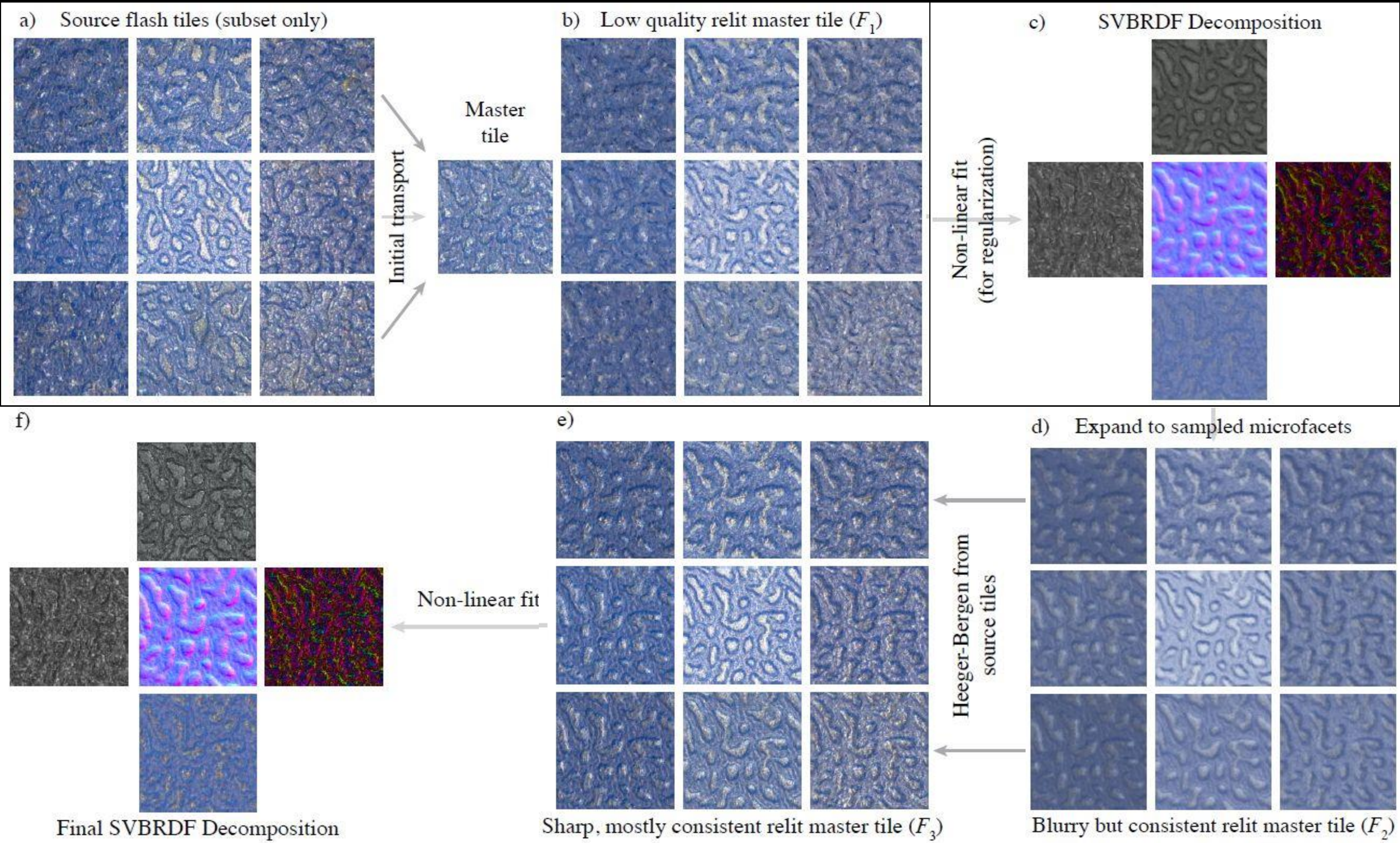
Isotropic SVBRDFs [Riviere et al. 16]

Stationary materials [Aitalla et al. 2015]

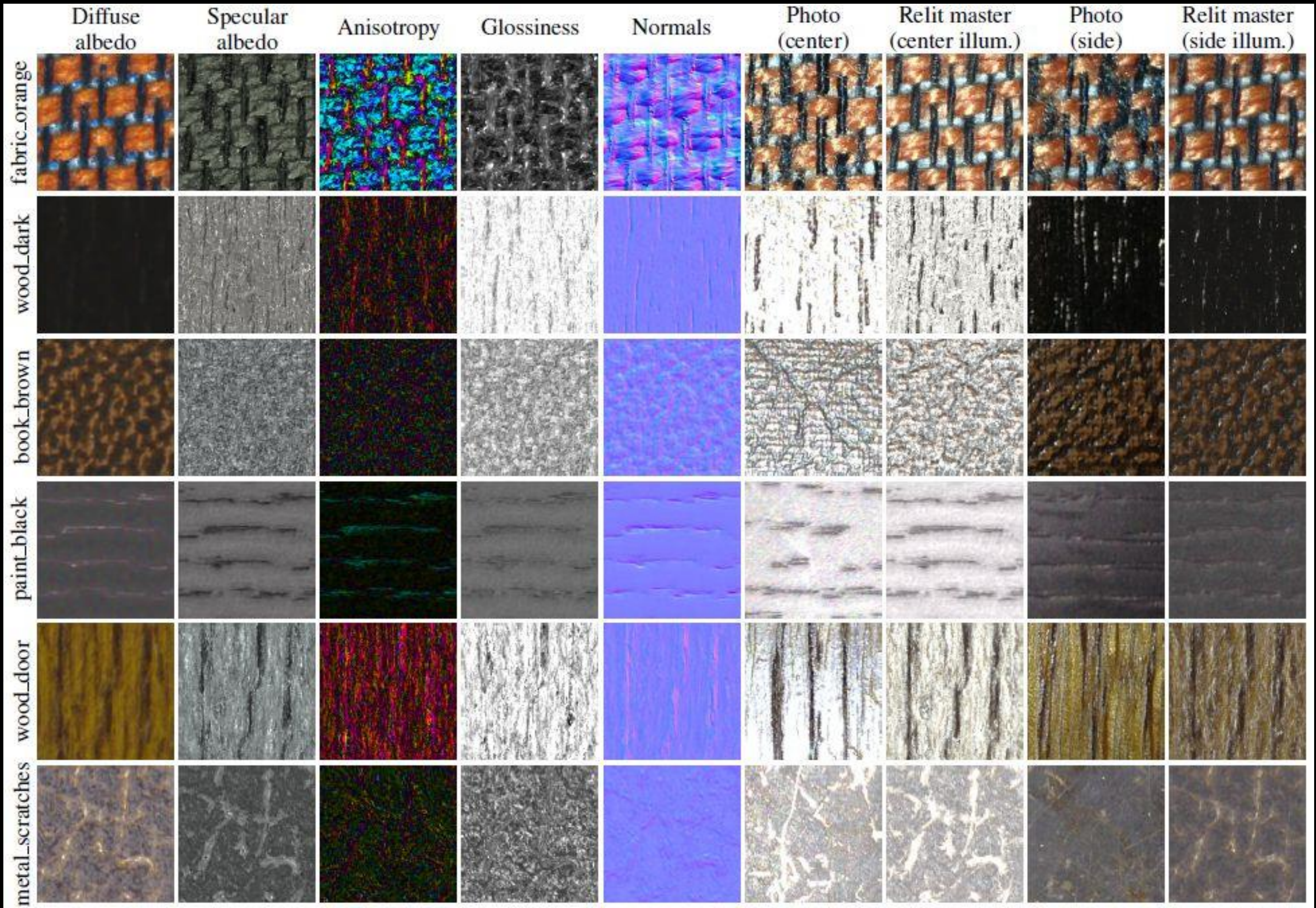


- Two shot capture!
  - Ambient + flash image
  - Repeating texture/material
  - Statistical appearance sharing

Stationary materials [Aitalla et al. 2015]



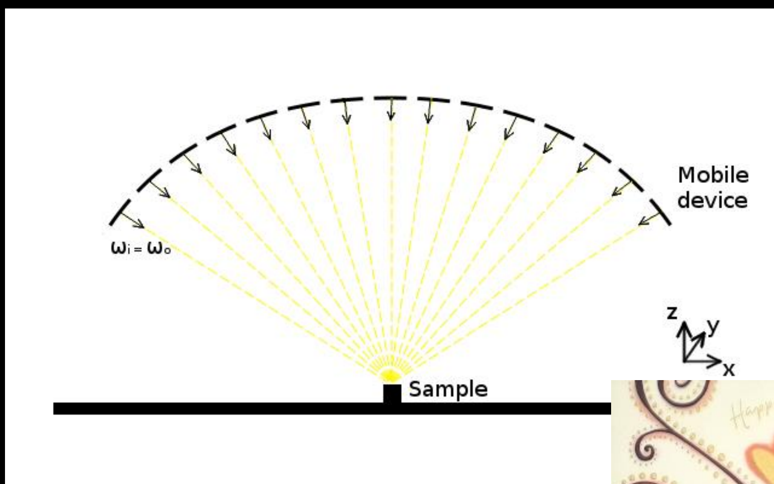
Stationary materials [Aitalla et al. 2015]



Mobile surface reflectometry

[Riviere et al. 16]

- Camera-flash pair
  - backscatter measurements
  - rough specular BRDFs



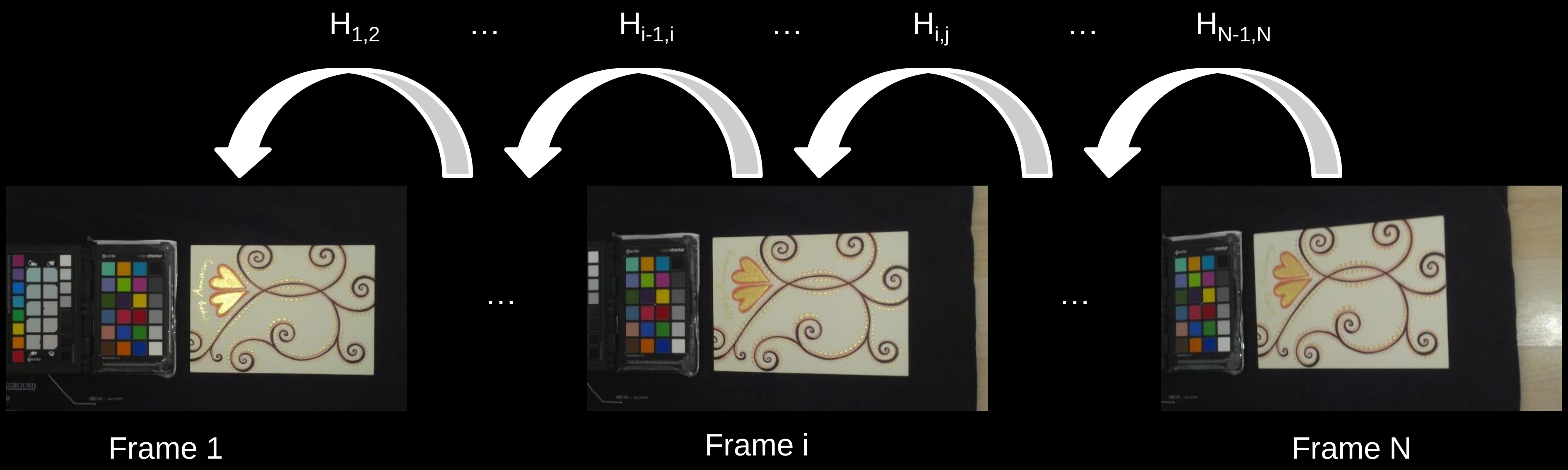
Hand-held acquisition

Rendering

[Riviere et al. 16]

Data registration

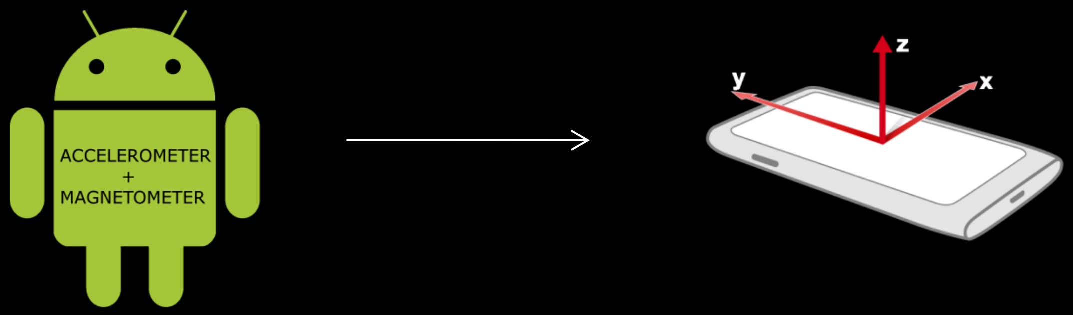
- Feature extraction (Harris corners)
  - Matched with optical flow
- Homography-based warping



[Riviere et al. 16]

Light/view direction estimation

- $\omega_i = \omega_r$ (back scattering direction)
- Android standard API (getRotationMatrix)

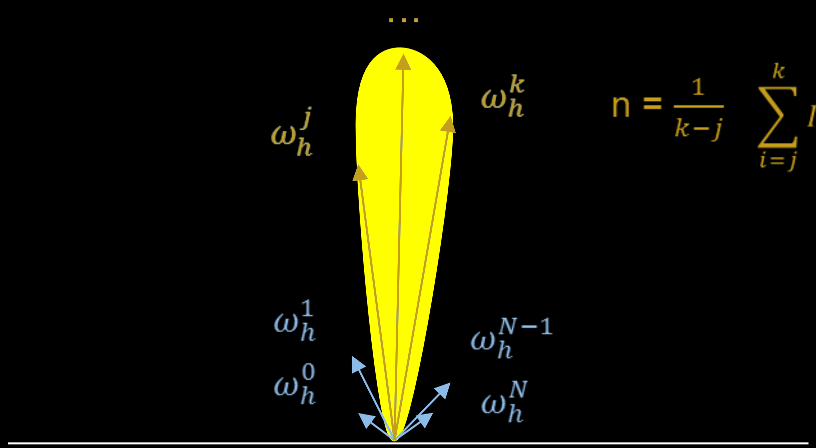


- 3D tracking
  - Simultaneous Localisation And Mapping (PTAM [G. Klein and D. Murray 2007])
  - Limited to feature rich scenes
  - SfM alternate solution

Mobile surface reflectometry

[Riviere et al. 16]

- Normal map: Weighted average



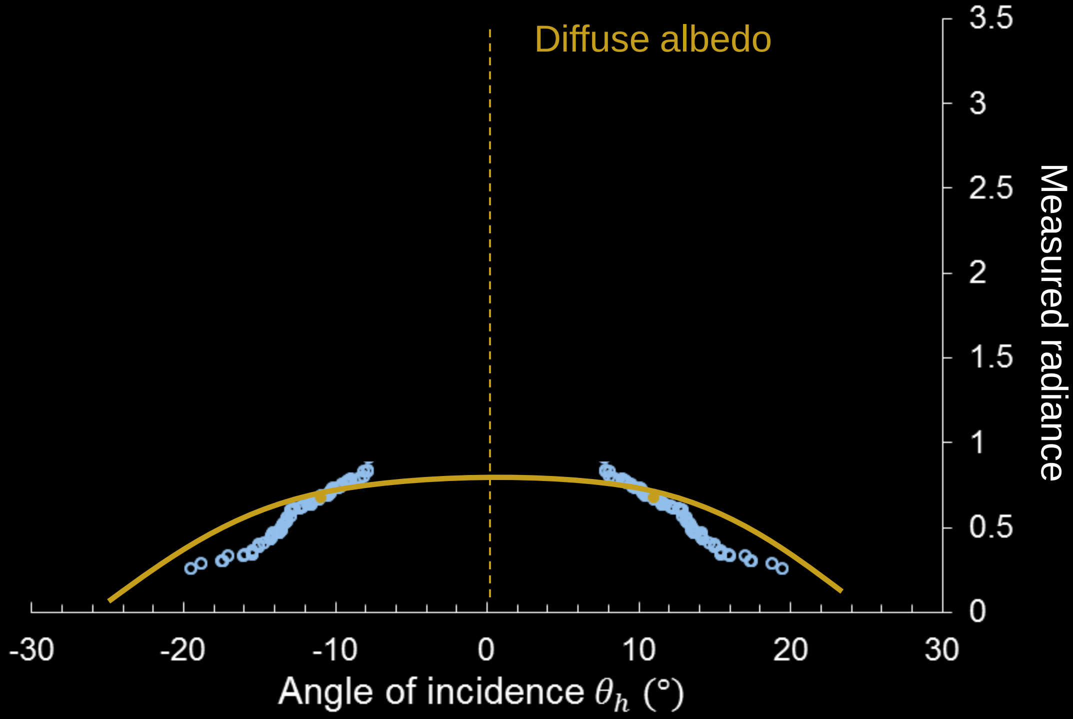
$$n = \frac{1}{k-j} \sum_{i=j}^{k} I_i * \omega_h^i$$

Normal map

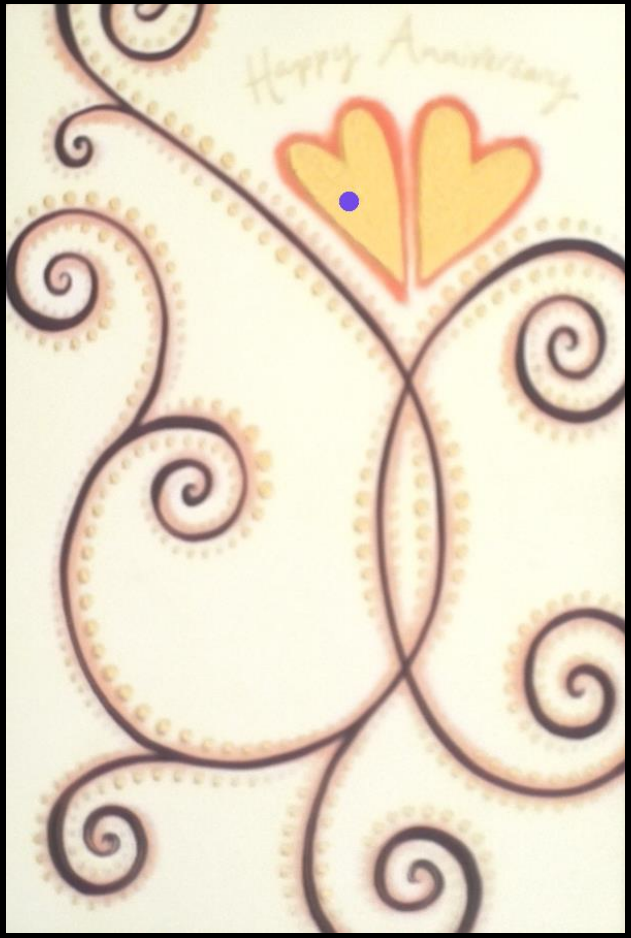
Mobile surface reflectometry

[Riviere et al. 16]

- Diffuse albedo: Median operator



Diffuse albedo map



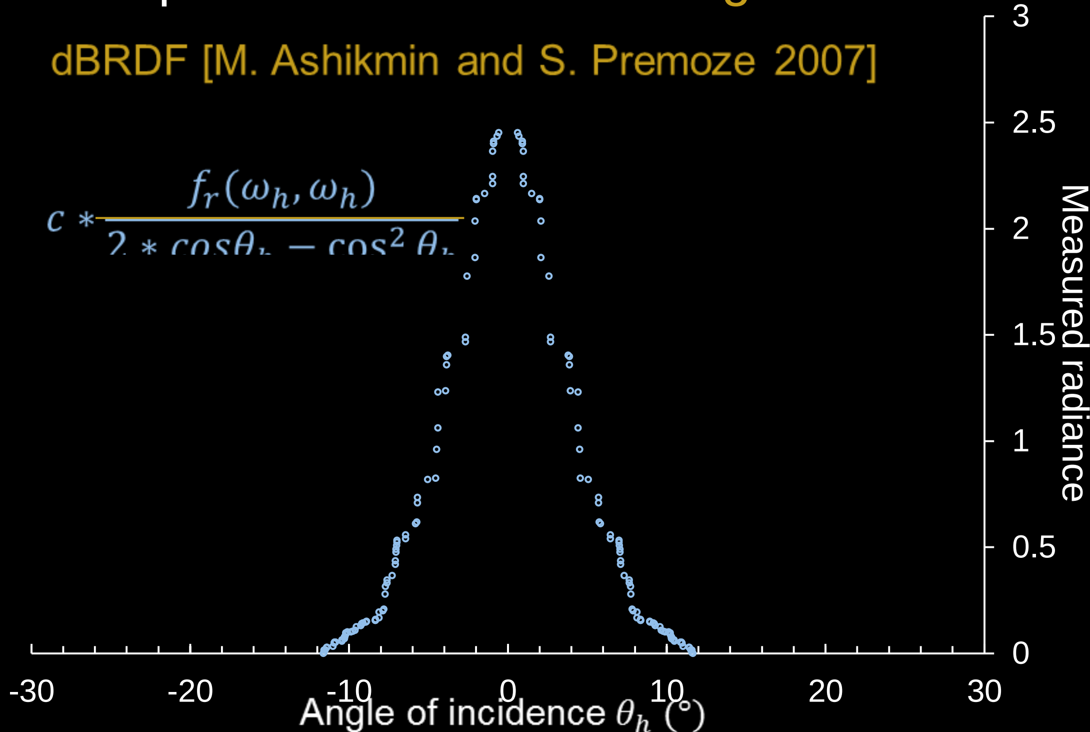
Mobile surface reflectometry

[Riviere et al. 16]

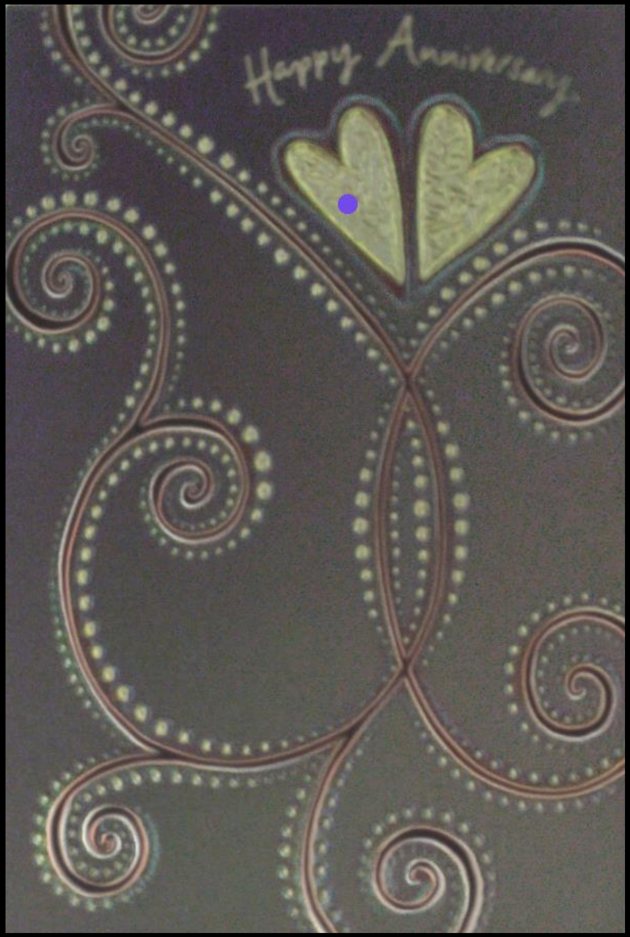
- Specular albedo: MC integration

dBRDF [M. Ashikmin and S. Premoze 2007]

$$c * \frac{f_r(\omega_h, \omega_h)}{2 * \cos\theta_h - \cos^2\theta_h}$$



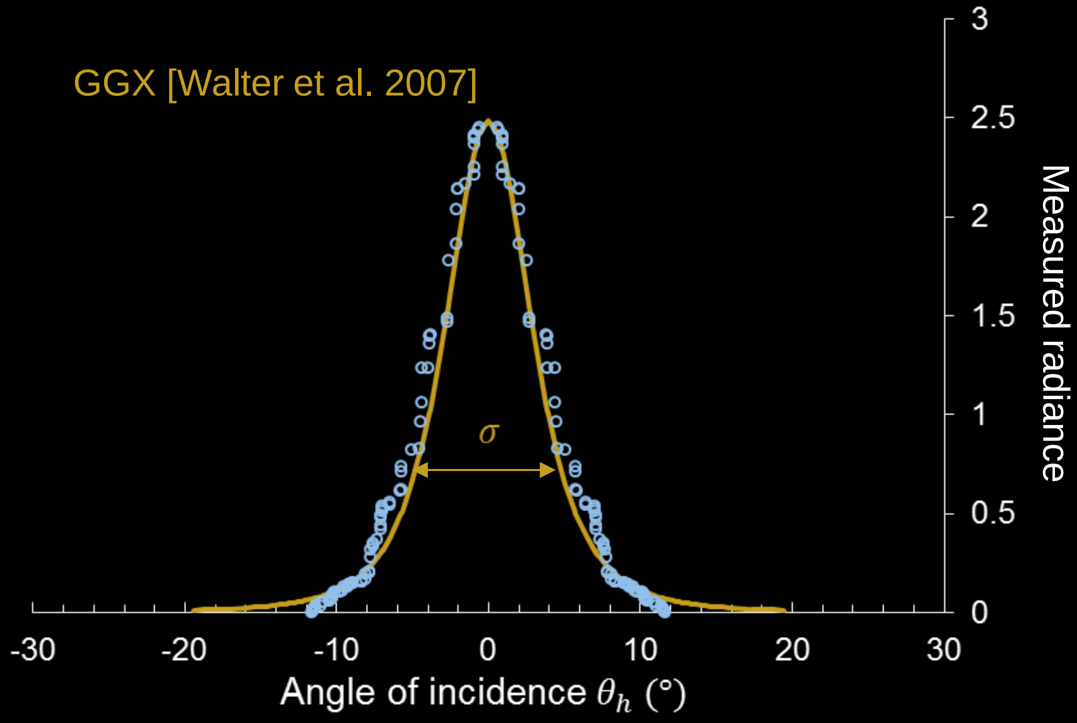
Specular albedo map



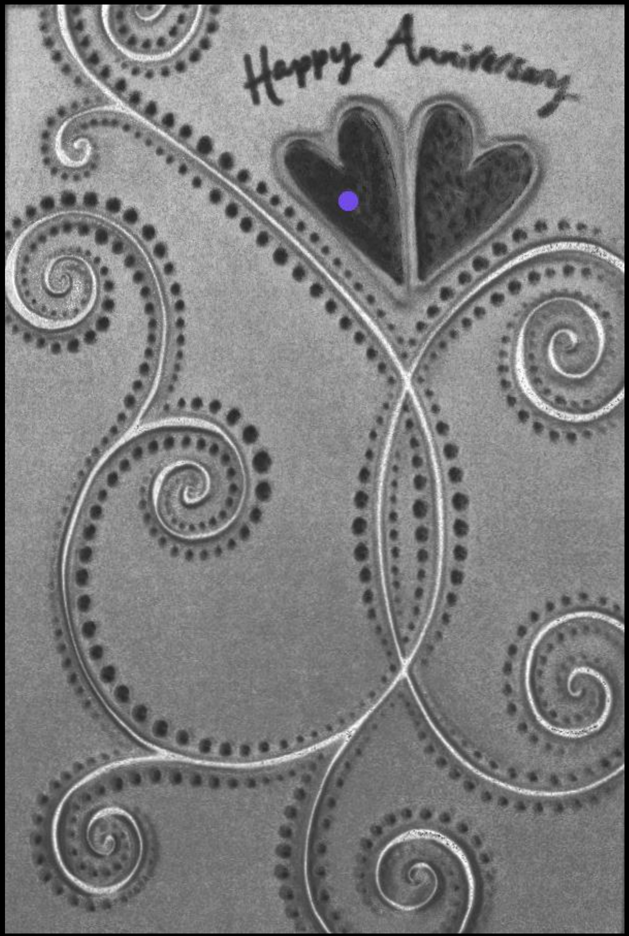
Mobile surface reflectometry

[Riviere et al. 16]

- Roughness: Microfacet BRDF fit

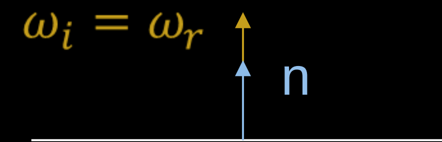


Roughness map



Mobile surface reflectometry

[Riviere et al. 16]



Rendering – frontal view

shaders

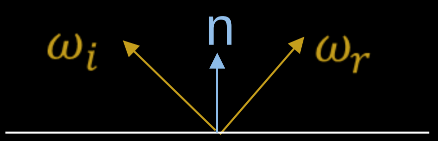
Rendering

Photograph

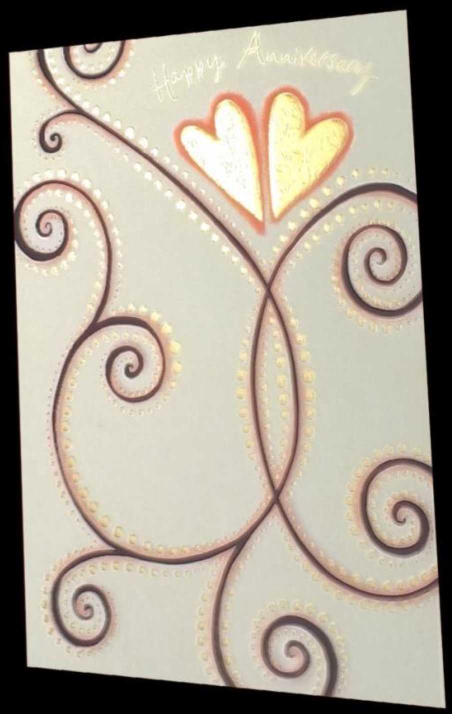
Mobile surface reflectometry

[Riviere et al. 16]

Rendering – novel view



shaders



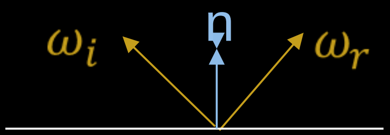
Rendering

Photograph

Mobile surface reflectometry

[Riviere et al. 16]

Rendering – novel view

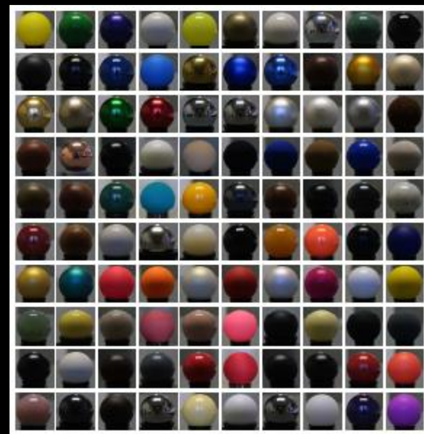


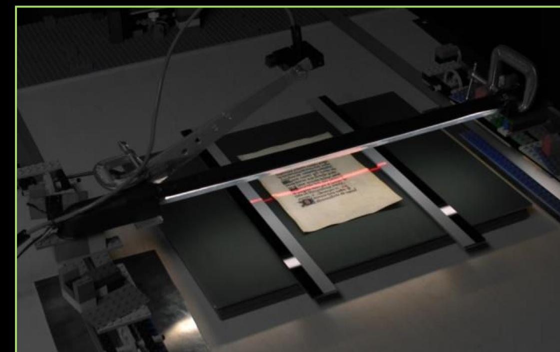
shaders

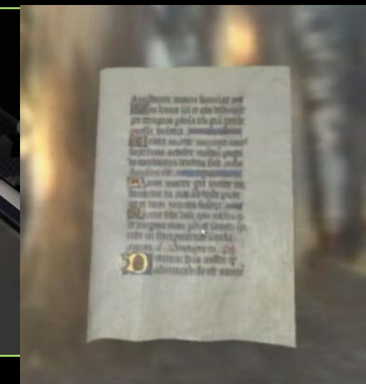
Rendering

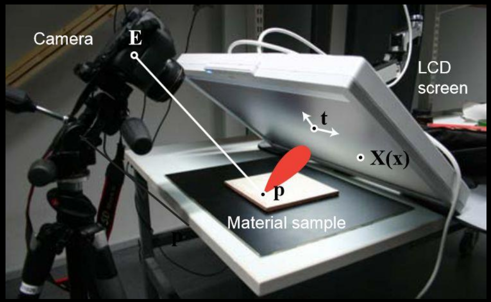
Photograph

Material appearance recap …









Thank You!