Experimental Analysis of BRDF Models

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Eurographics Symposium on Rendering 2005

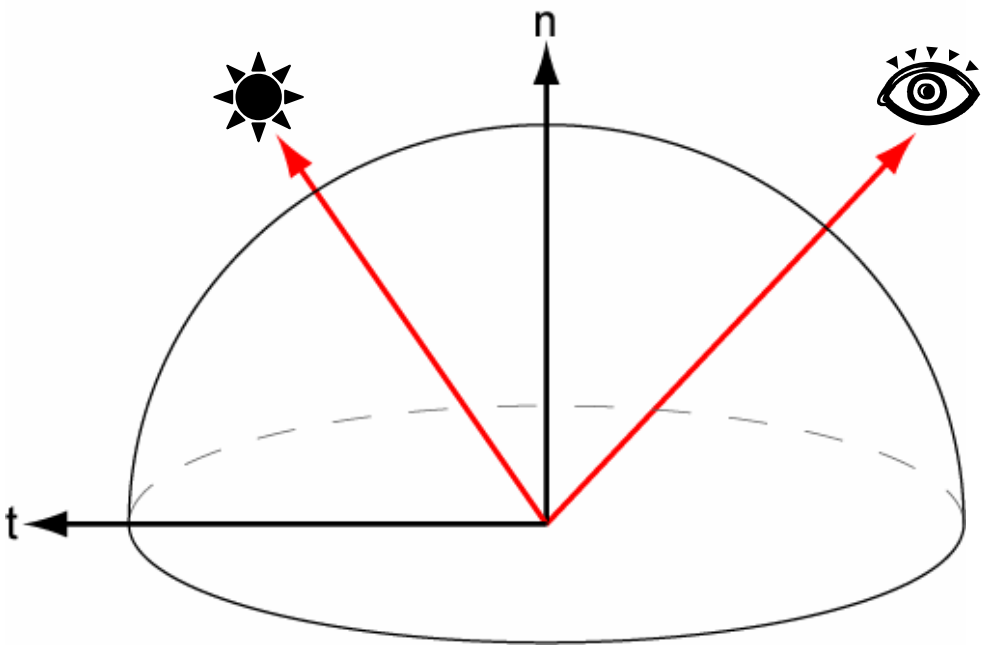
CSAIL

Goal

- Evaluate the performance of analytical reflectance models
- Based on measured data

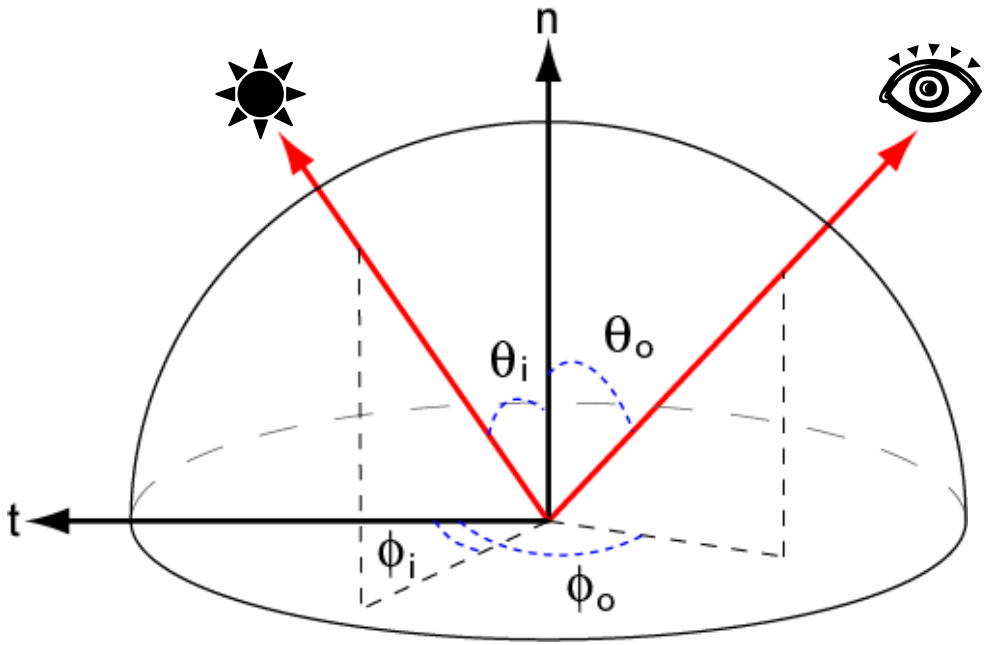
Background

- Bidirectional Reflectance Distribution Function



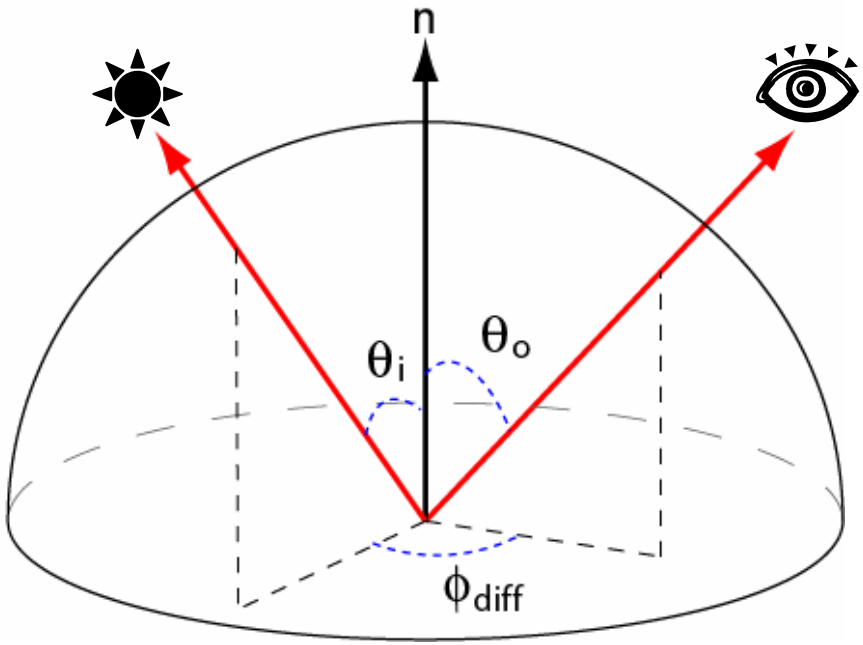
BRDF

- Bidirectional Reflectance Distribution Function
  - $\rho(\theta_i, \phi_i ; \theta_o, \phi_o)$



BRDF

- Bidirectional Reflectance Distribution Function
  - $\rho(\theta_i, \phi_i ; \theta_o, \phi_o)$
- Isotropic material
  - Invariant when material is rotated
  - BRDF is 3D

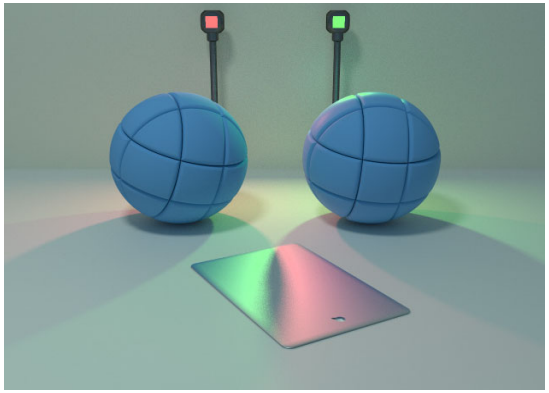


Previous Measurements

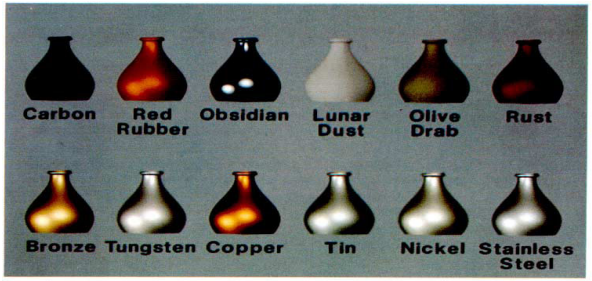
- Columbia-Utrecht Reflectance and Texture Database
  - ~60 materials, 205 measurements per BRDF
- Cornell's measurements
  - ~10 materials, 1439 measurements per BRDF
- Bonn BTF Database
  - 6 materials, 6561 view/light combinations
- Matusik's image-based measurements
  - ~100 materials, ~10^6 measurements per BRDF
  - Include metals, plastic, paints, fabrics.

BRDF Models

- Phenomenological
  - Phong [75]
    - Blinn-Phong [77]
  - Ward [92]
  - Lafortune et al. [97]
  - Ashikhmin et al. [00]
- Physical
  - Cook-Torrance [81]
  - He et al. [91]



Lafortune [97]



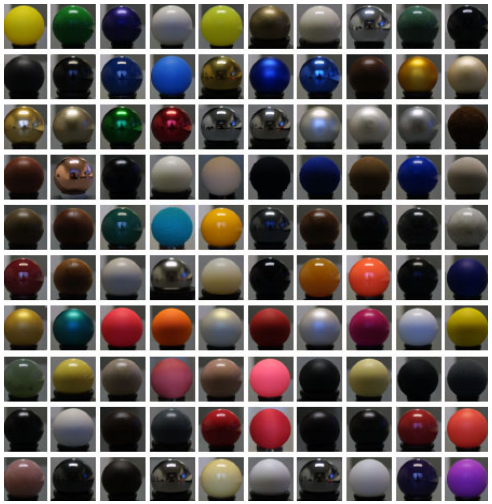
Cook-Torrance [81]

Outline

- Background
- BRDF Measurements
- BRDF Fitting
- Isotropic materials results
- Anisotropic materials results
- Conclusion

BRDF Measurements

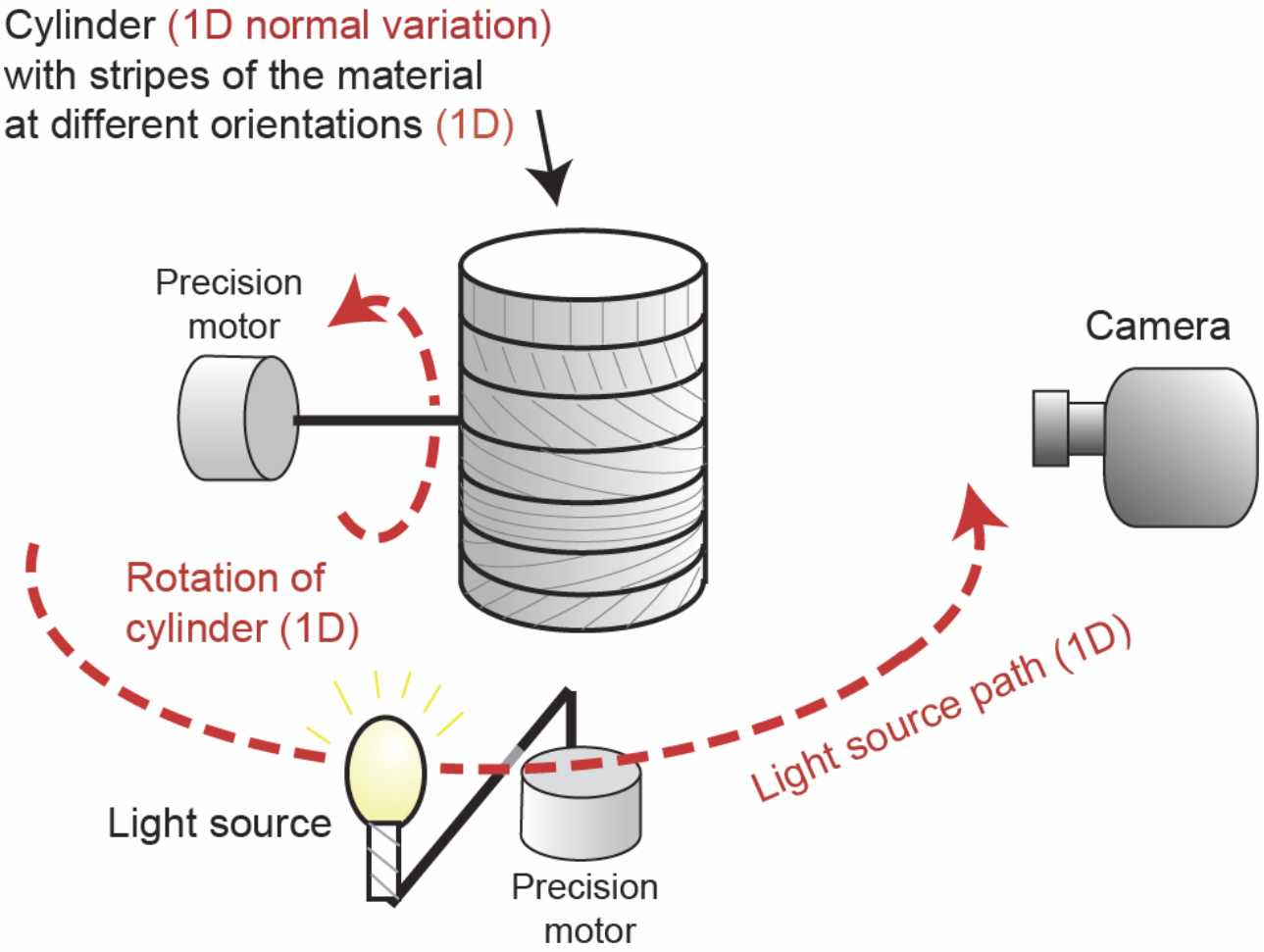
- Isotropic : Data from Matusik [03]
  - 100 materials chosen
  - Reprocessed to remove unreliable data
    - Flare
    - Near grazing angle



- Anisotropic : New acquisition

Anisotropic Measurements

- Similar to Lu et al. [00]



Anisotropic Measurements

- 4 materials measured (brushed aluminum, satins, velvet)
  - Each: 18 hours acquisition time, 30GB raw data
  - Tabulated into bins in 2° intervals (~10^8 bins)
  - 10-20% bins populated

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BRDF Fitting

- Target models: Blinn-Phong, Cook-Torrance, He et al., Lafortune et al. , Ward, Ashikhmin-Shirley

- Metric:
  - RMS of $(\rho_{measured} - M(\mathbf{p}))\ (\cos \theta_i)$
  - Linear w.r.t. diffuse/specular intensity

BRDF Fitting

- Other potential metrics
  - Logarithmic remapping
    - Arbitrary scale
    - Highlights overly blurry
  - Perceptual metrics
    - Context dependent
    - Costly to compute/fit
    - Intensity parameters become nonlinear – optimization less stable

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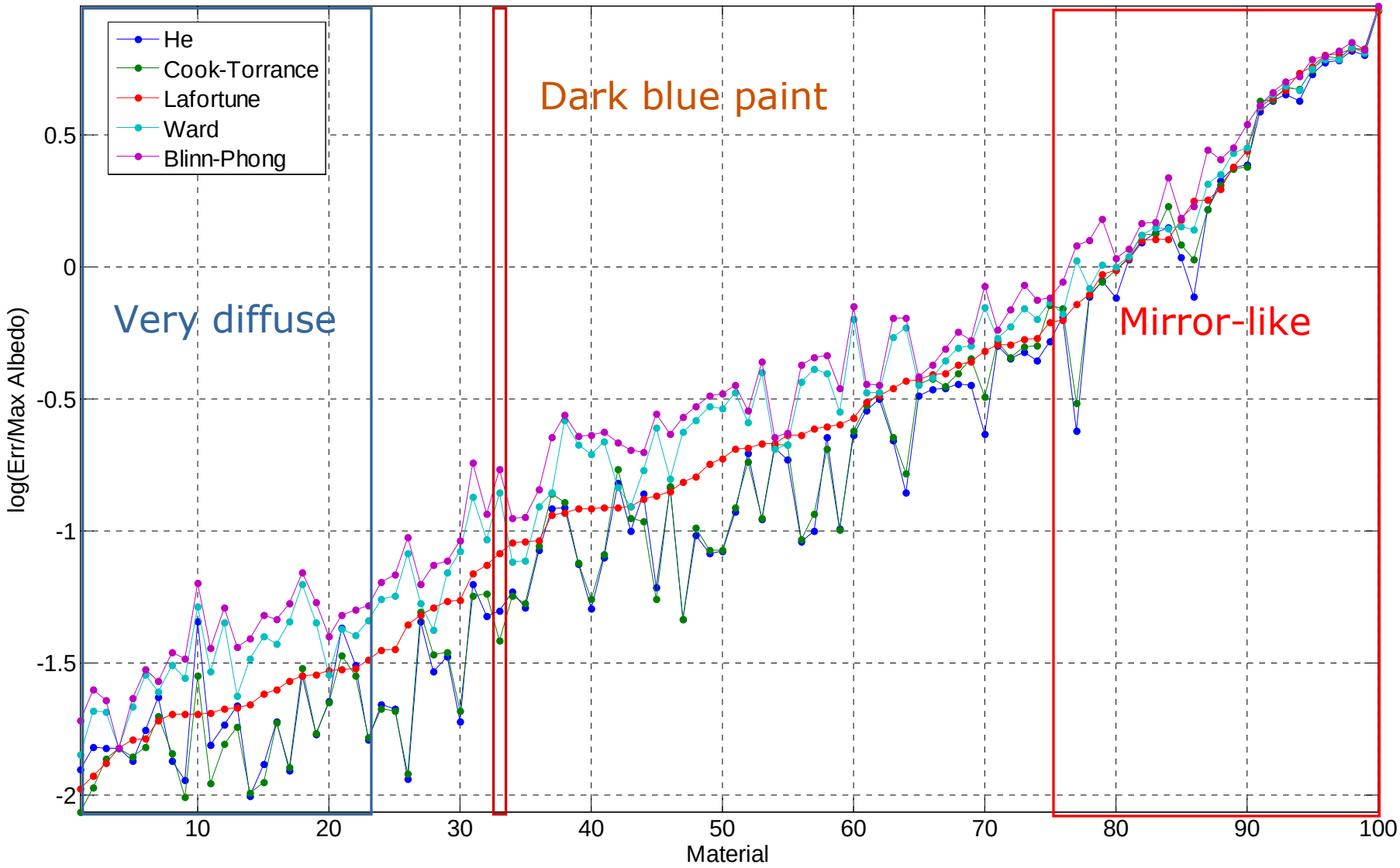
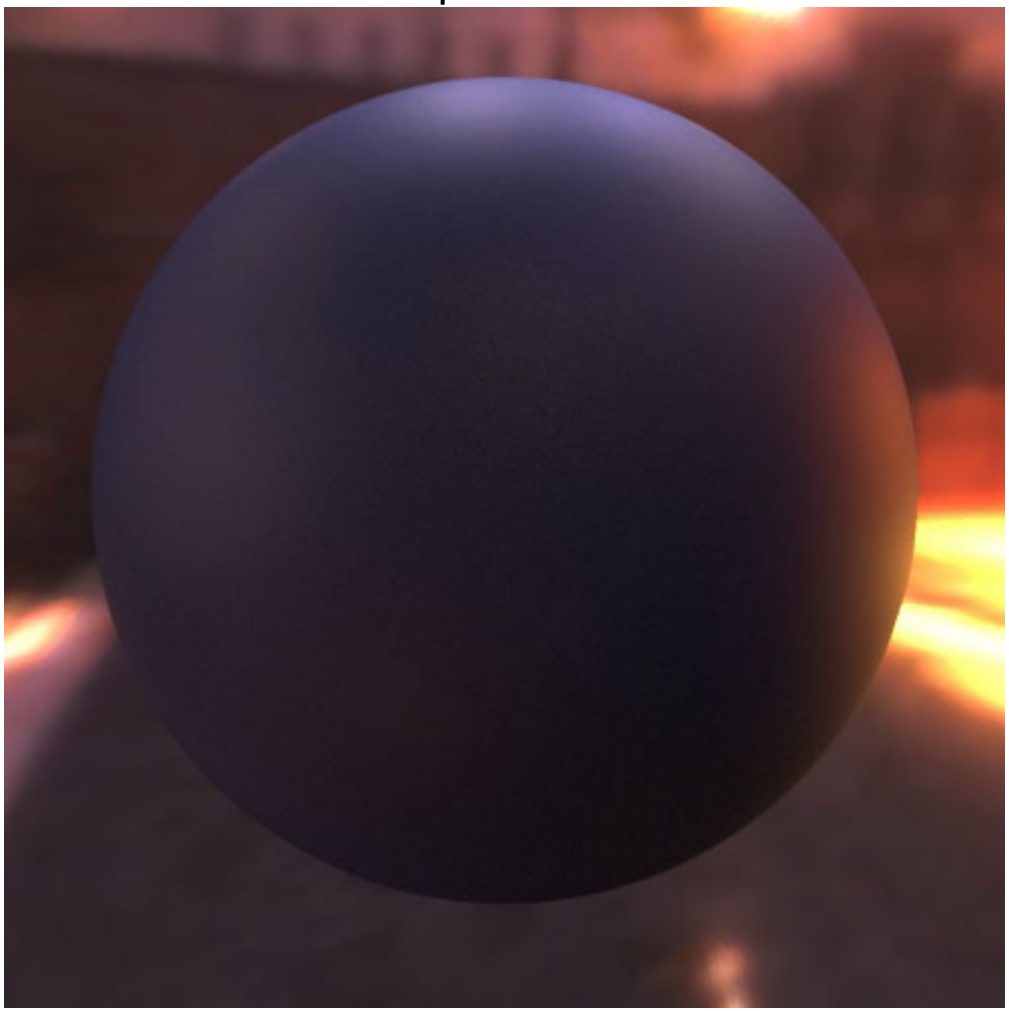
Fitting Errors



Dark blue paint

Acquired data

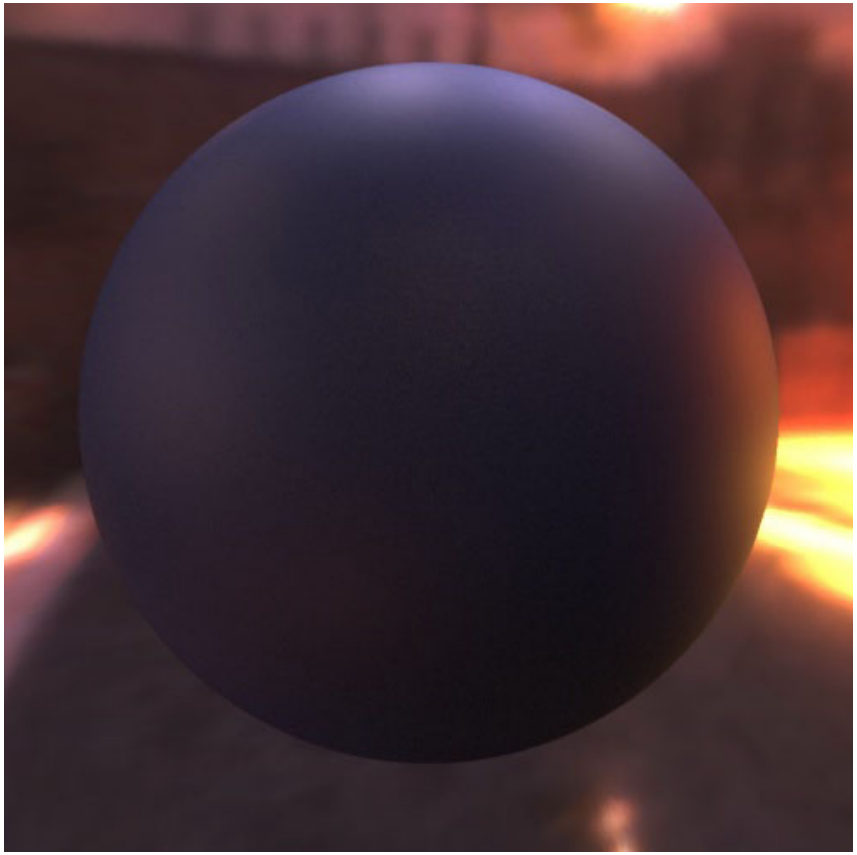


Environment map

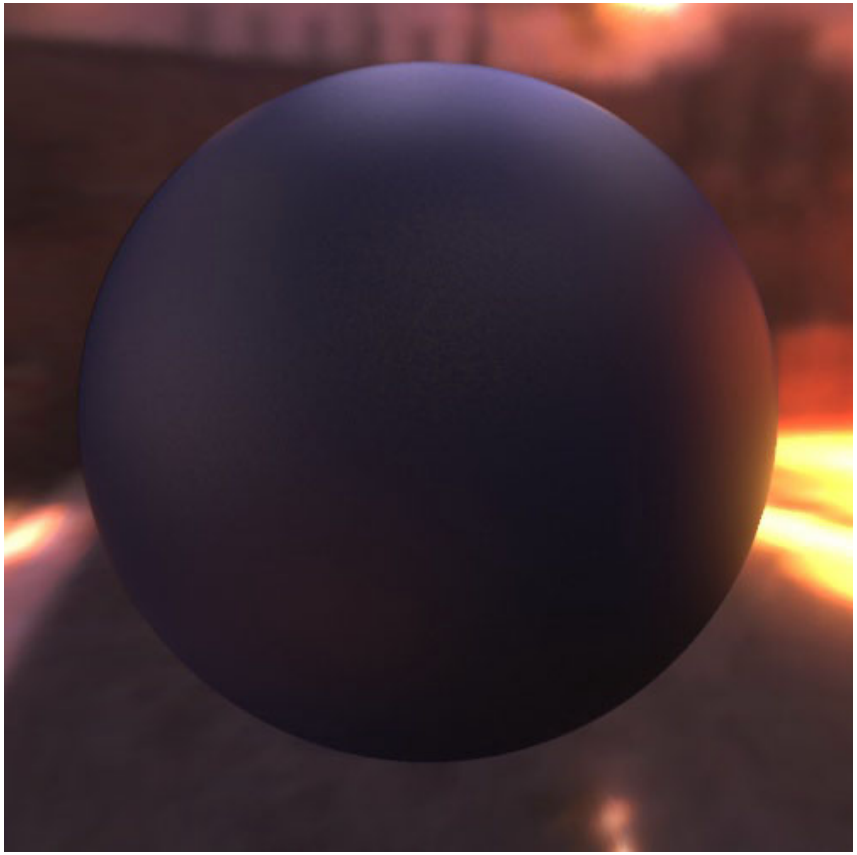
Material – Dark blue paint

Dark blue paint

Acquired data



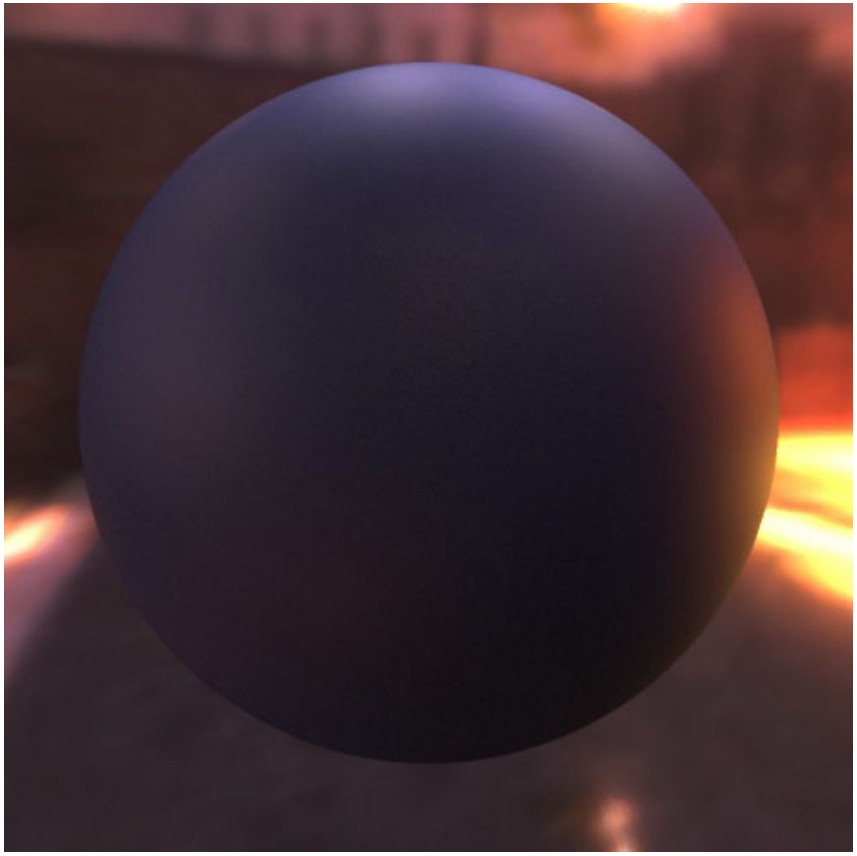
Cook-Torrance



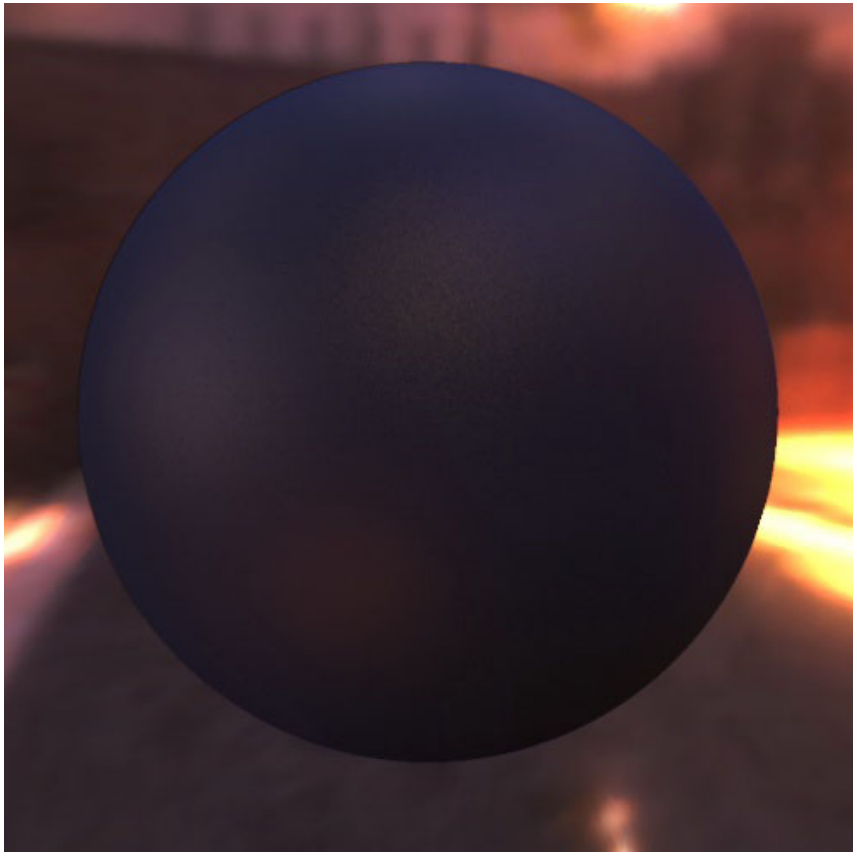
Material – Dark blue paint

Dark blue paint

Acquired data



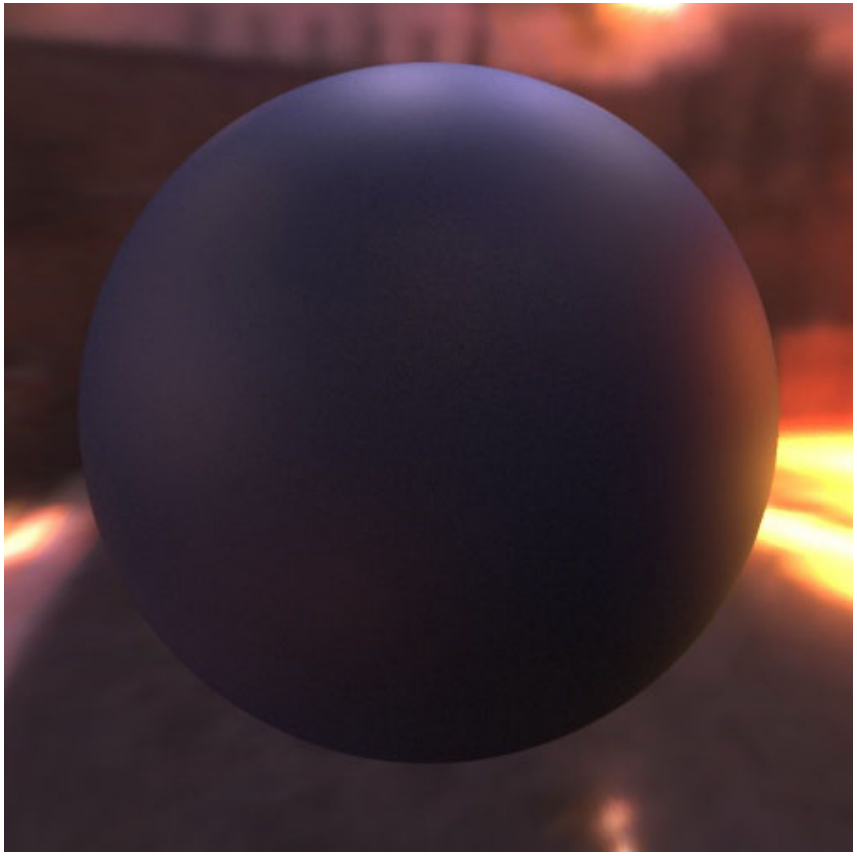
Blinn-Phong



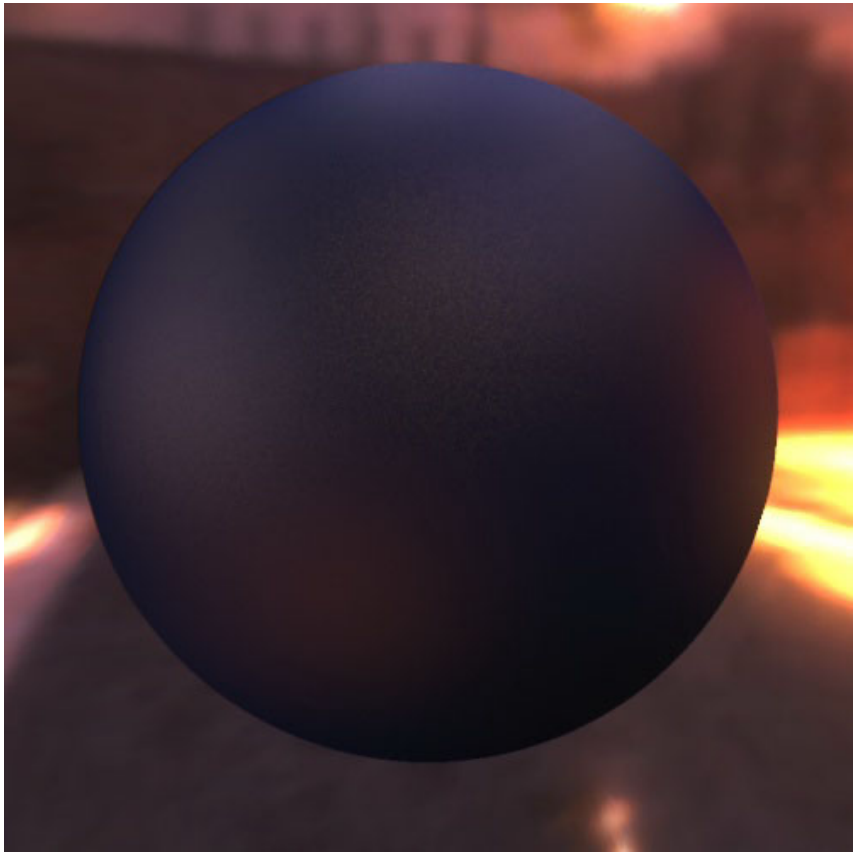
Material – Dark blue paint

Dark blue paint

Acquired data



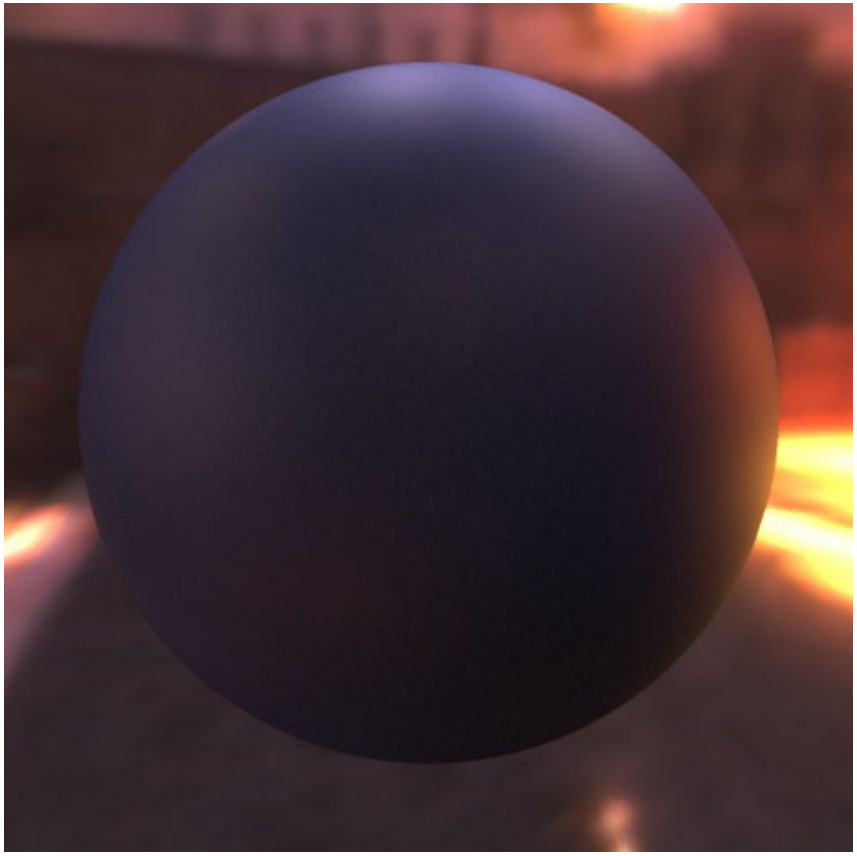
Ward



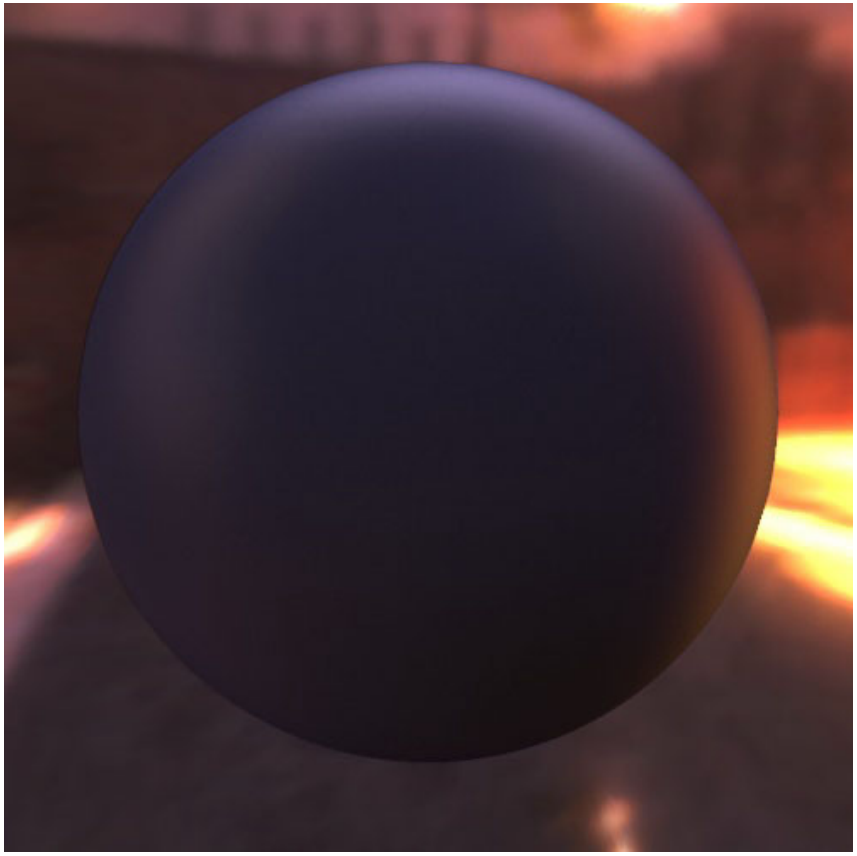
Material – Dark blue paint

Dark blue paint

Acquired data

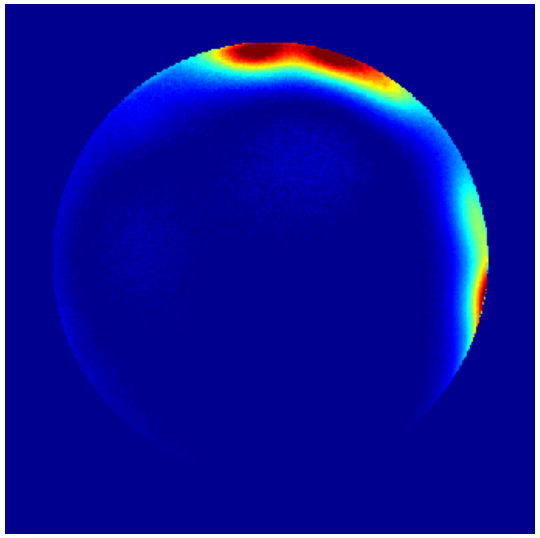


Lafortune

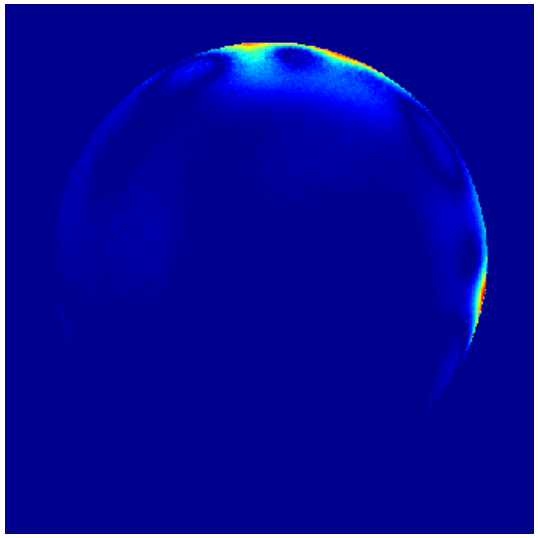


Material – Dark blue paint

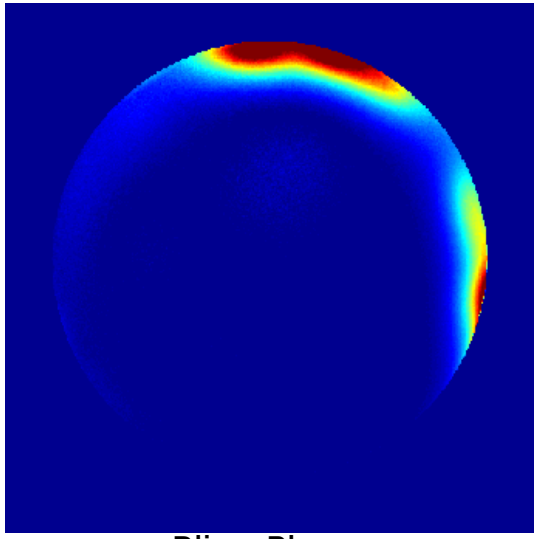
Dark blue paint – error plots



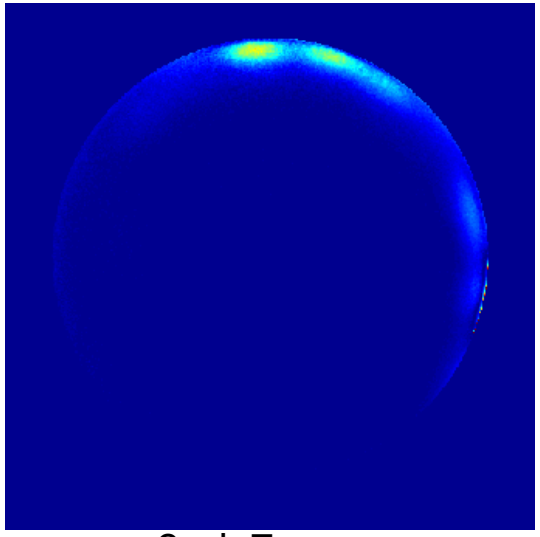
Ward



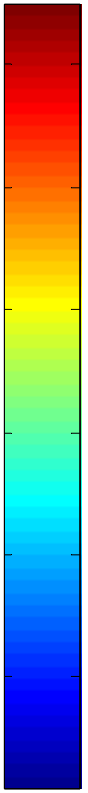
Lafortune



Blinn-Phong

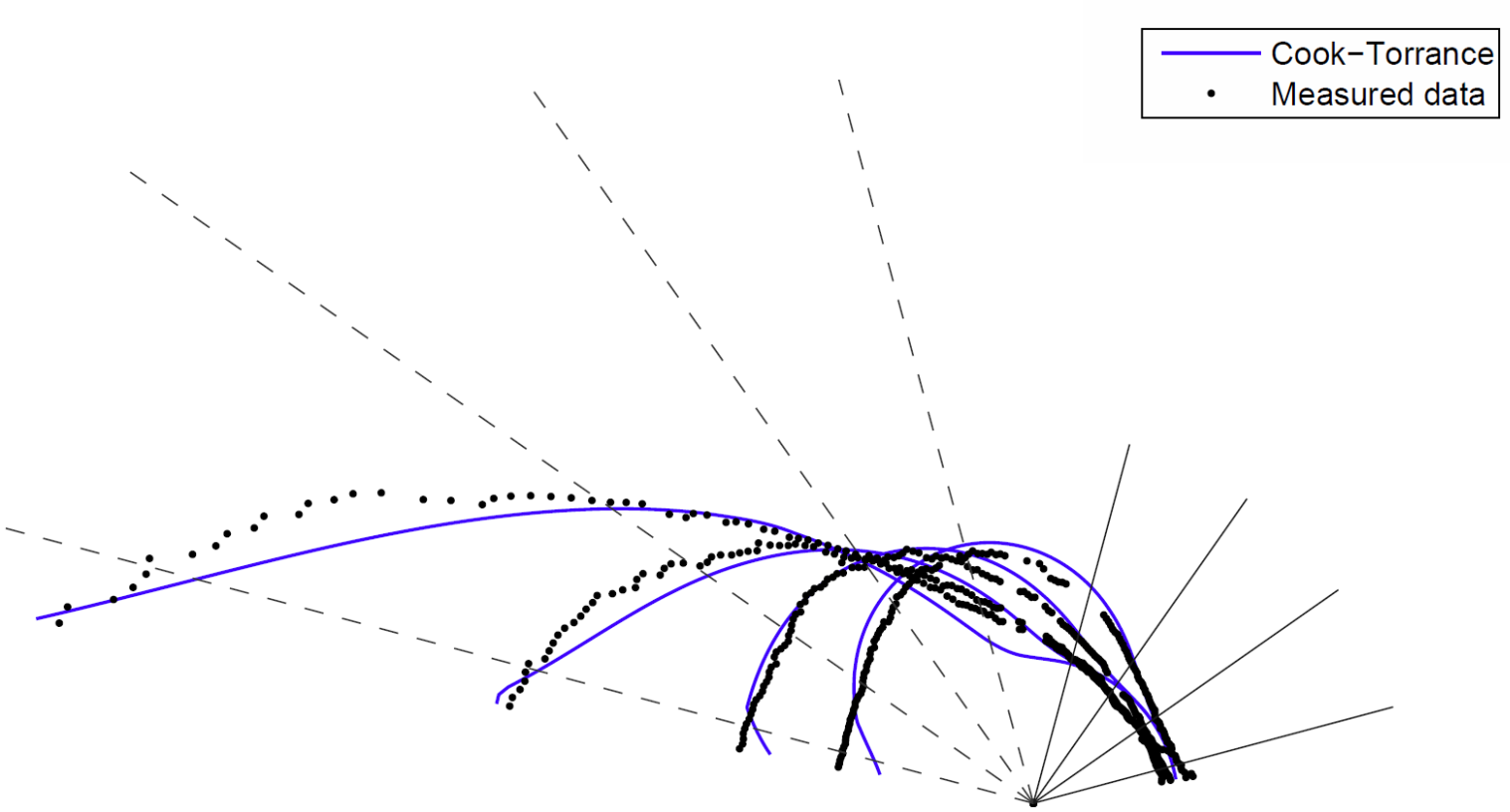


Cook-Torrance



Dark blue paint

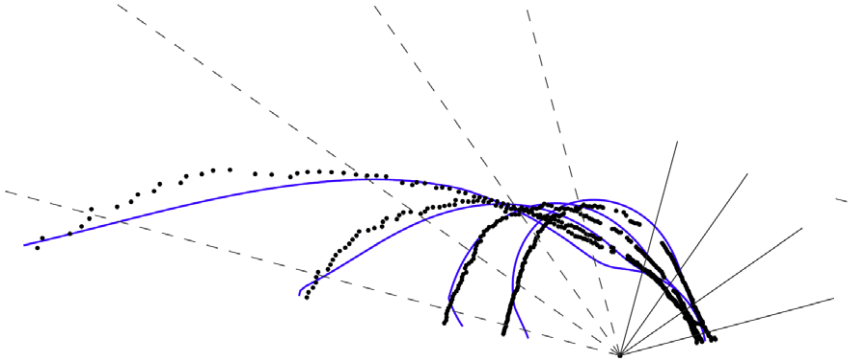
- Cook-Torrance fit, incidence plane, 4 different incident angles



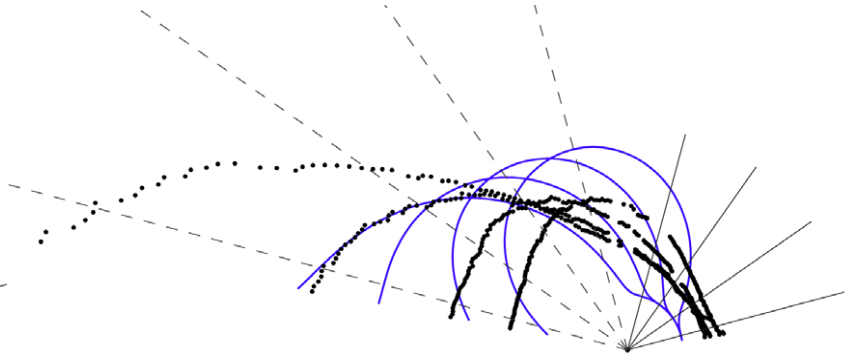
Material – Dark blue paint

Dark blue paint

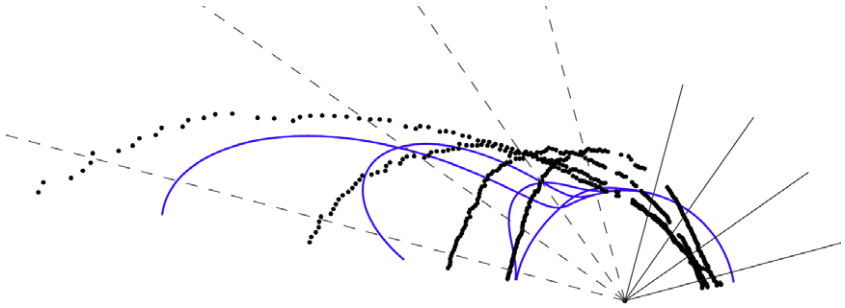
Cook-Torrance



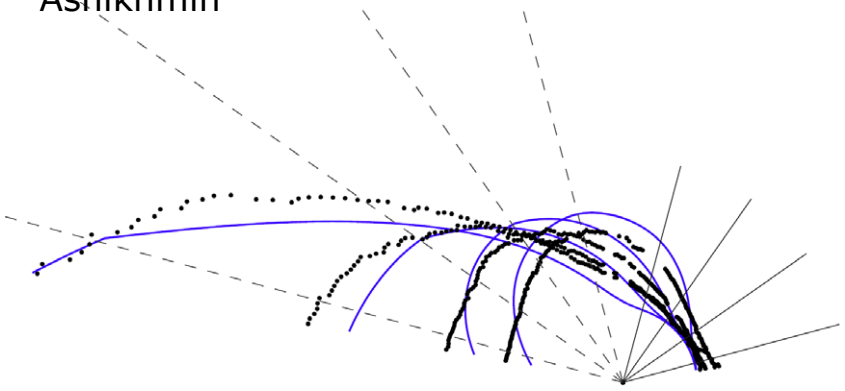
Ward



Lafortune



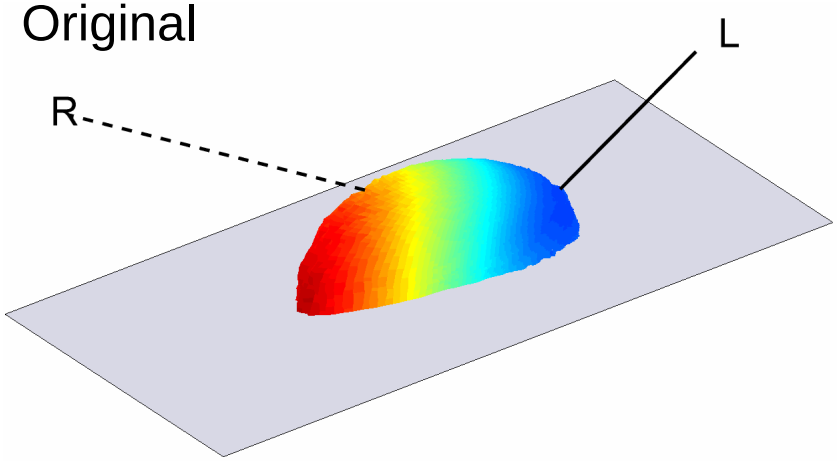
Ashikhmin



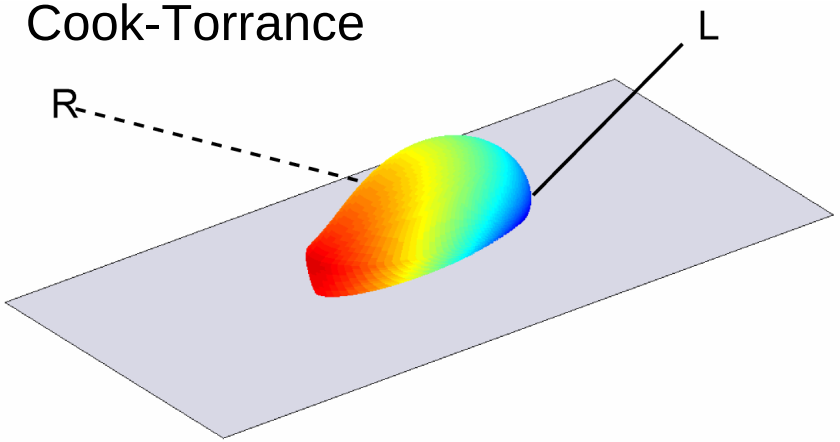
Material – Dark blue paint

Dark blue paint

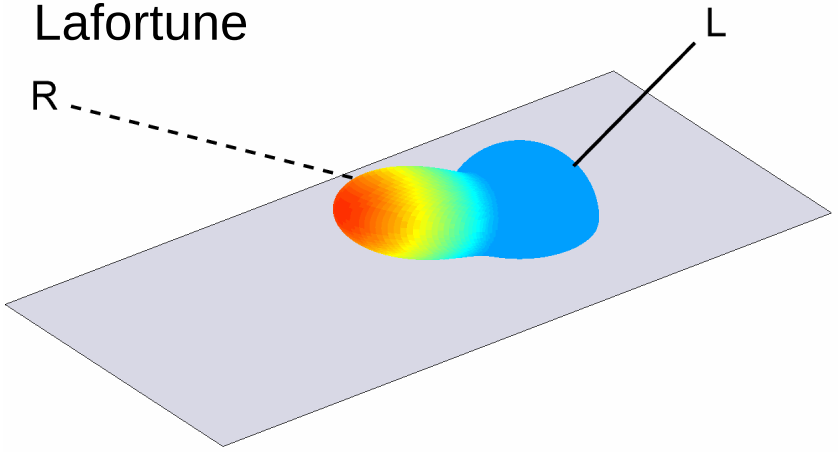
Original



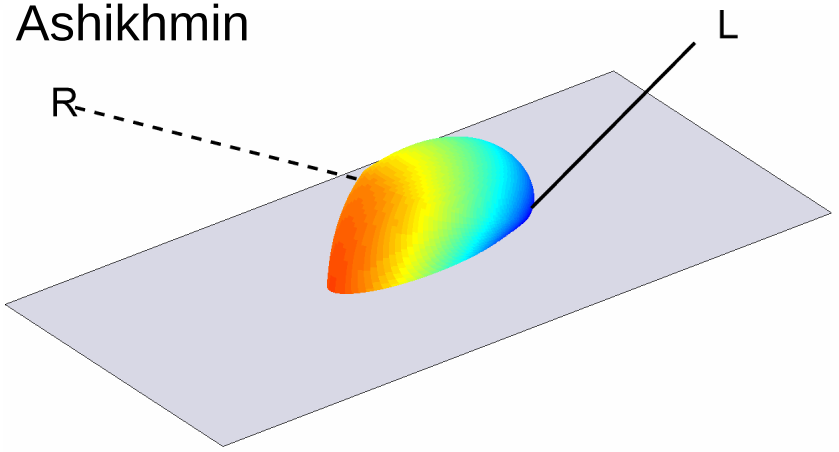
Cook-Torrance



Lafortune



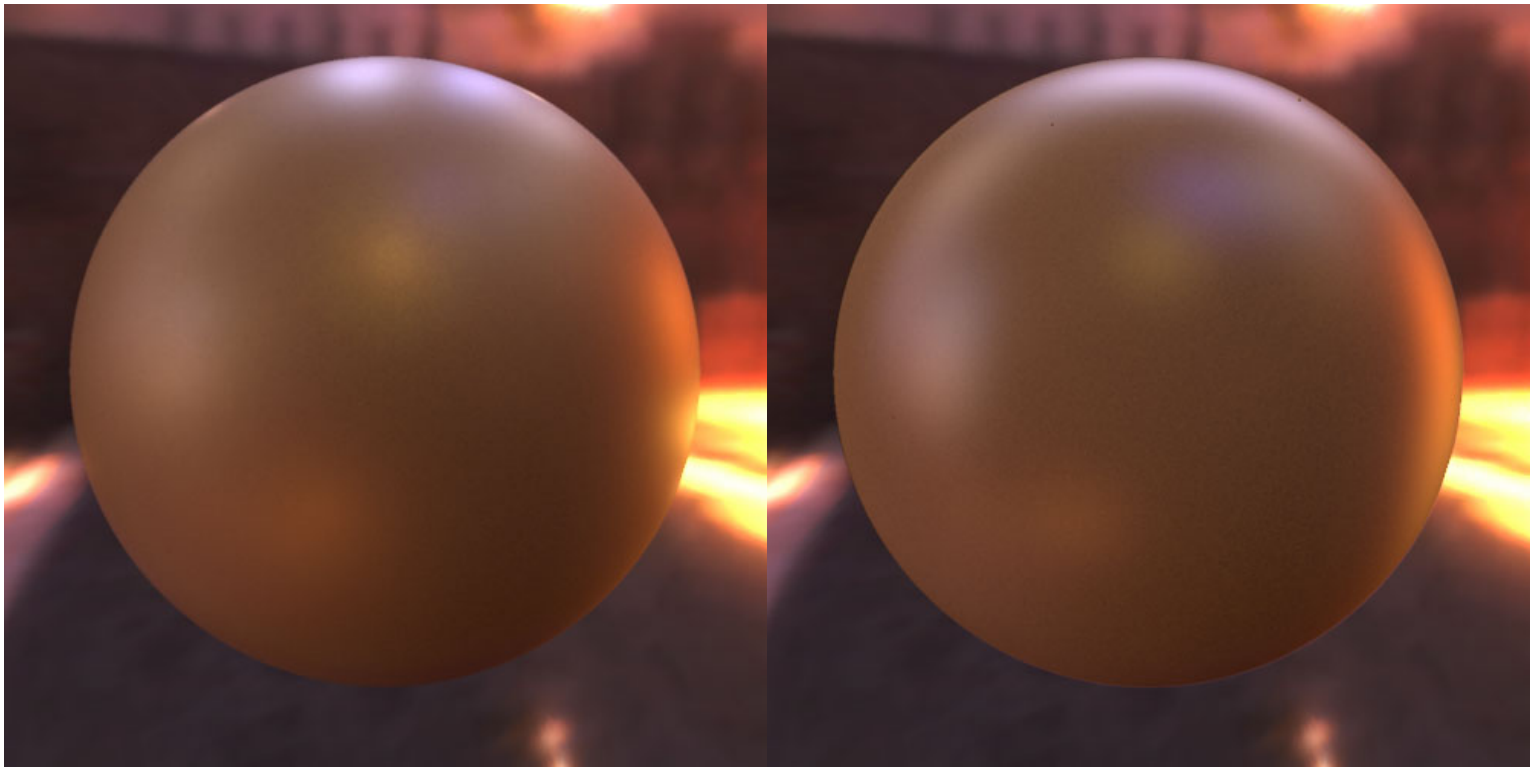
Ashikhmin



Material – Dark blue paint

Lafortune Lobe

- Distorted highlights near grazing angle

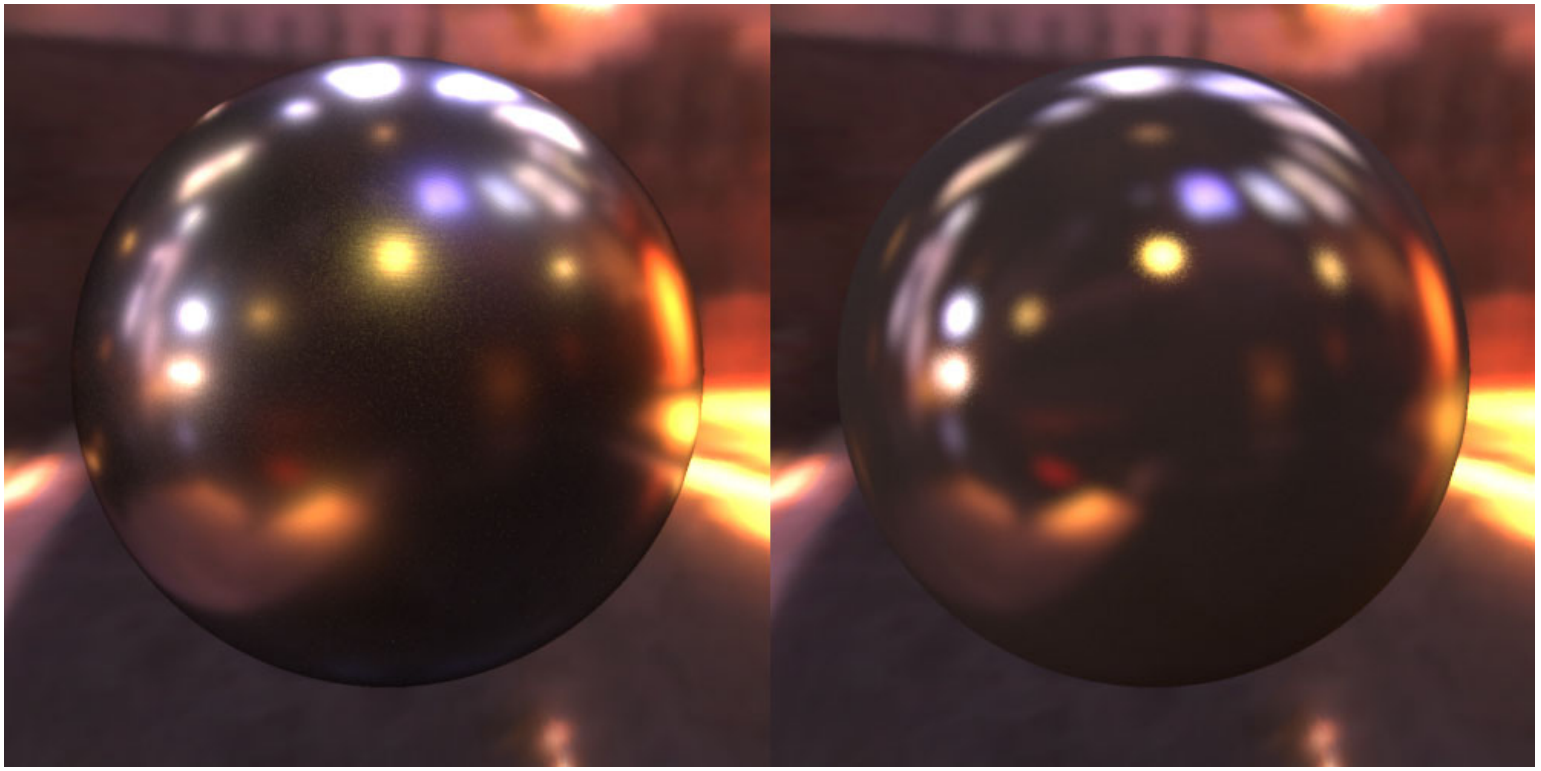


Acquired data – gold paint

Lafortune fit

Lafortune Lobe

- Distorted highlights near grazing angle

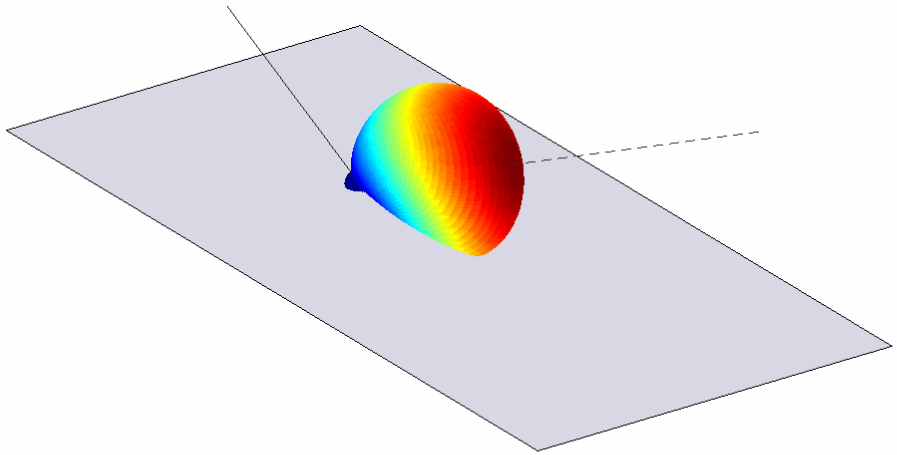


Acquired data – nickel

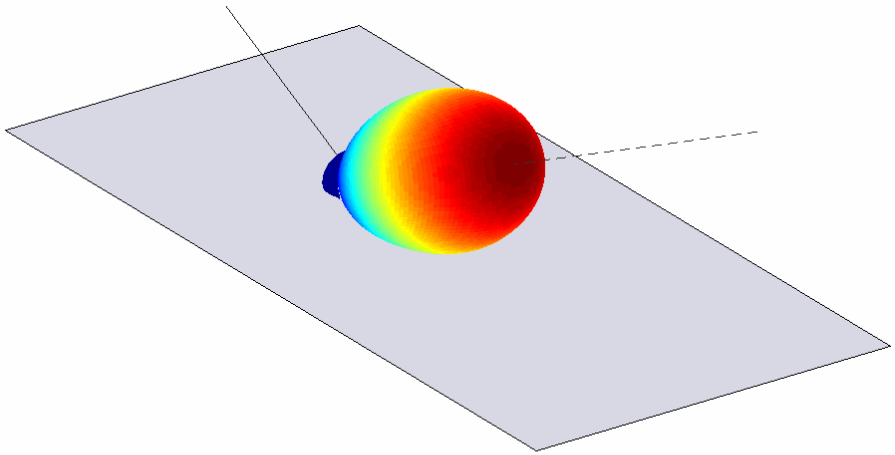
Lafortune fit

Lobe Comparison

- Half vector lobe
  - Gradually narrower when approaching grazing
- Mirror lobe
  - Always circular



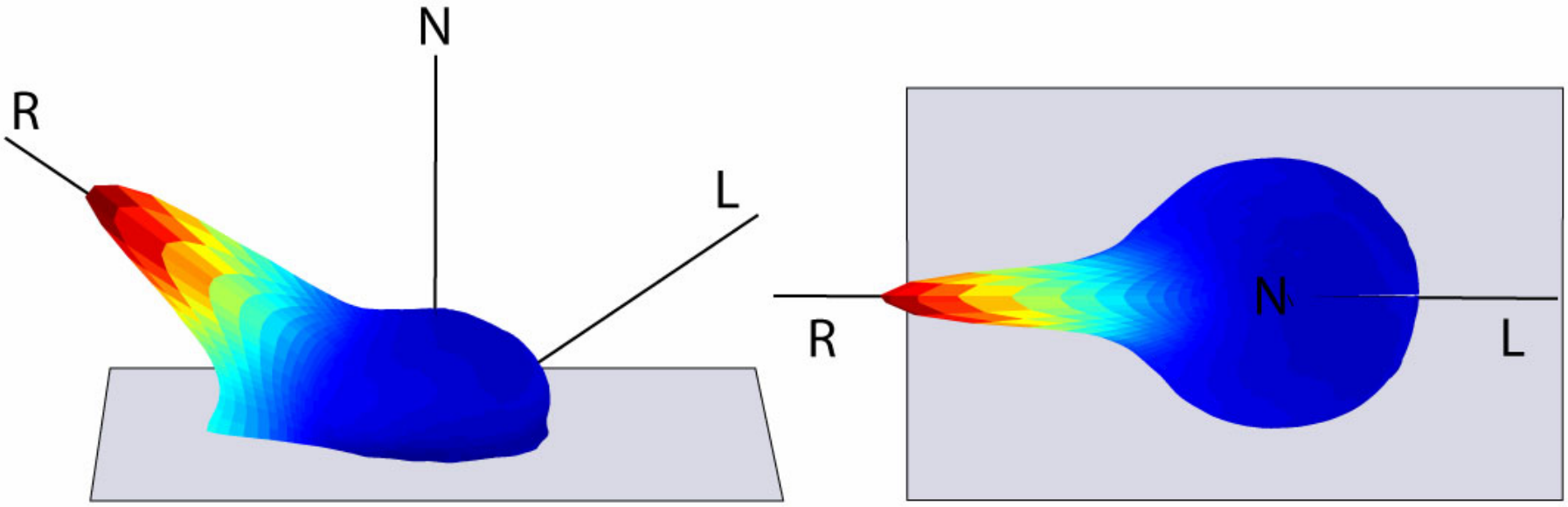
Half vector lobe



Mirror lobe

Half vector lobe

- Consistent with what we observe in the dataset.
- More details in the paper



Example: Plot of “PVC” BRDF at 55° incidence

Observations - numerical

- Rough order of quality
  - He, Cook-Torrance, Ashikhmin
  - Lafortune
  - Ward
  - Blinn-Phong

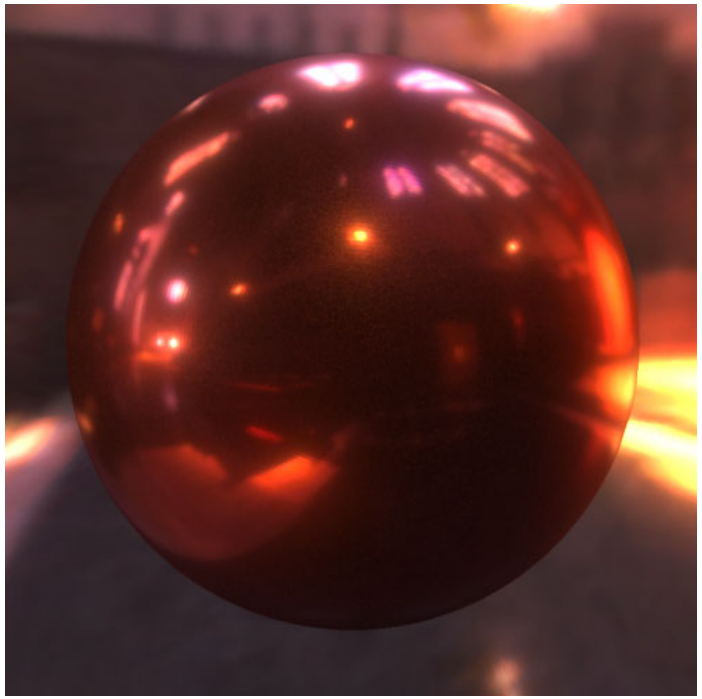
Observations - visual

- Mirror-like
  - metals, some plastics
  - All models match well visually
- Glossy
  - paints, some metals, some wood
  - Fresnel effect
  - Distorted shape for Lafortune highlight
- Near diffuse
  - fabrics, paints
  - Fresnel effect

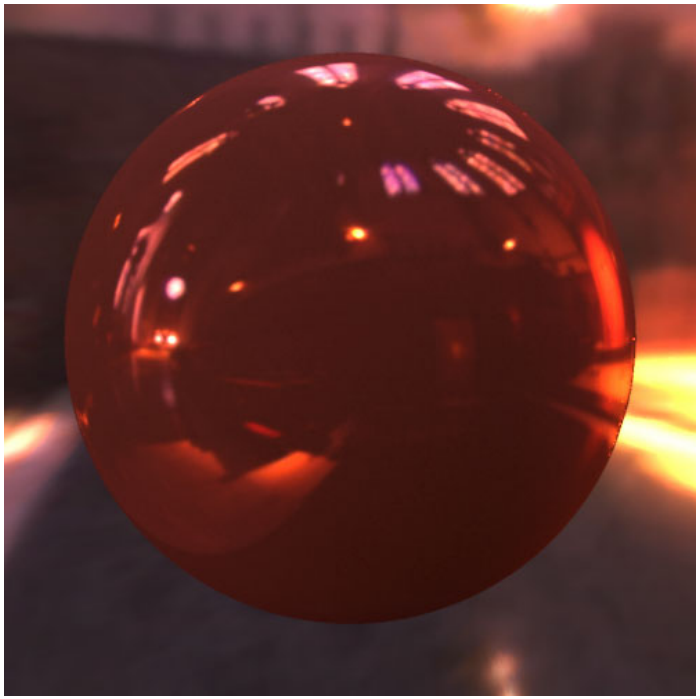
Observations

- Some materials impossible to represent with a single lobe

Acquired data



Cook-Torrance

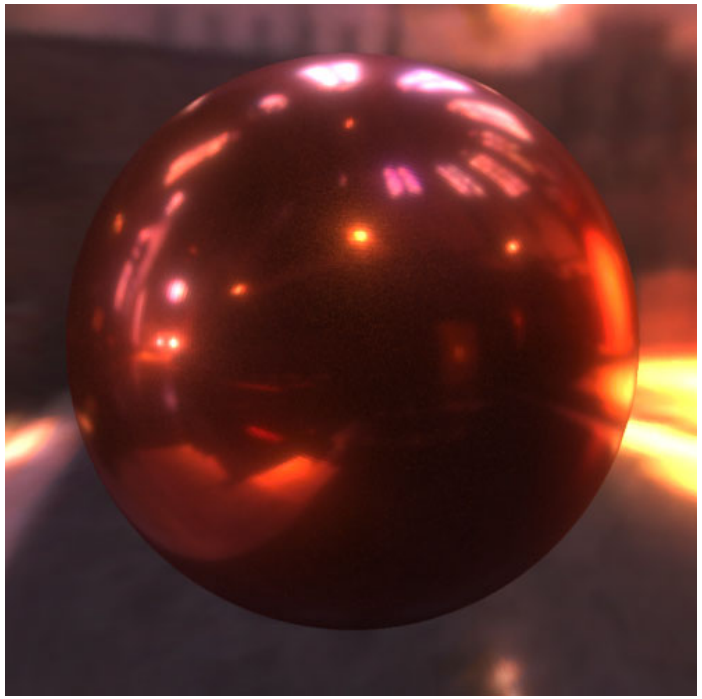


Material – Red Christmas Ball

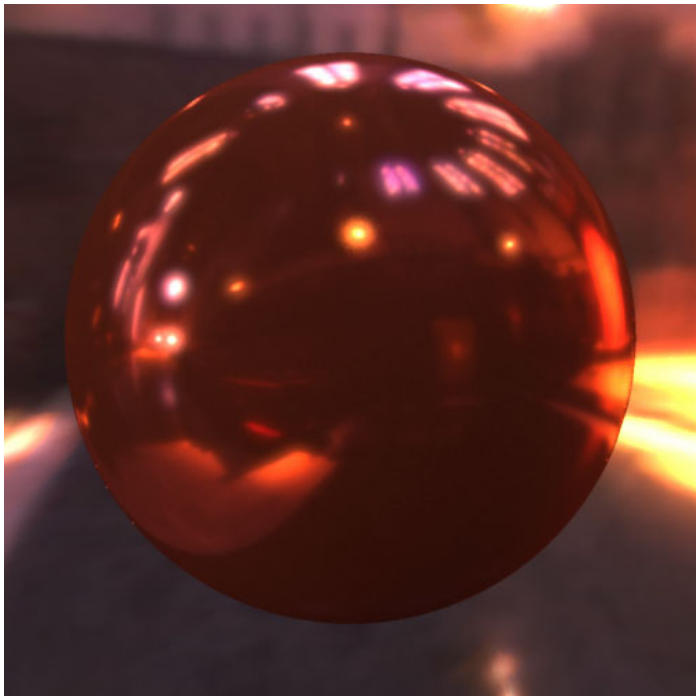
Adding a second lobe

- Some materials impossible to represent with a single lobe

Acquired data



Cook-Torrance 2 lobes



Material – Red Christmas Ball

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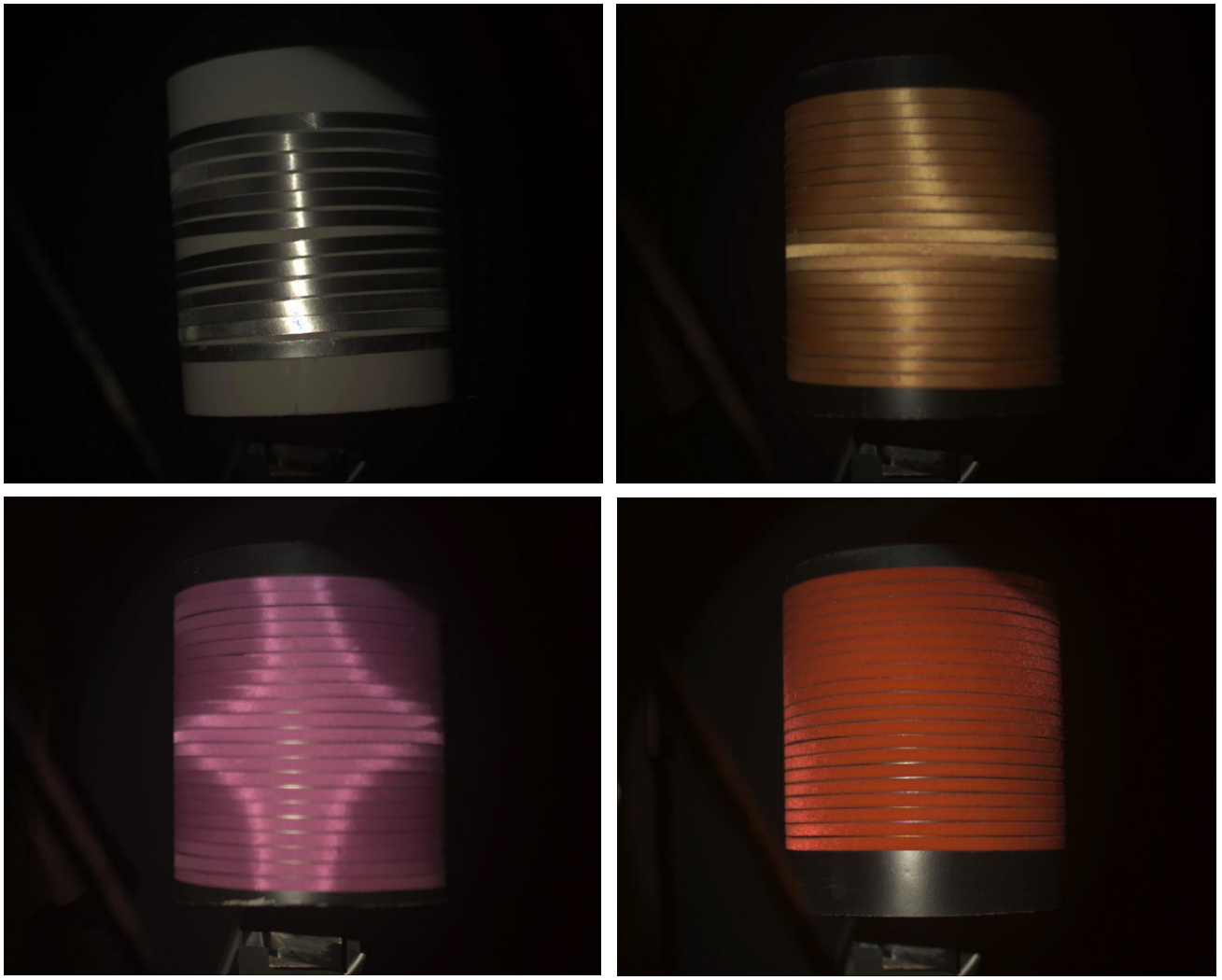
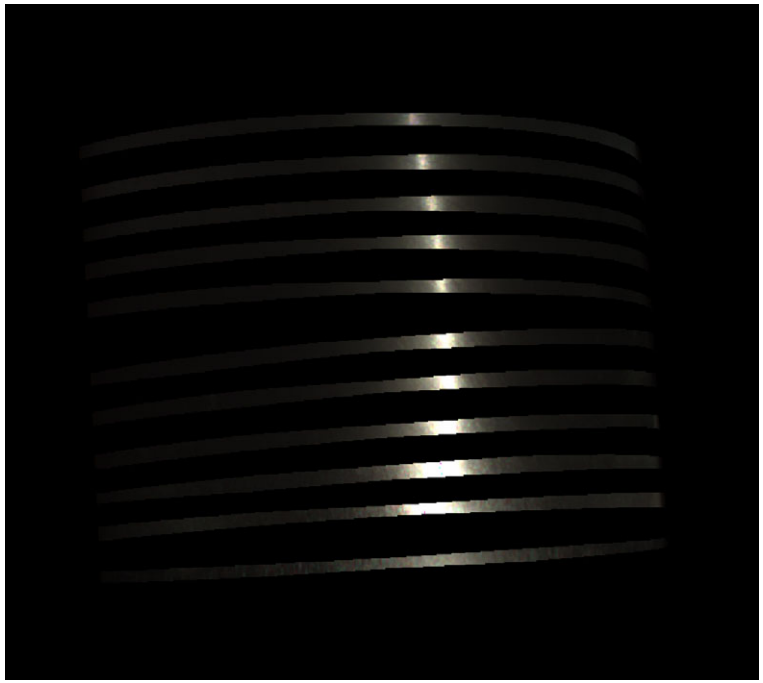
Anisotropic Materials

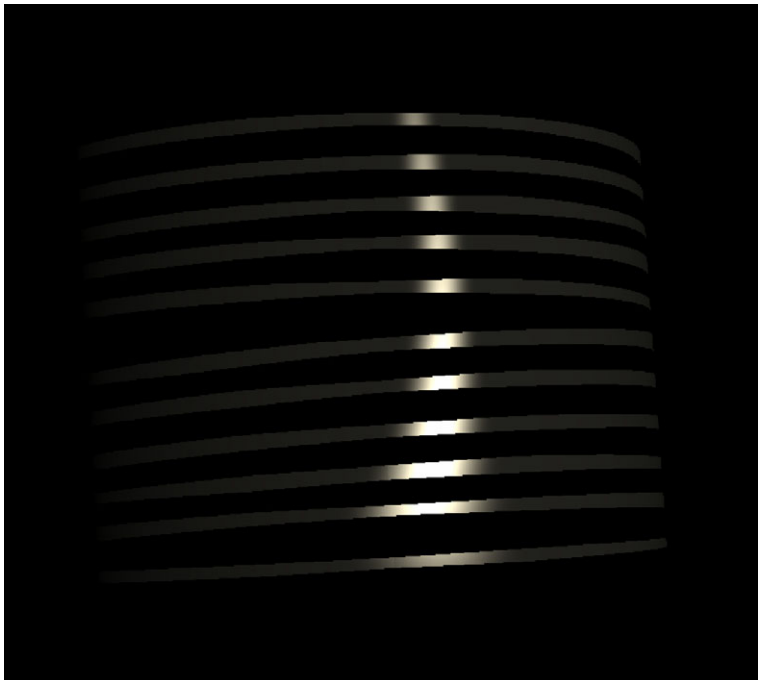


Brushed Aluminum

- Reasonable qualitative fit



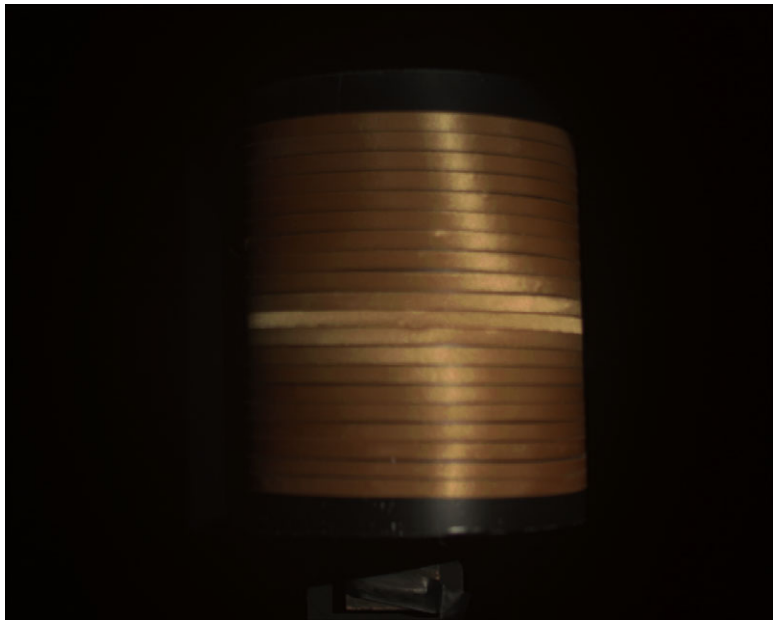
Acquired data



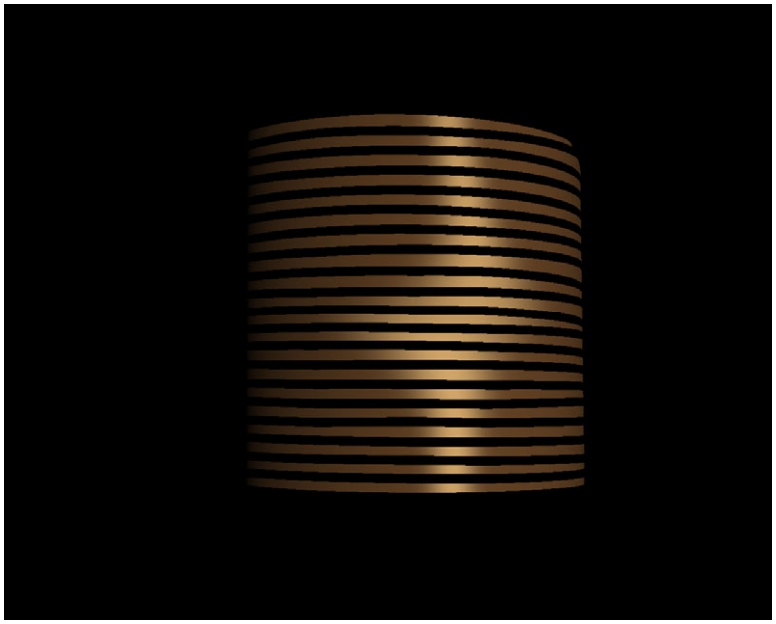
Ward

Yellow Satin

- Reasonable qualitative fit



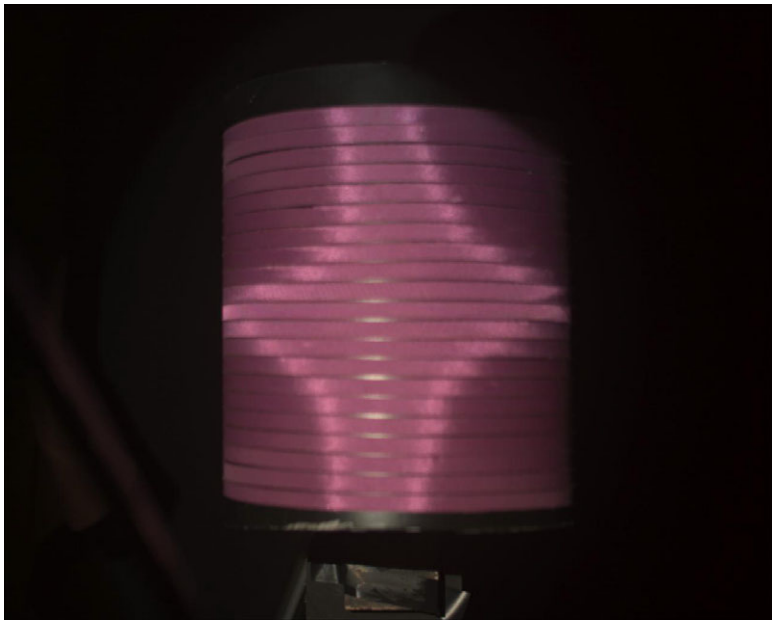
Acquired data



Ward

Purple Satin

- Split highlights



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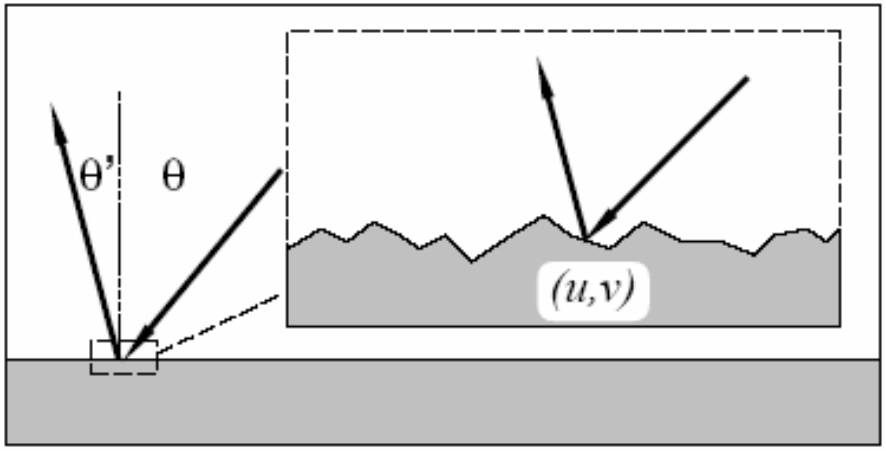
- Anisotropic materials results
  - Estimation of microfacet distribution
- Conclusion

Microfacet Theory

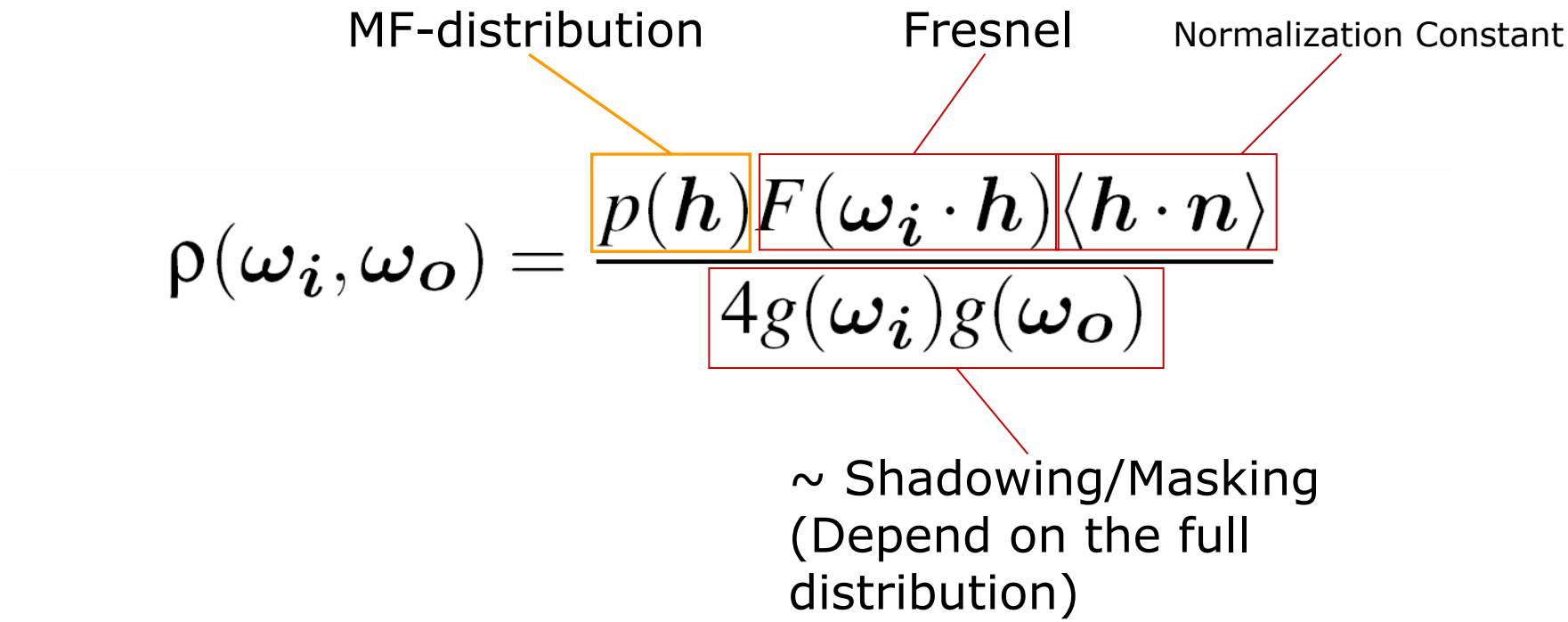
- [Torrance & Sparrow 1967]
  - Surface modeled by tiny mirrors
  - Value of BRDF at (ω_i, ω_o)
    - # of mirrors oriented halfway between ω_i and ω_o
    - Modulated by Fresnel, shadowing/masking



[Shirley 97]

Estimating the MF distribution

- Ashikhmin's microfacet-based BRDF generator [00]



Estimating the MF distribution

- Rearranging terms:

$$\rho(\omega_i, \omega_o) = \frac{p(h)F(\omega_i \cdot h)\langle h \cdot n \rangle}{4g(\omega_i)g(\omega_o)}$$

Measurements

$$p(h) \propto \frac{\rho(\omega_i, \omega_o)F(\omega_i \cdot h)}{g(\omega_i)g(\omega_o)}$$

Estimating the MF distribution

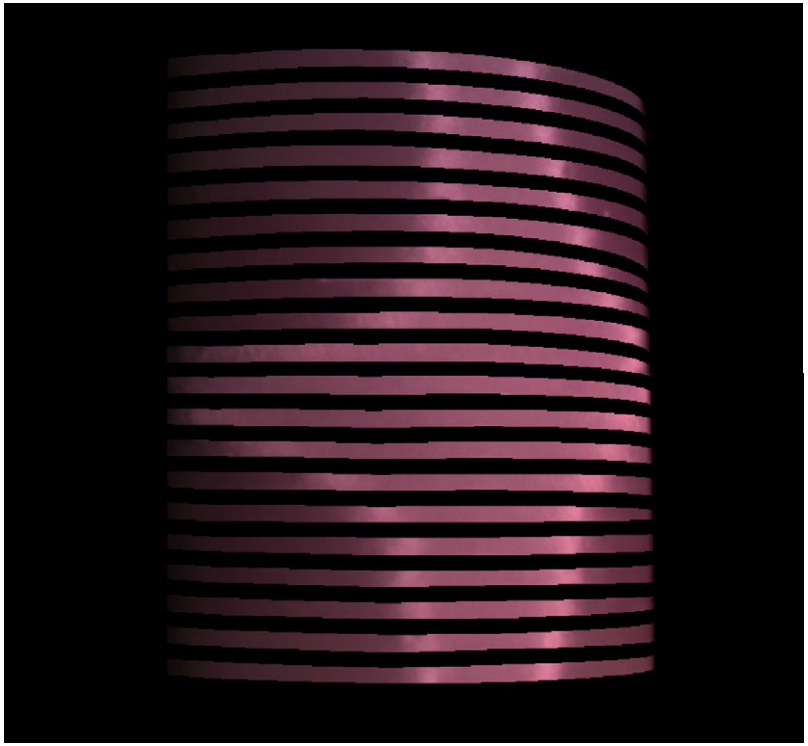
Measurements

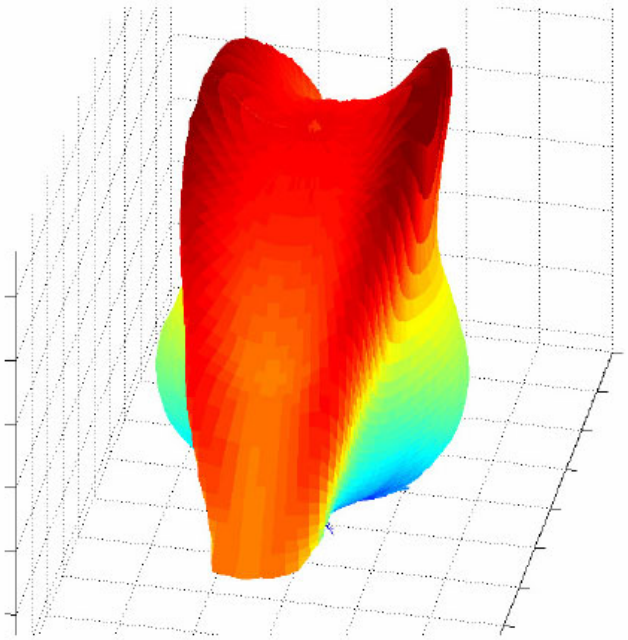
$$p(\boldsymbol{h}) \propto \frac{\rho(\omega_i, \omega_o) F(\omega_i \cdot \boldsymbol{h})}{g(\omega_i) g(\omega_o)}$$

- $g(\,)$ depends on the distribution
- Iterate to solve for $p(\boldsymbol{h})$
  - Compute $g(\,)$ using current estimate $p(\boldsymbol{h})$
  - Estimate $p(\boldsymbol{h})$ given $g(\,)$
- Converges quickly in practice

Purple Satin

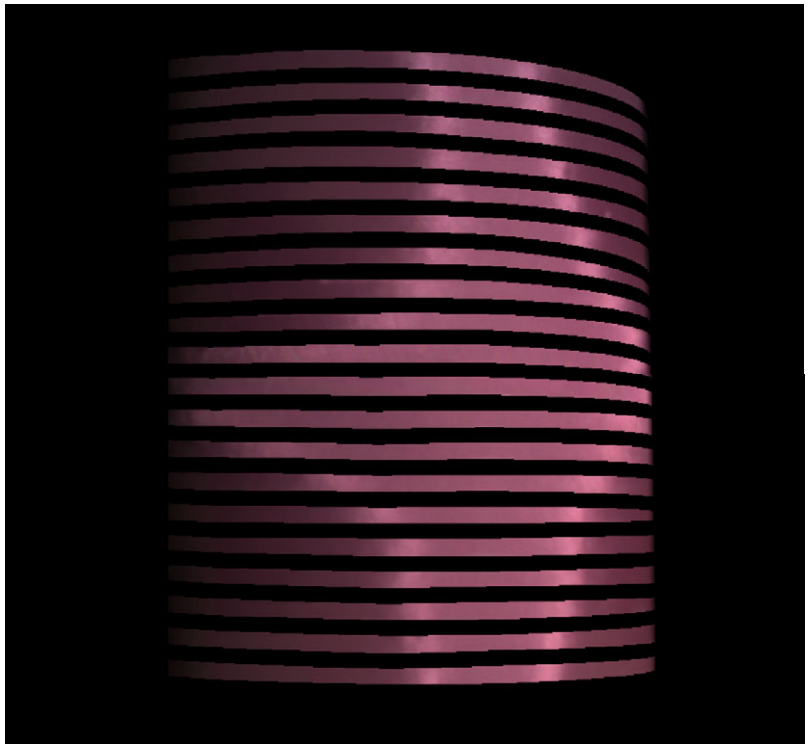
- Split specular reflection



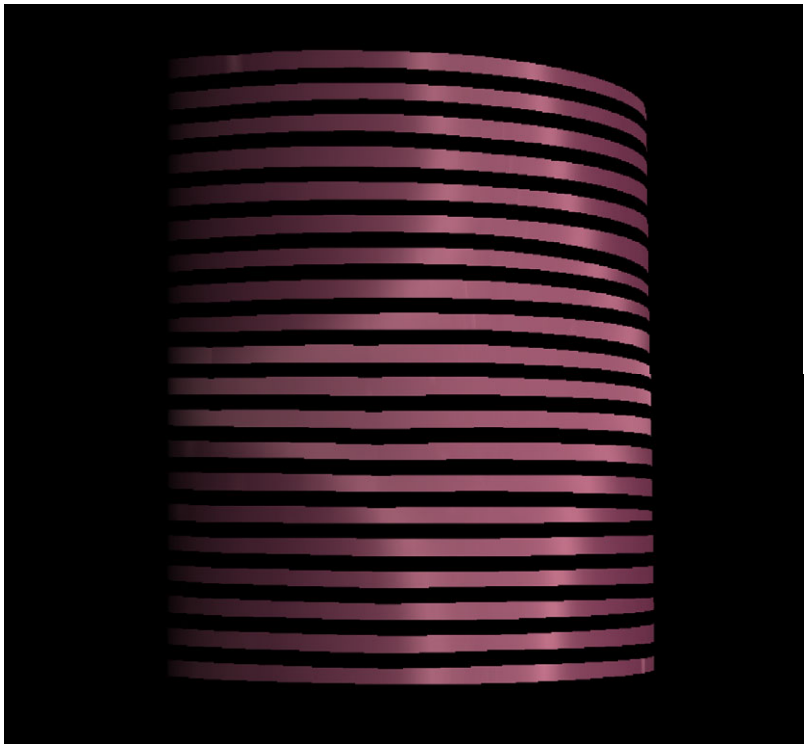


microfacet distribution

Purple Satin

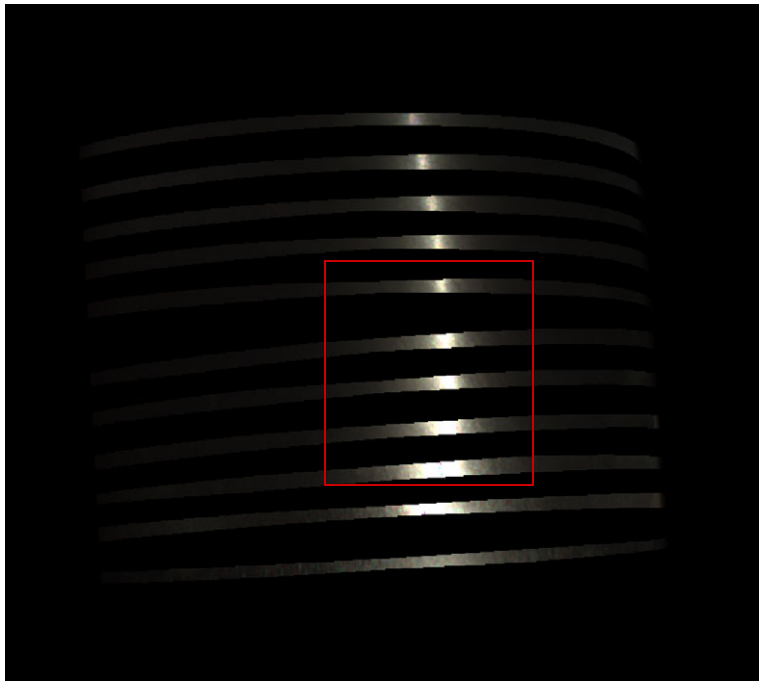


Acquired data

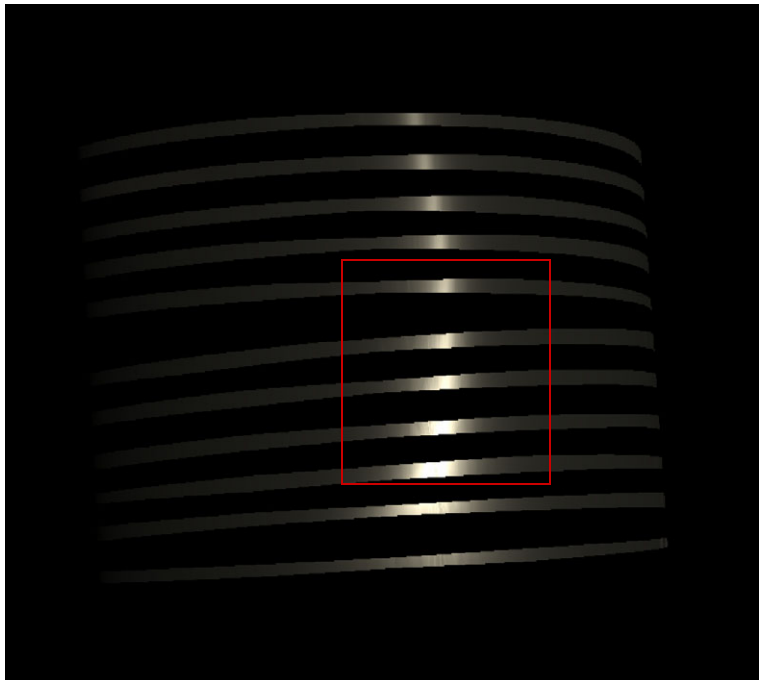


microfacet distribution fit

Brushed Aluminum



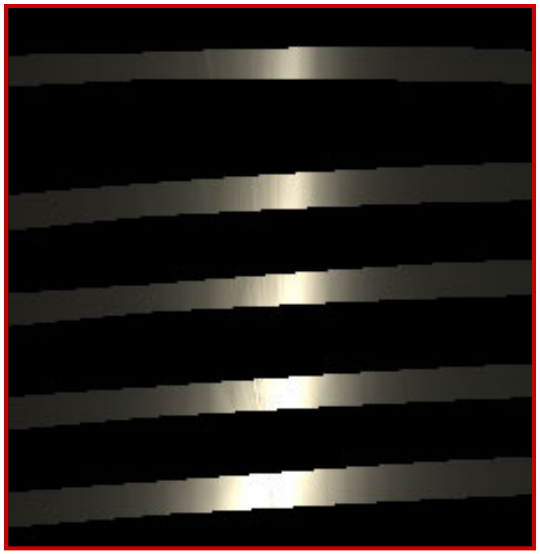
Acquired data



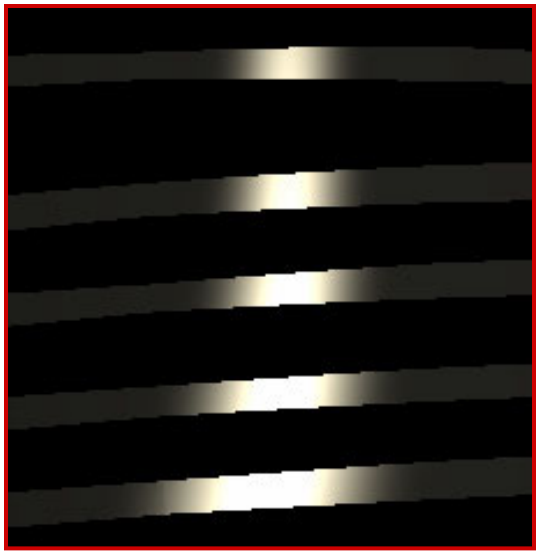
microfacet distribution fit

Brushed Aluminum

measured data



microfacet distribution fit



Ward fit

MF-based BRDF generator

- Expressive
- Easy to estimate
  - No optimization necessary
- Inexpensive to compute

Outline

- Background
- BRDF Measurements
- BRDF Fitting
- Isotropic materials results
- Anisotropic materials results
- Conclusion

Conclusion

- Isotropic materials
  - He, Cook-Torrance, Ashikhmin perform well
    - Explicit Fresnel
    - *multiple lobes help
  - Half-vector based lobe performs better
  - Most materials can be well-represented

- Anisotropic materials
  - Cases where analytical models cannot match qualitatively
  - Estimation of the microfacet distribution is straightforward
  - Ashikhmin’s MF-based BRDF generator does well

Future Work

- Metric
- Generalized lobe based on half vector
- Efficient acquisition based on the microfacet distribution

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Questions?