SIGGRAPH2004

Experimental Validation of Analytical BRDF Models

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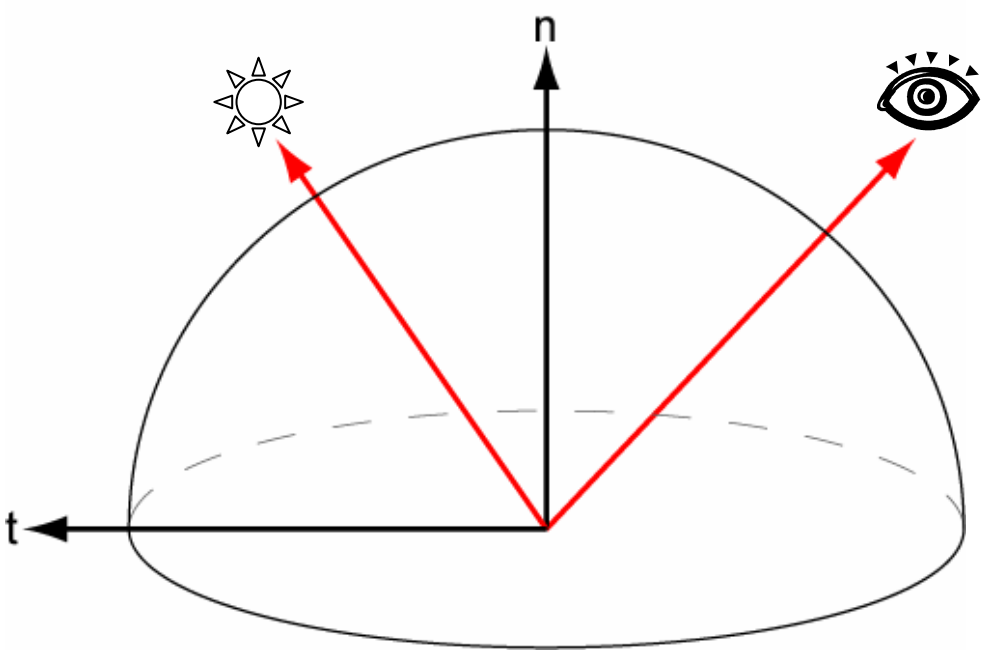
CSAIL

Goal

- Evaluate and analyze the performance of analytical reflectance models

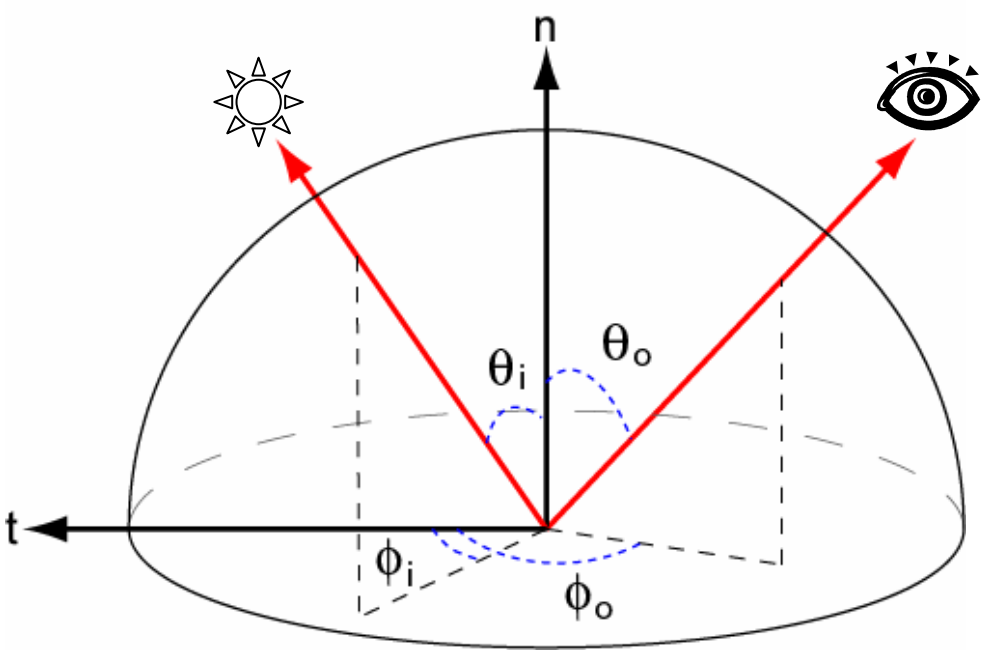
BRDF

- Bidirectional Reflectance Distribution Function



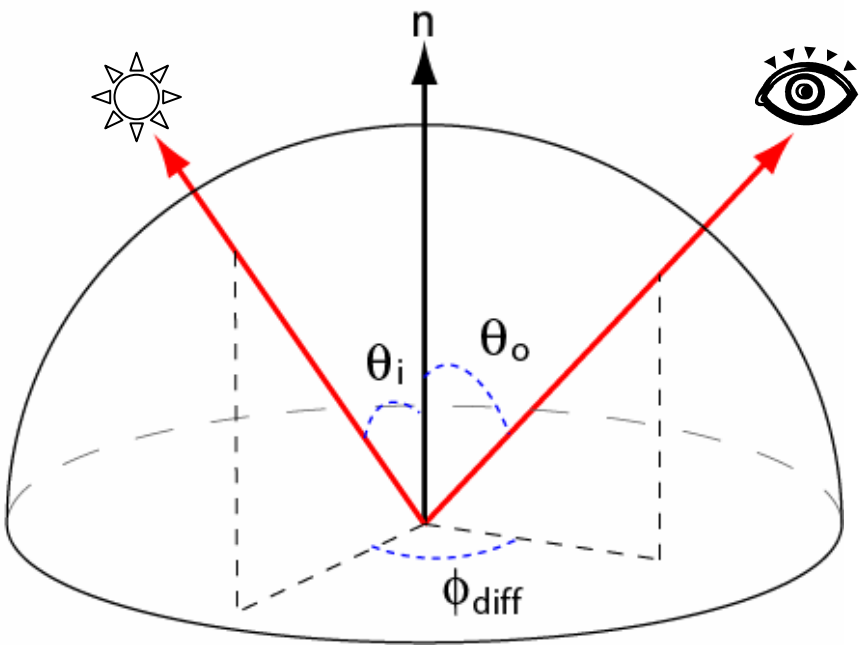
BRDF

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



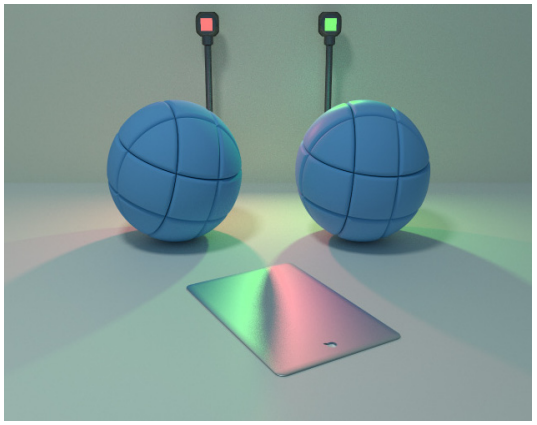
BRDF

- Bidirectional Reflectance Distribution Function
  - $R(\theta_i, \phi_i; \theta_o, \phi_o)$
- Our study: isotropic material
  - Invariant when material is rotated
  - BRDF is 3D



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]



BRDF Models

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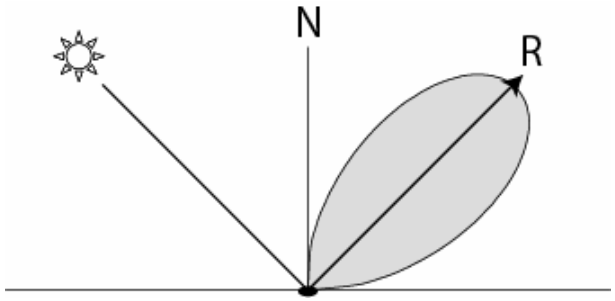
Roughly increasing computation time

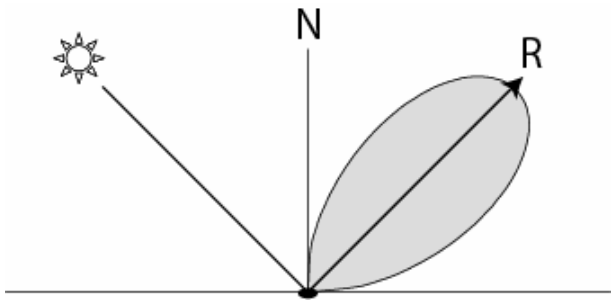
Differences in BRDF Models

- Specular lobe definition
  - Mirror direction
  - Half vector
- Specular lobe falloff
  - $\cos^n$ (cosine lobe)
  - Gaussian



Differences in BRDF Models

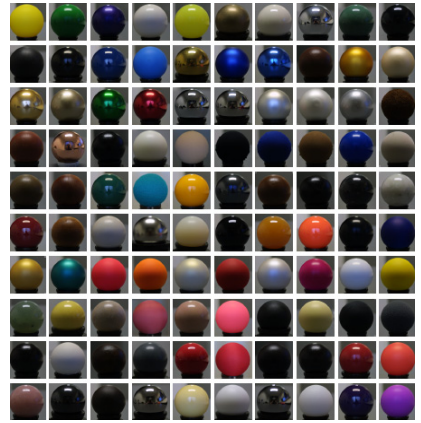
- Specular lobe definition
  - Mirror direction
  - Half vector
- Specular lobe falloff
  - $\cos^n$ (cosine lobe)
  - Gaussian
- Fresnel effect
  - surface becomes more reflective near grazing angle



[Lafortune 97]

Available Measurements

- Columbia-Utrecht Reflectance and Texture Database –
  - ~60 materials, 205 measurements per BRDF
- Cornell's measurements
  - ~10 materials, 1439 measurements per BRDF
- Matusik's image-based measurements
  - ~100 materials, ~4 million measurements per BRDF
  - Include metals, plastic, paints, fabric, etc.



Matusik's measurements

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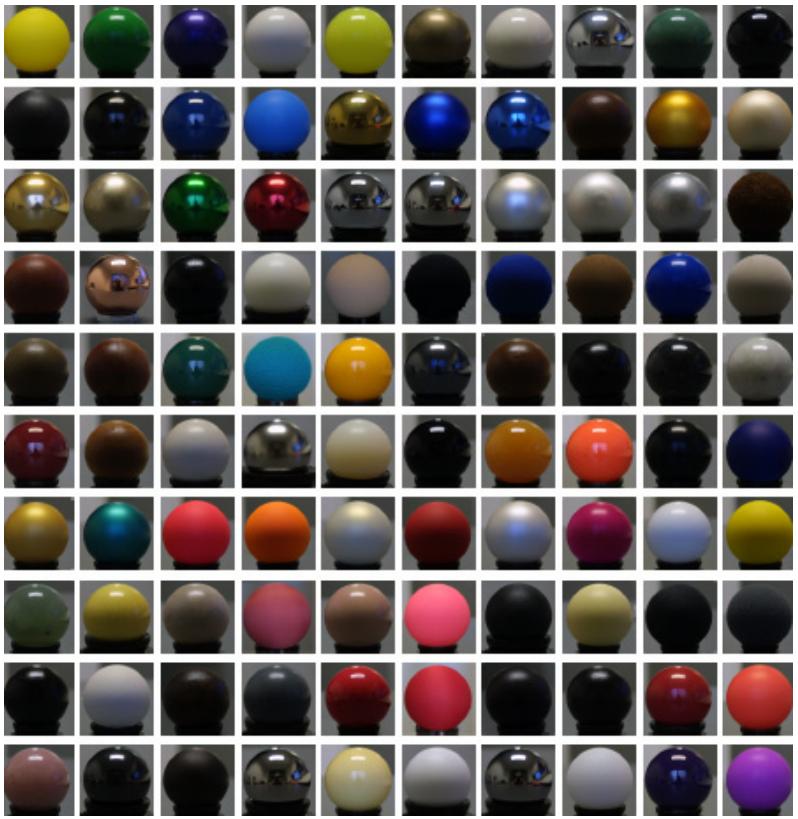
- Basis of our validation and analysis
- Part of the dataset is available on the web !

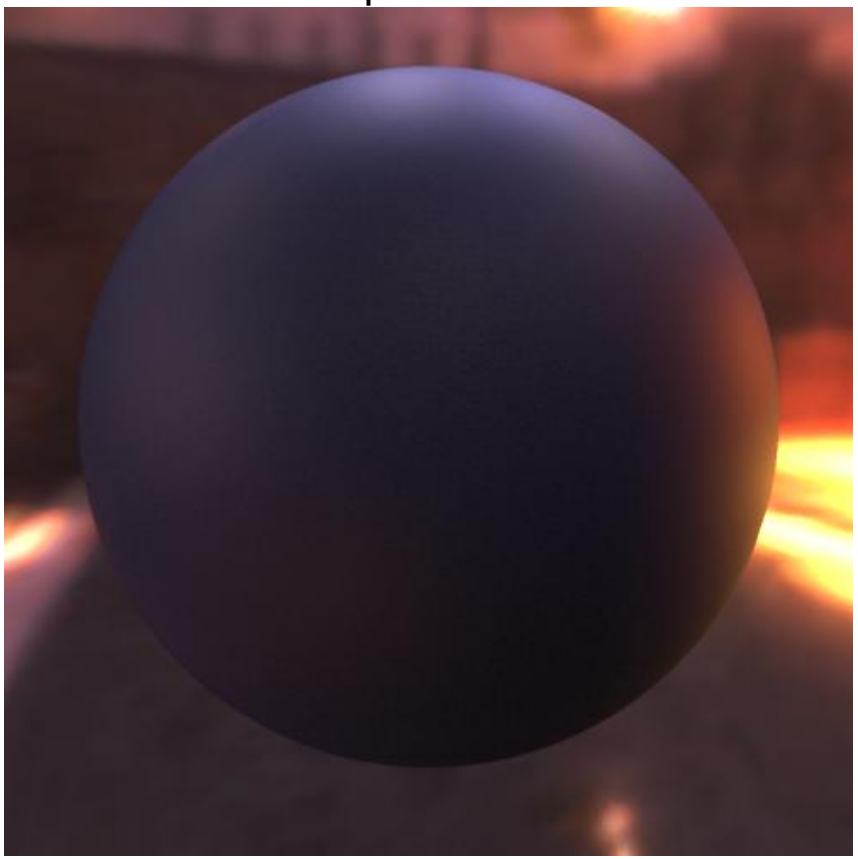


Validation Method

- BRDF Models
  - Phong, Blinn-Phong, Ward, Lafortune, Ashikhmin, Cook-Torrance
- Data fitting
  - Each material is fitted to each of the models
  - Minimize
    - L^2 error of the BRDF multiplied by the cosine of incident angle

Dark blue paint

Acquired data



Environment map

Material – Dark blue paint

Dark blue paint

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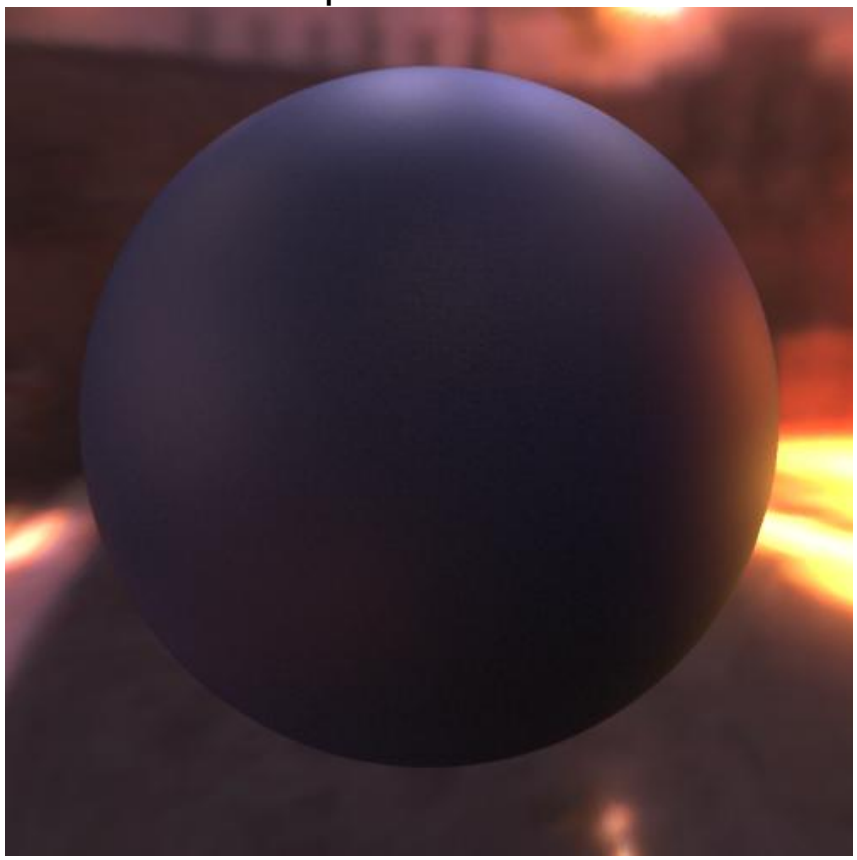
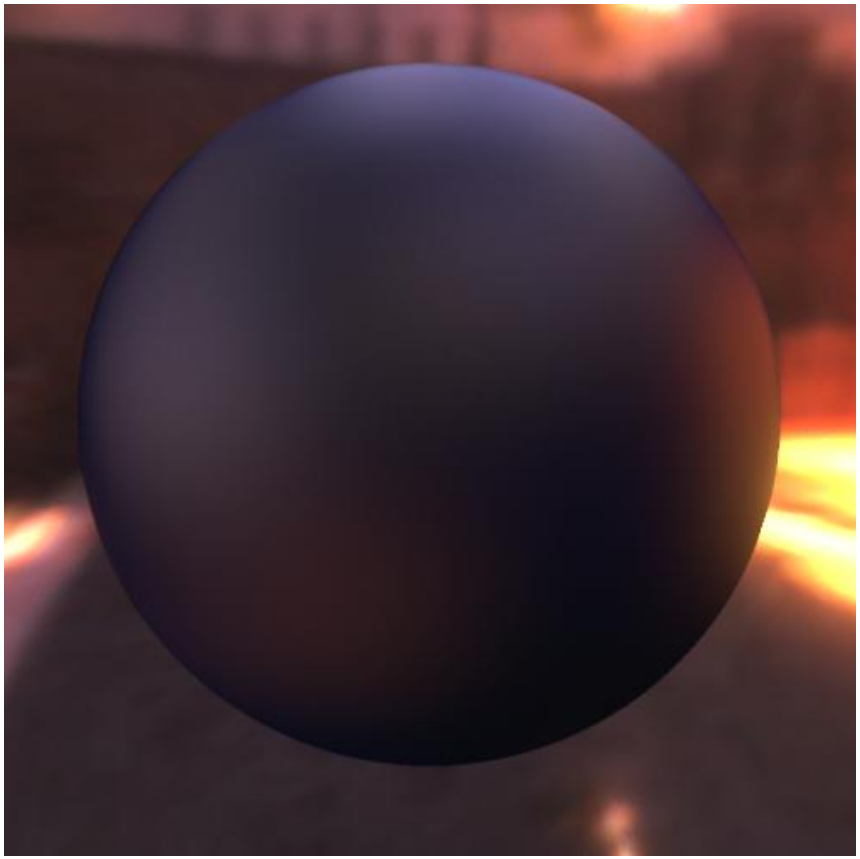
Acquired data



Cook-Torrance



Material – Dark blue paint

Dark blue paint

SIGGRAPH2004

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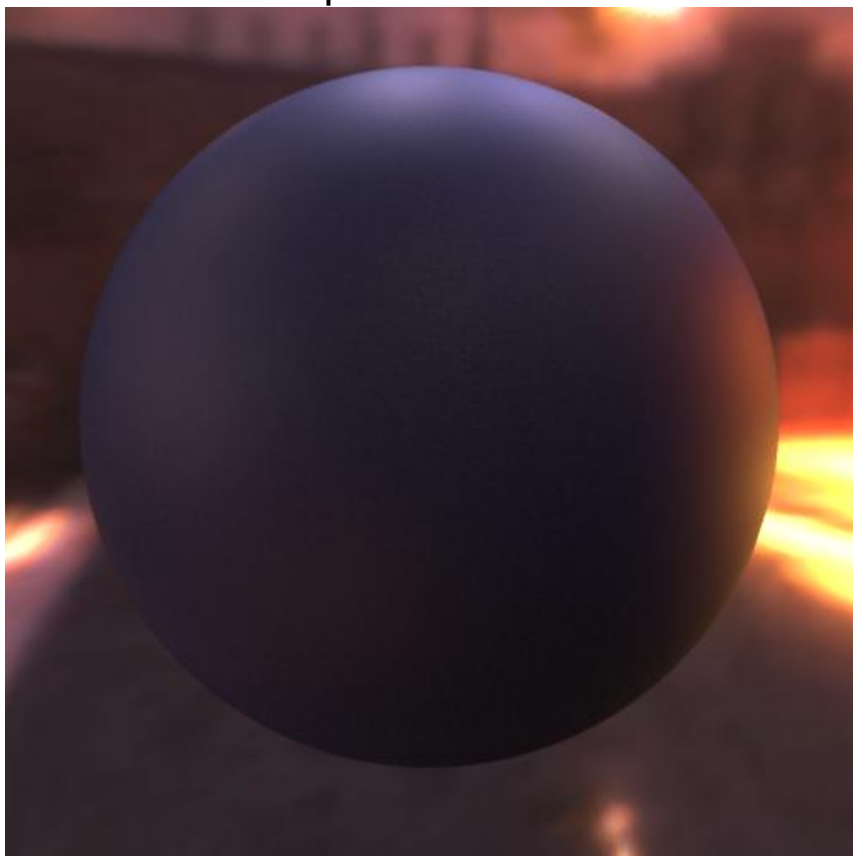
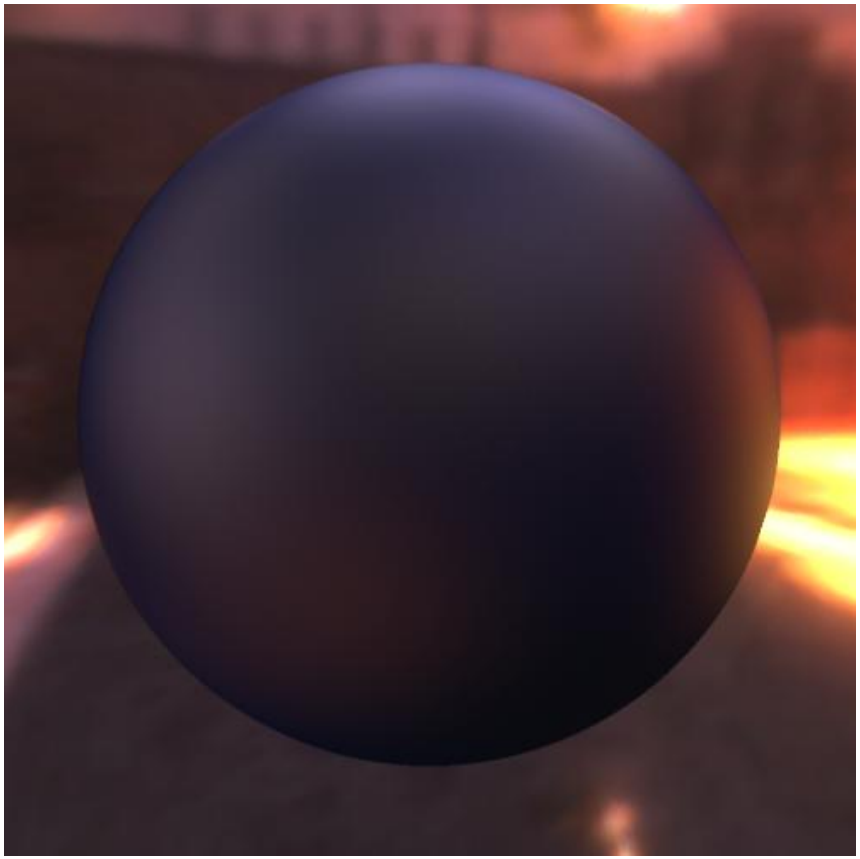


Ashikhmin

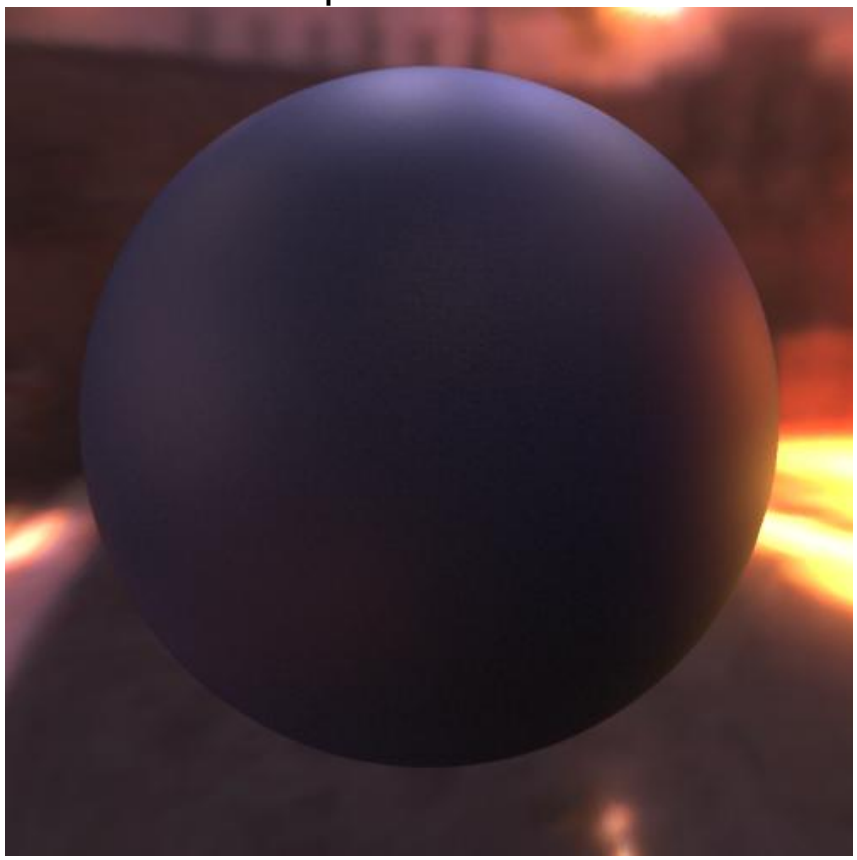


Material – Dark blue paint

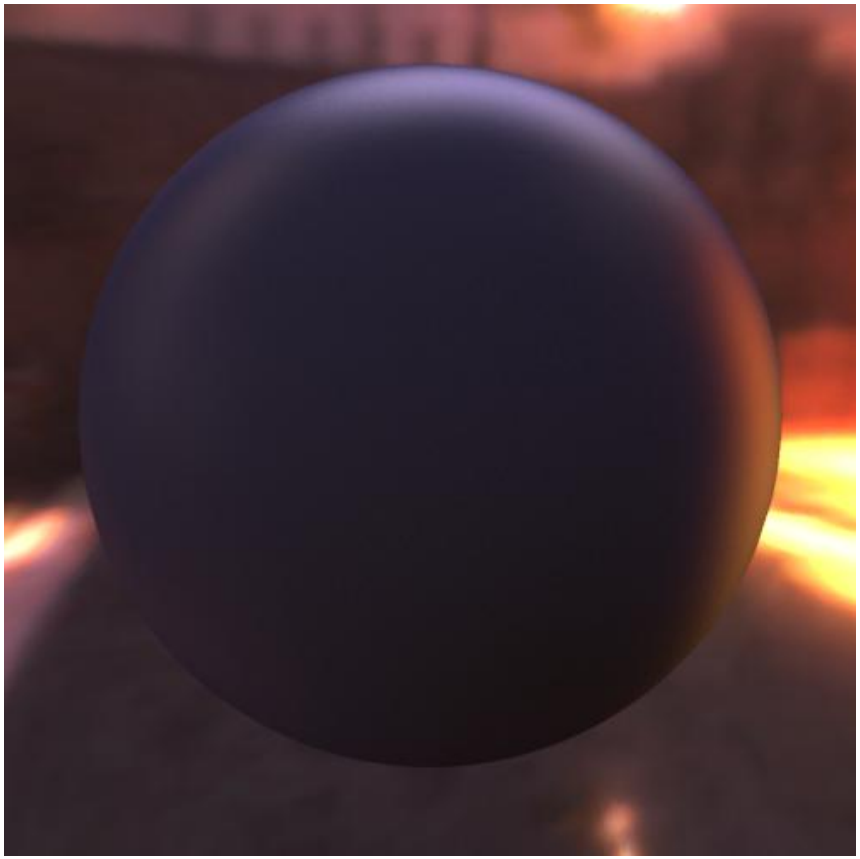
Dark blue paint

SIGGRAPH2004

Acquired data



Lafortune



Material – Dark blue paint

Dark blue paint

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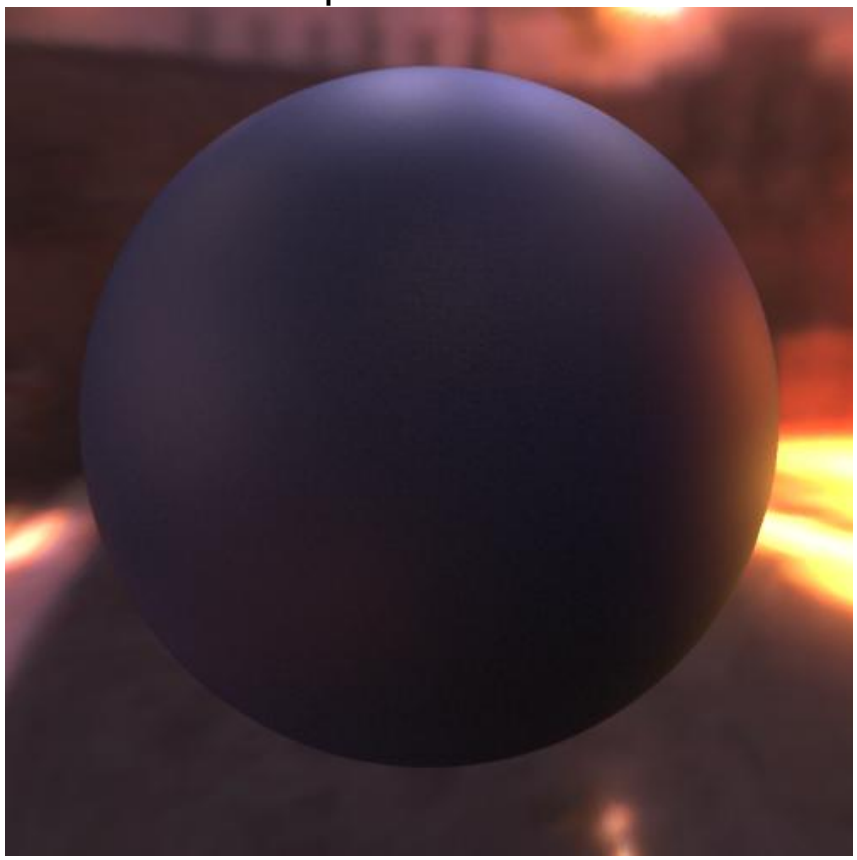
Acquired data



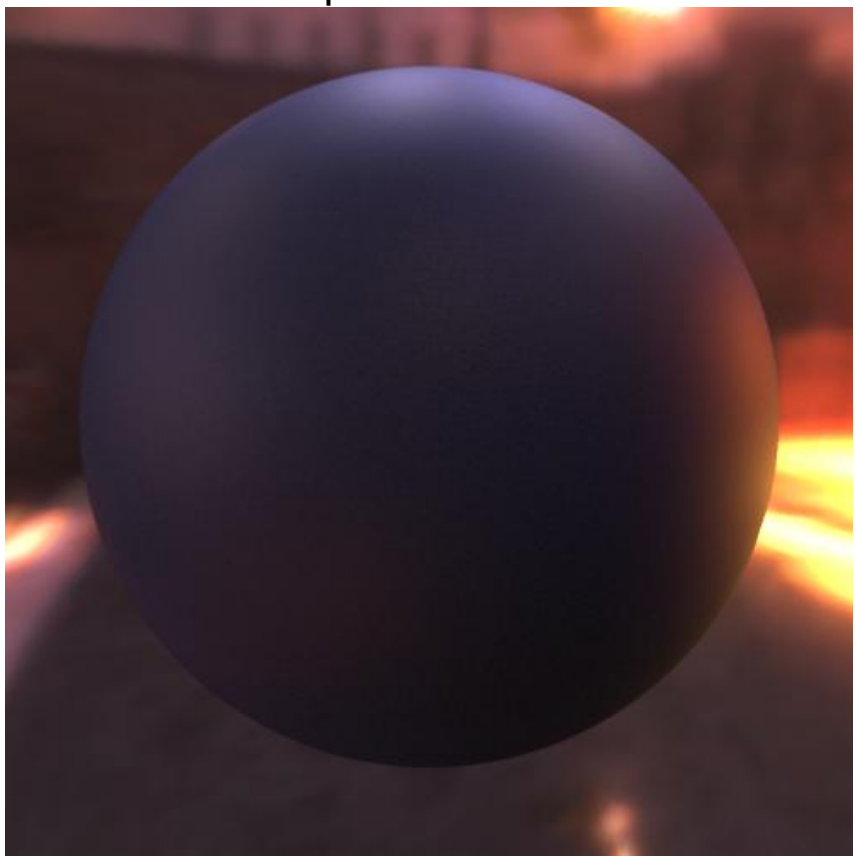
Blinn-Phong

Material – Dark blue paint

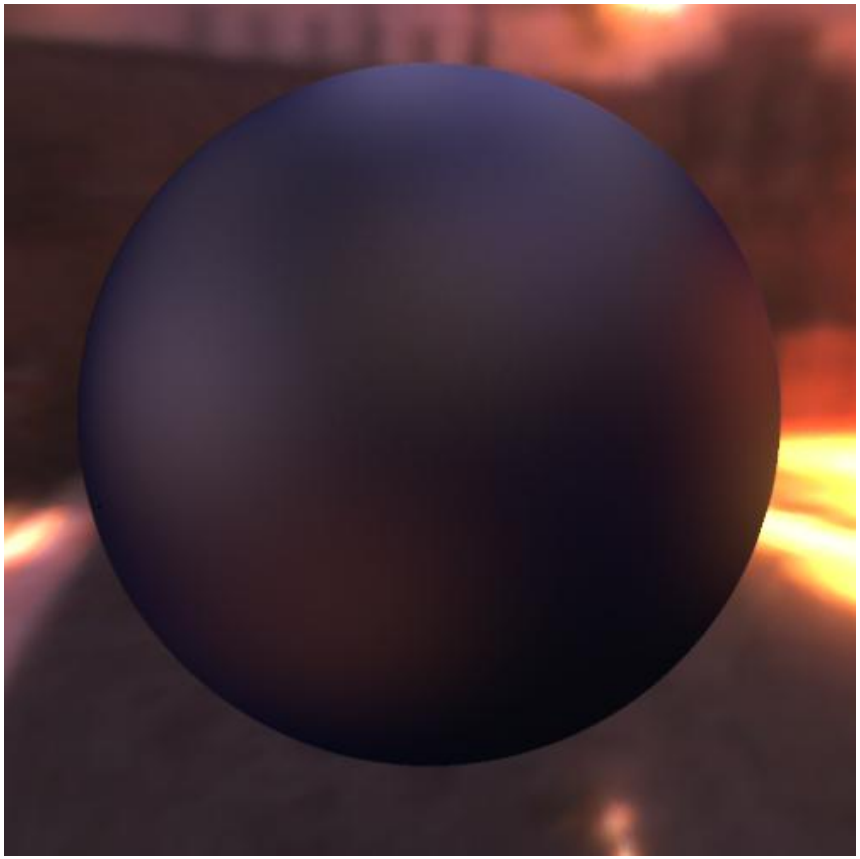
Dark blue paint

SIGGRAPH2004

Acquired data

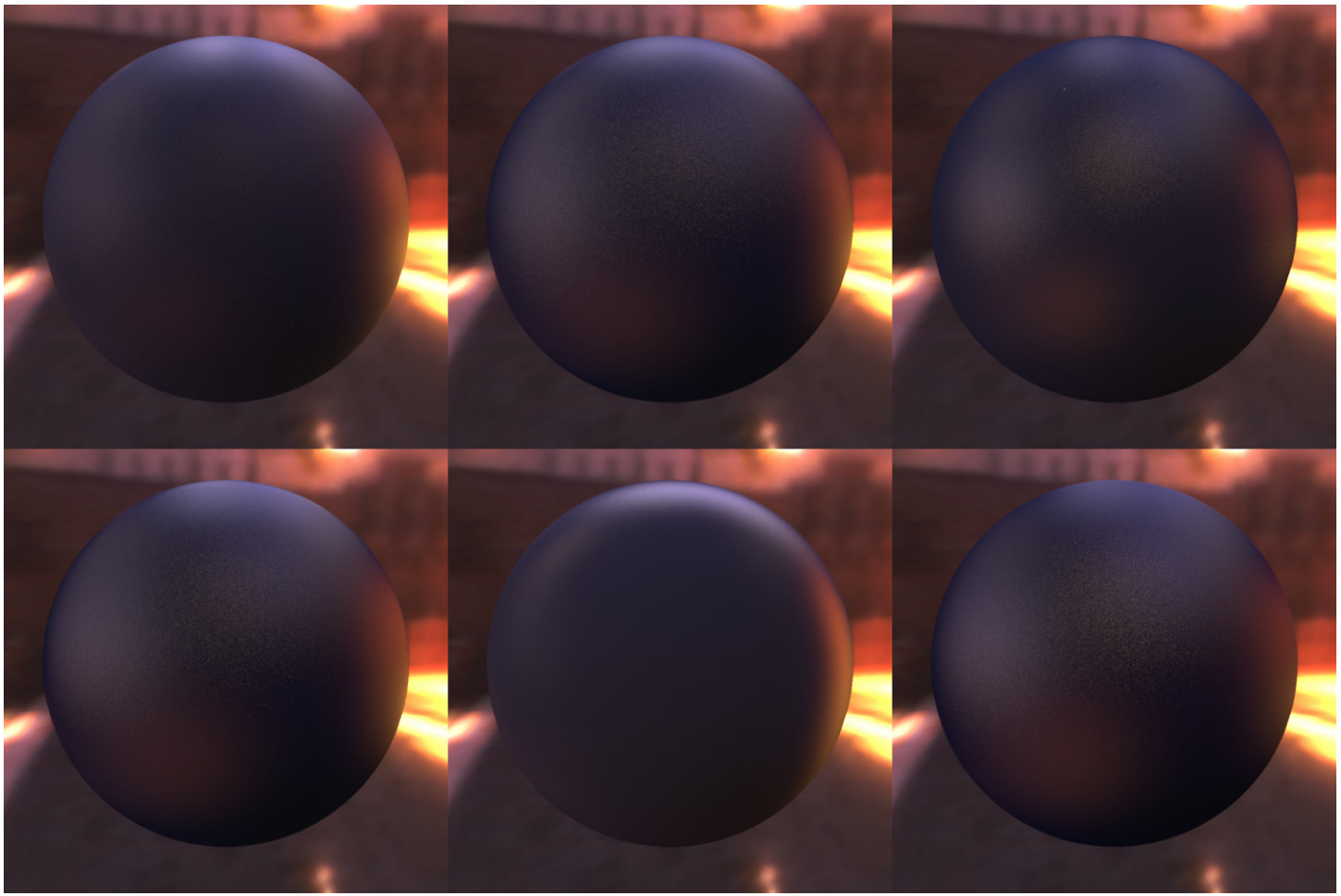


Ward



Material – Dark blue paint

Dark blue paint



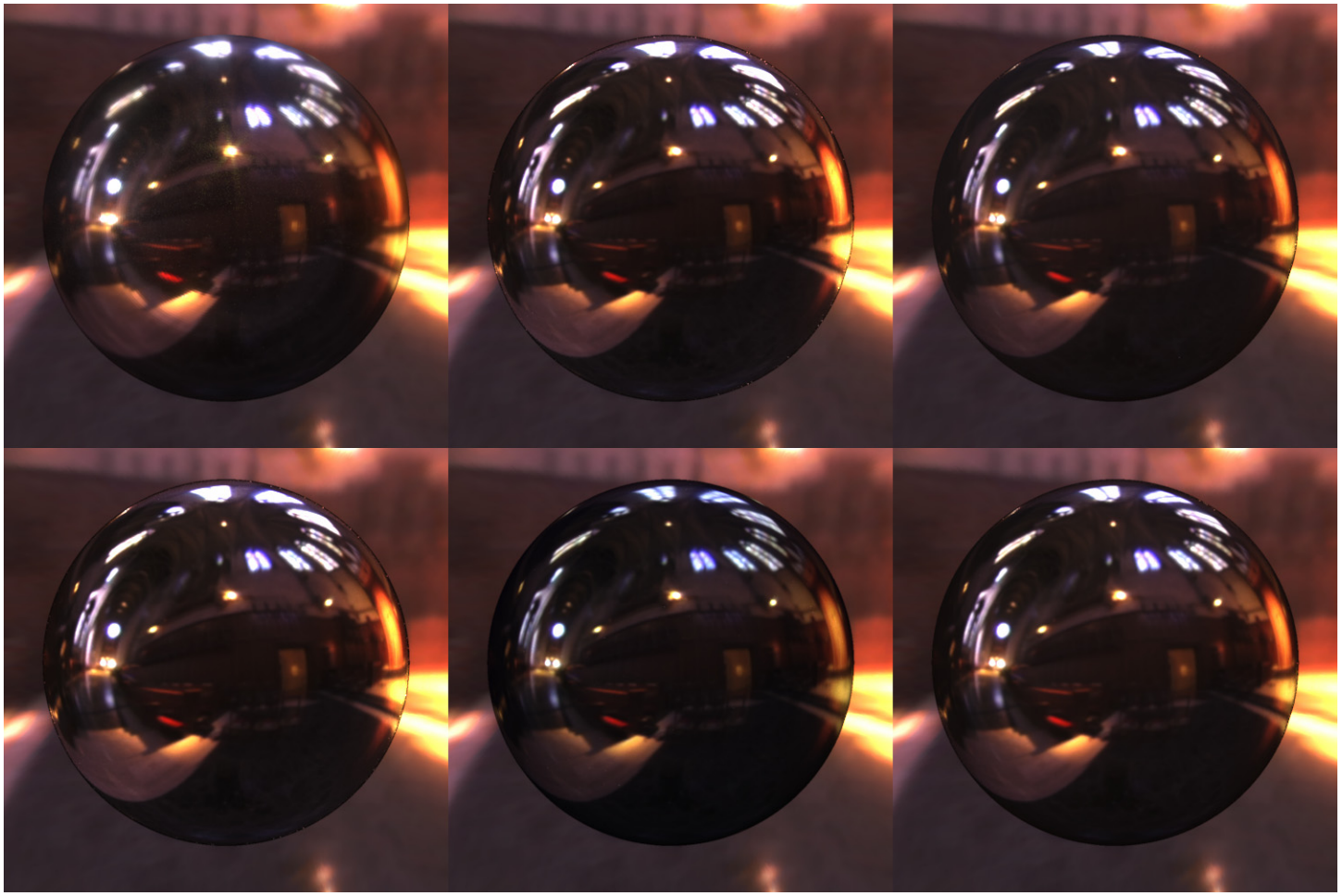
Material – Dark blue paint

Chrome

Acquired data

Chrome

Original | Ashikhmin | Blinn-Phong



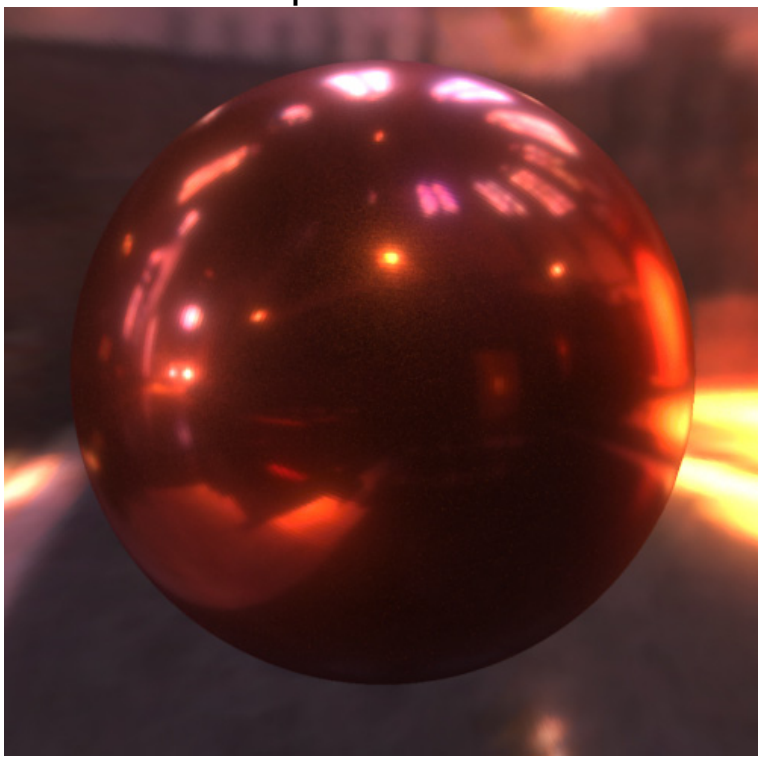
Cook-Torrance | Lafortune | Ward

Material – Chrome

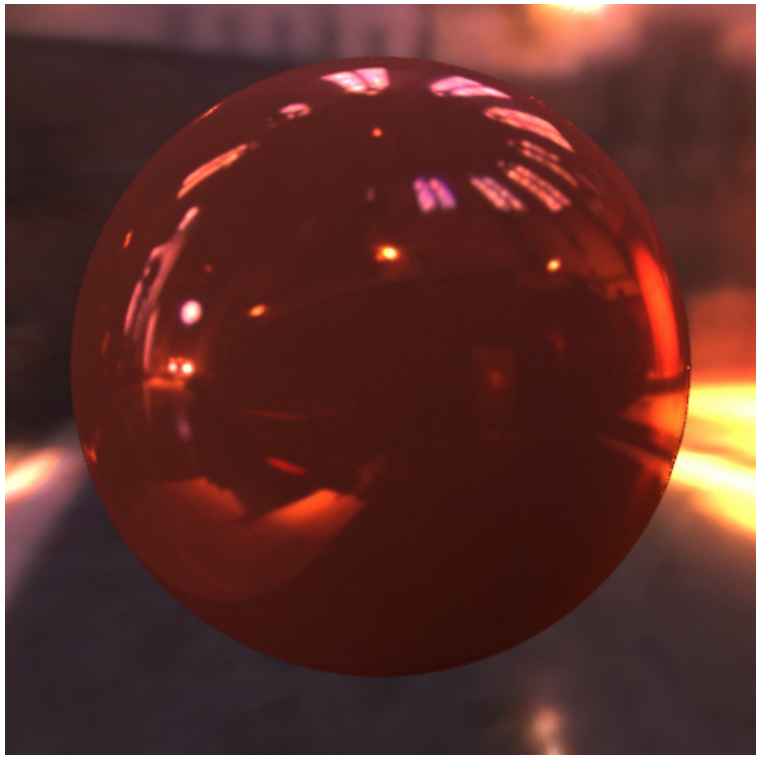
Observations

- Some materials impossible to represent with a single lobe

Acquired data



Cook-Torrance

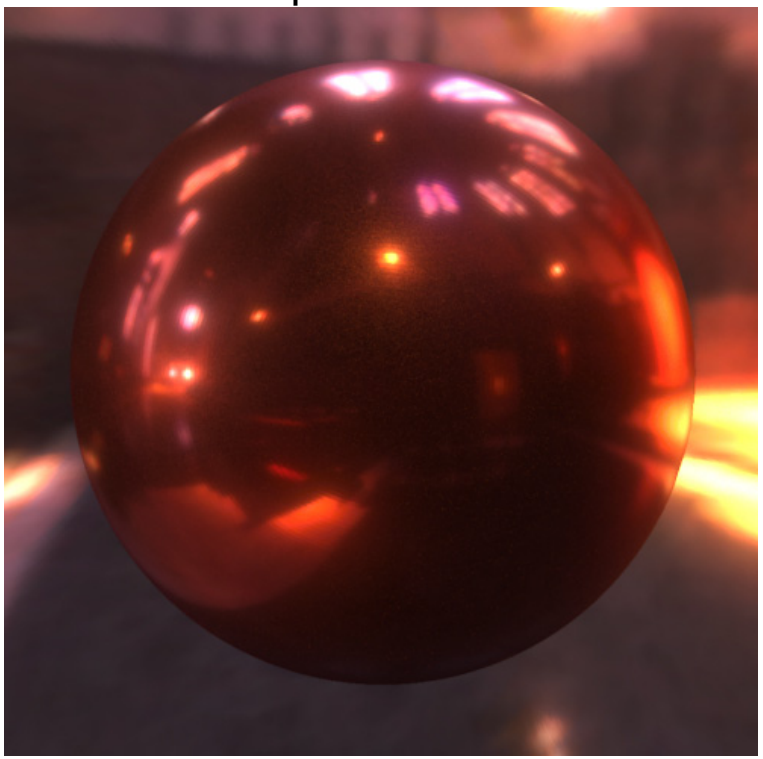


Material – Red Christmas Ball

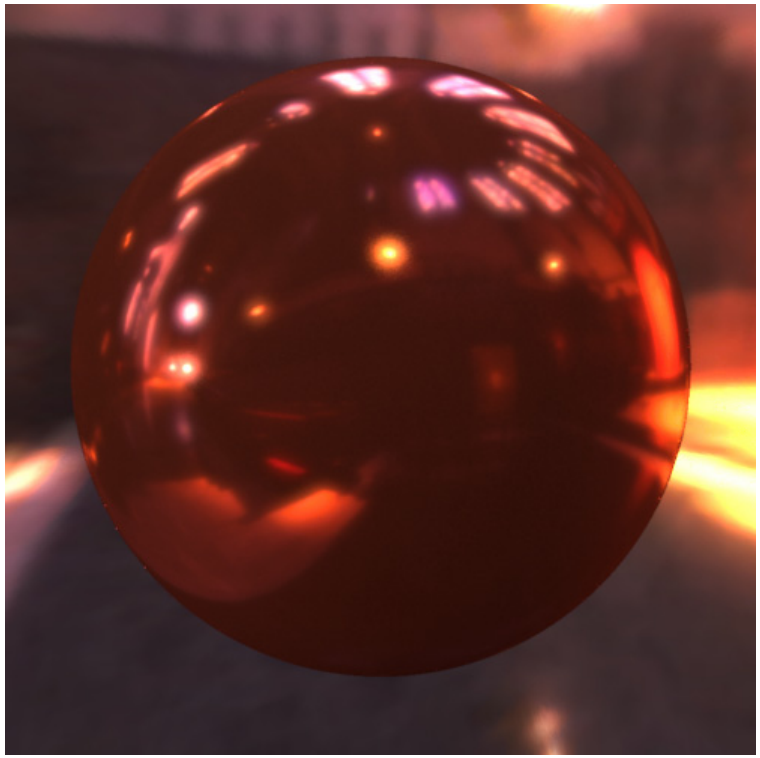
Adding a second lobe

- Some materials impossible to represent with a single lobe

Acquired data



Cook-Torrance 2 lobes



Material – Red Christmas Ball

Fitting Errors

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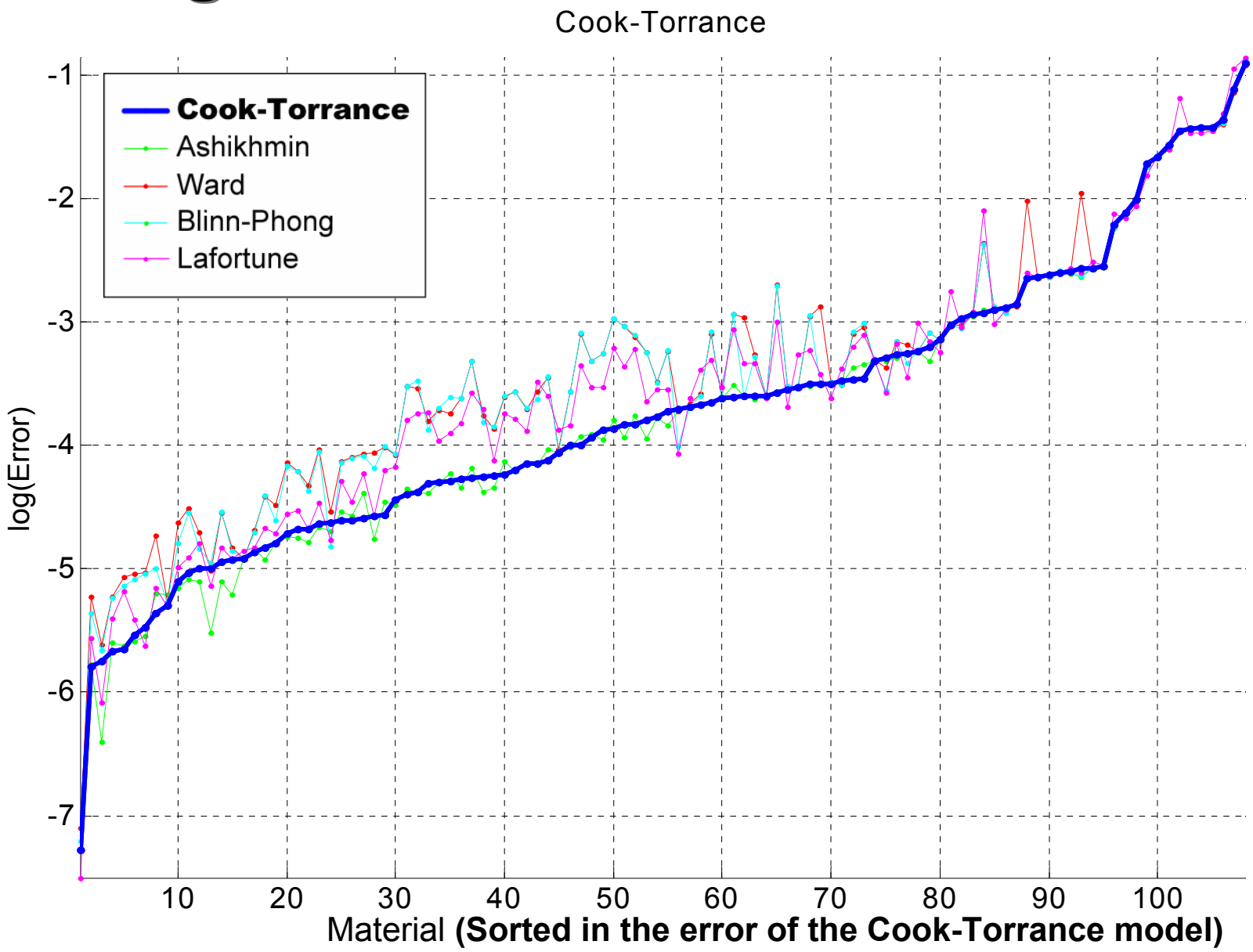

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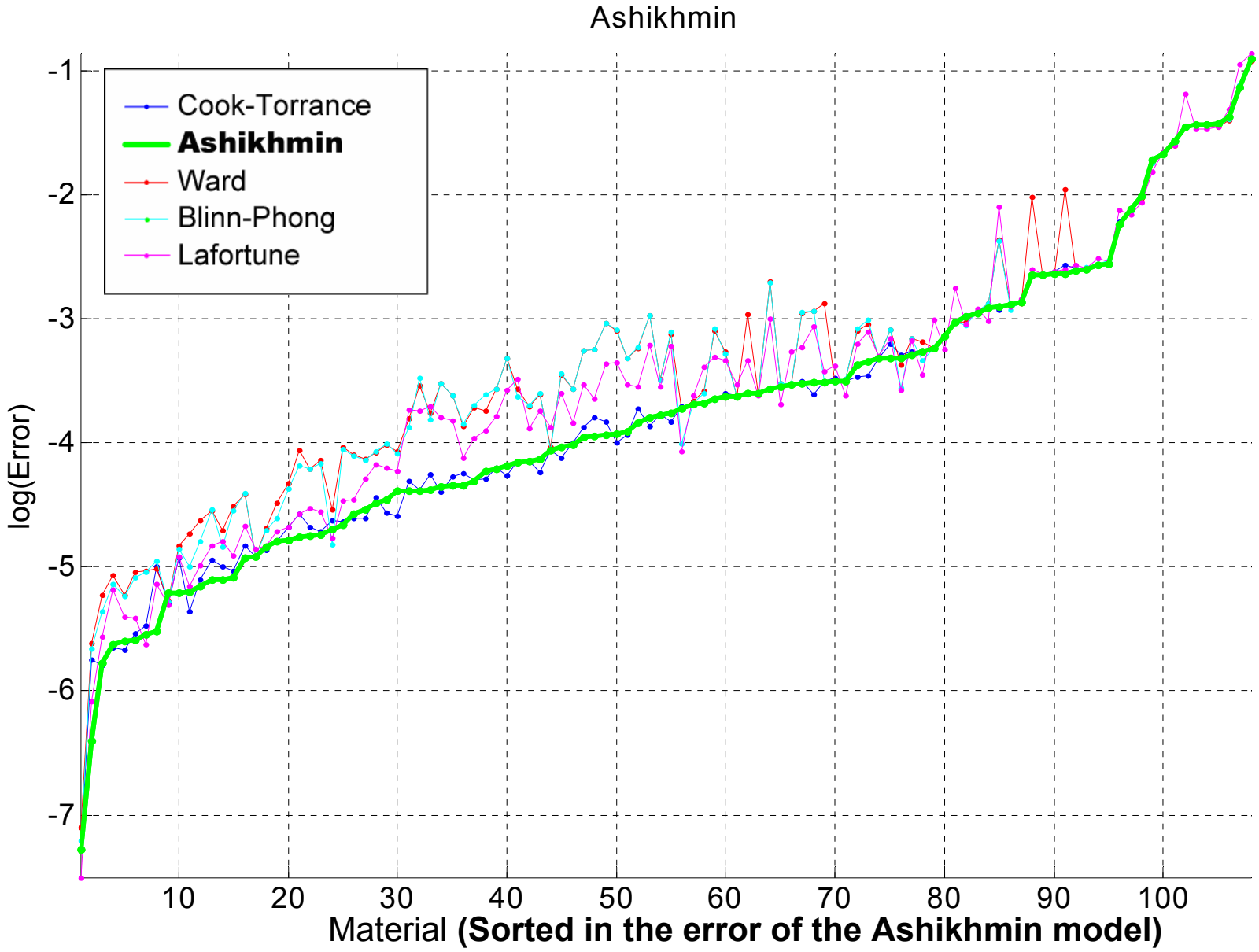

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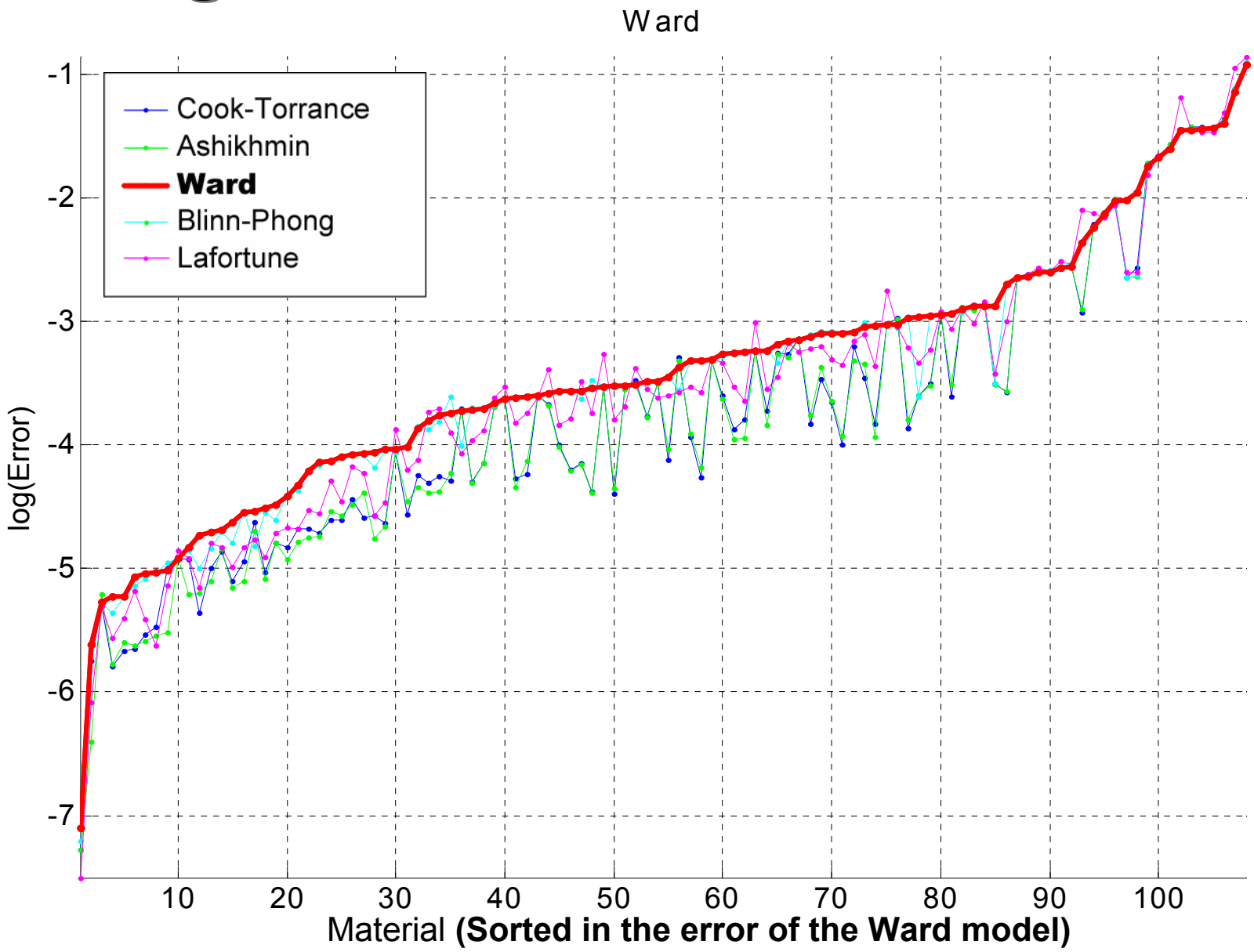

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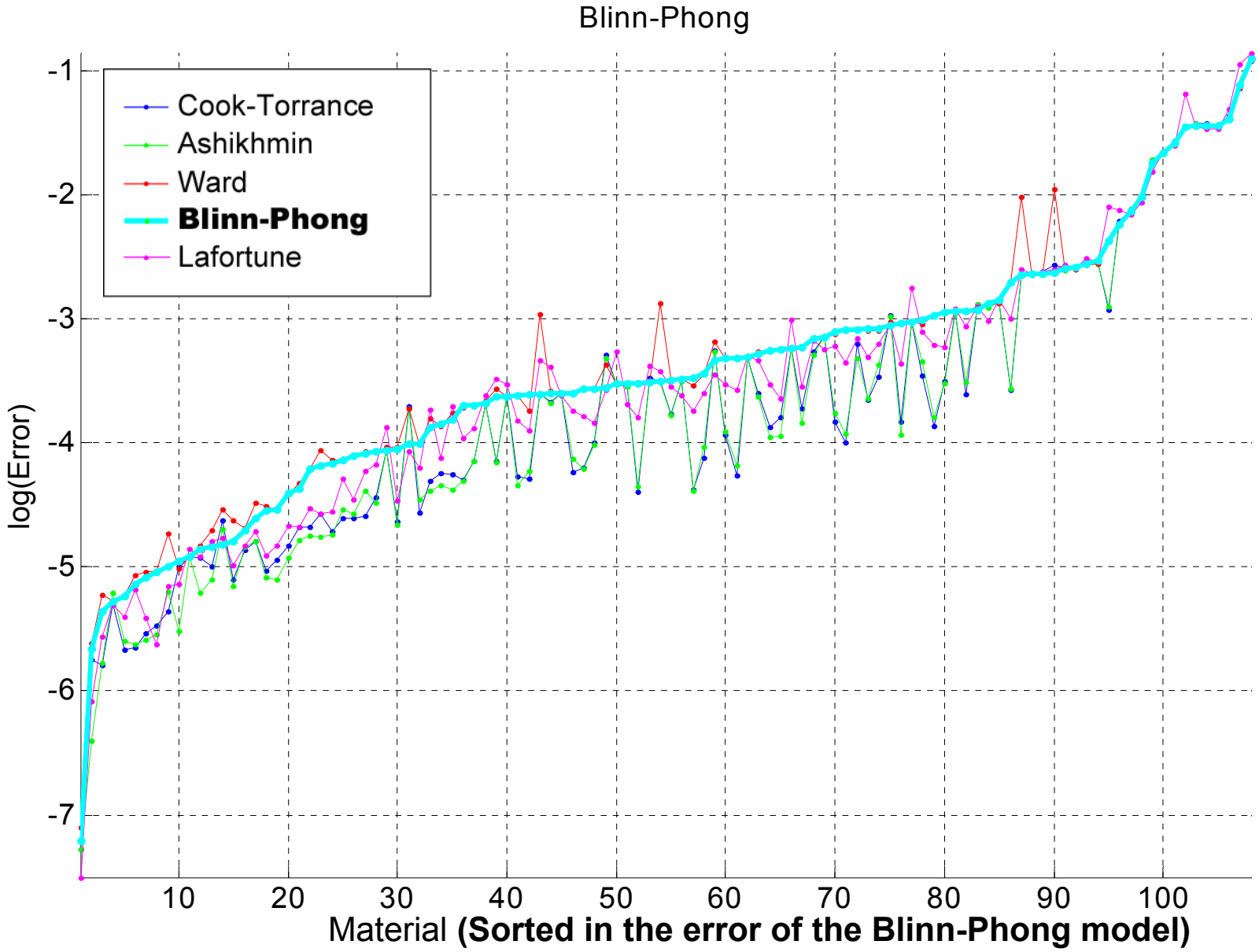

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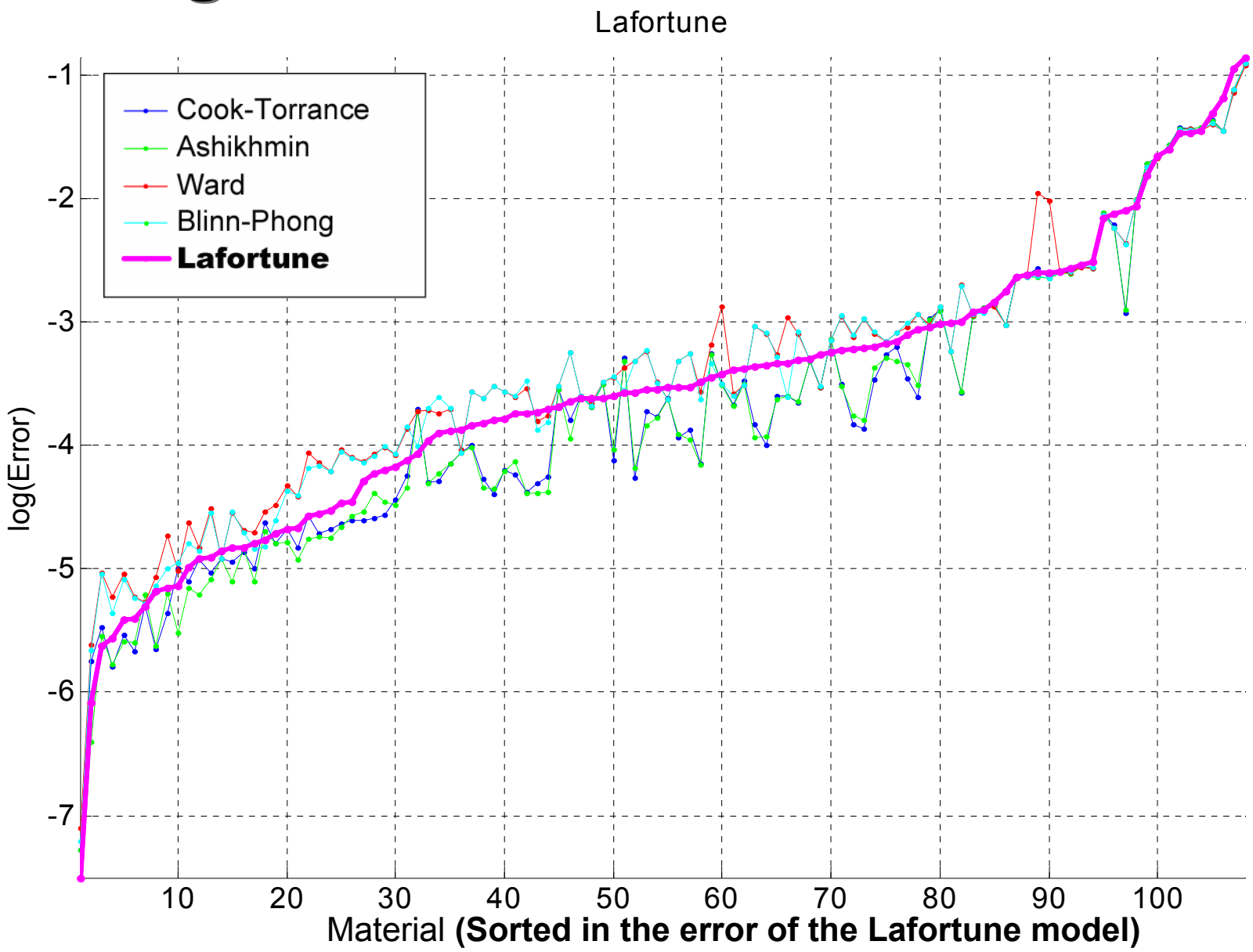
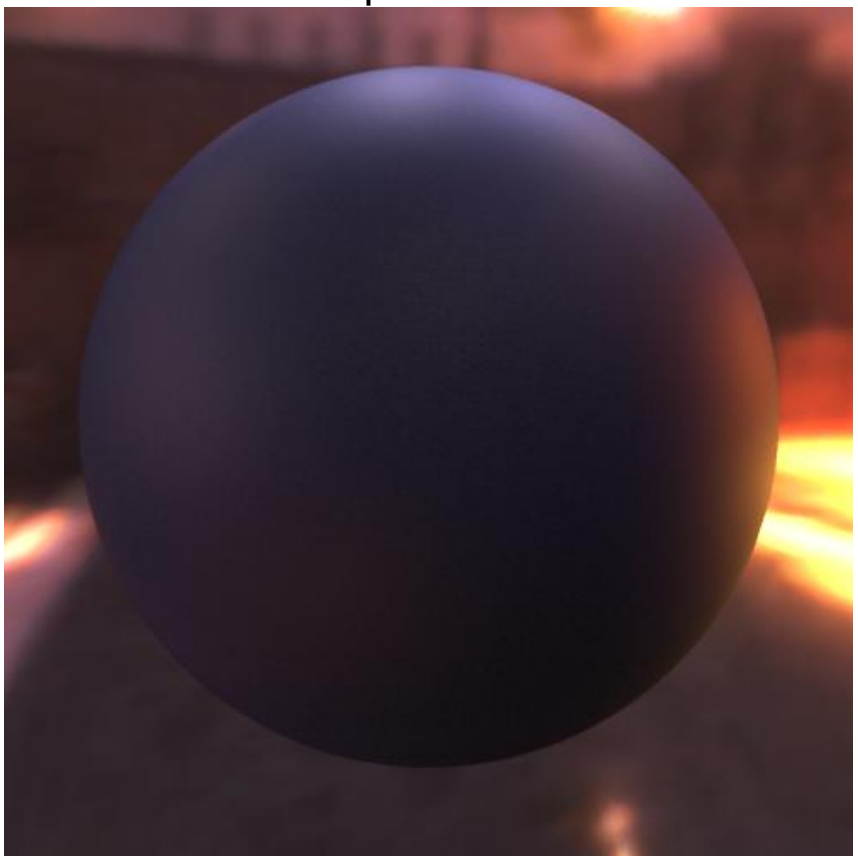


Dark blue paint

Acquired data



Material – Dark blue paint

Dark blue paint

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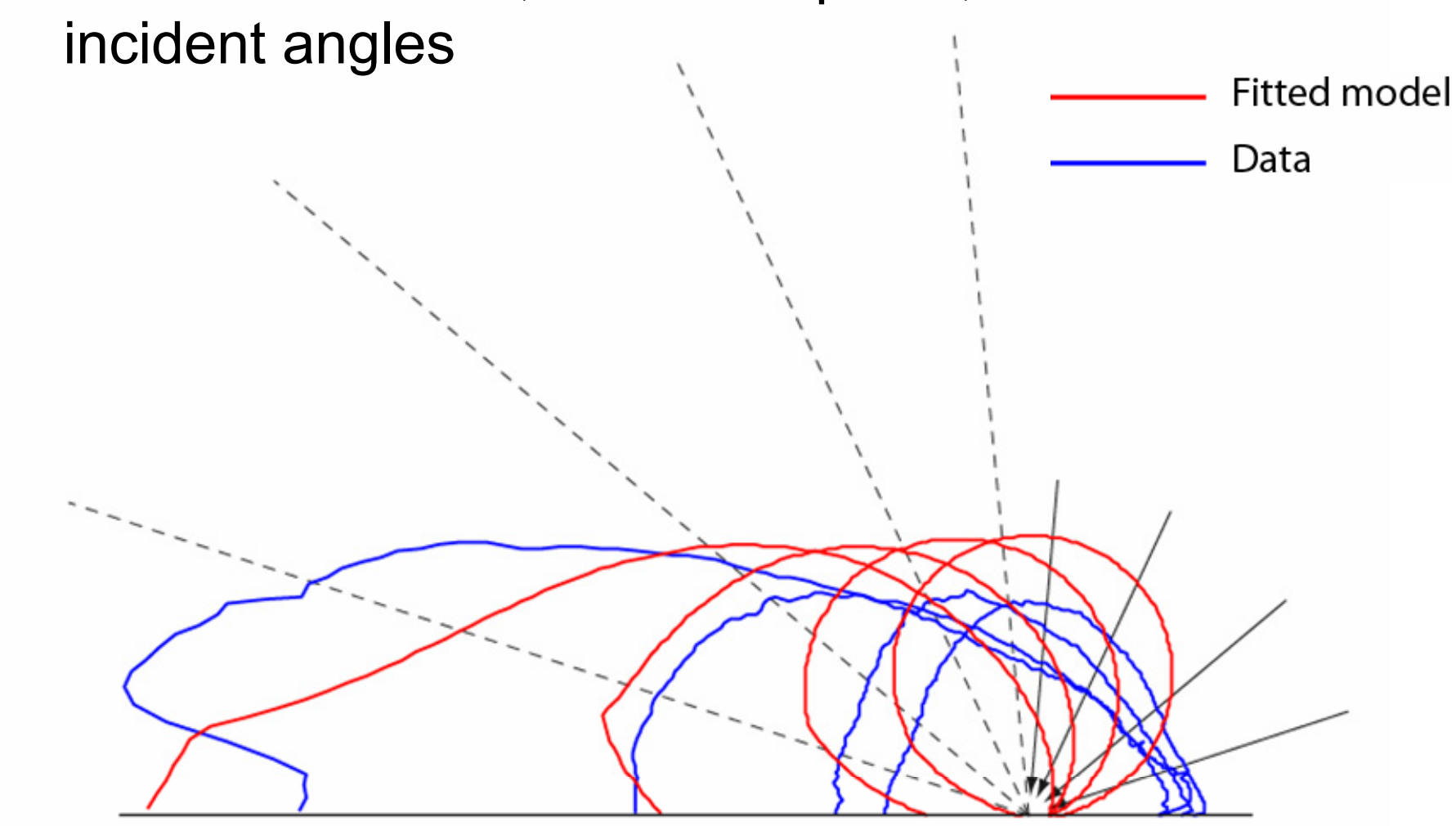
- Cook-Torrance fit, incidence plane, 4 different incident angles



Material – Dark blue paint

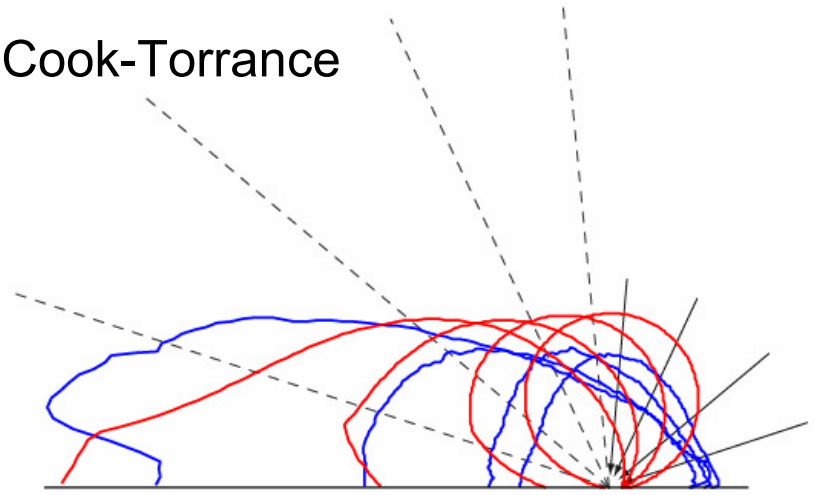
Dark blue paint

Fitted model

Data

SIGGRAPH2004

Cook-Torrance



Material – Dark blue paint

Dark blue paint

Fitted model

Data

SIGGRAPH2004

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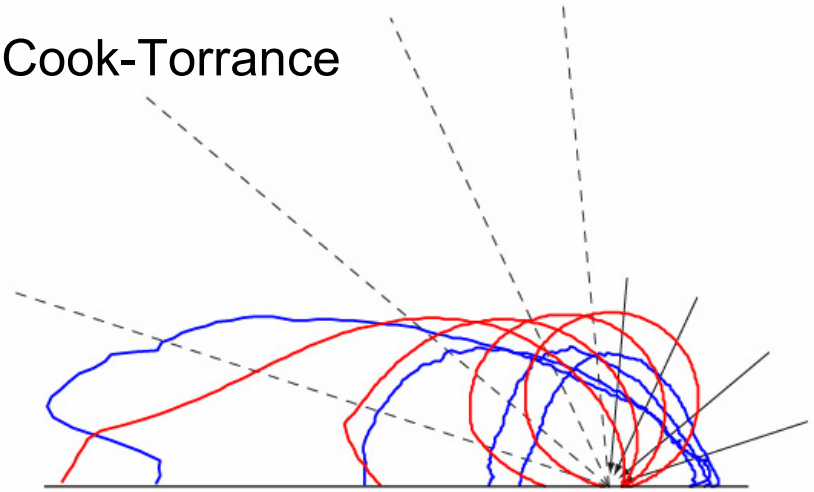
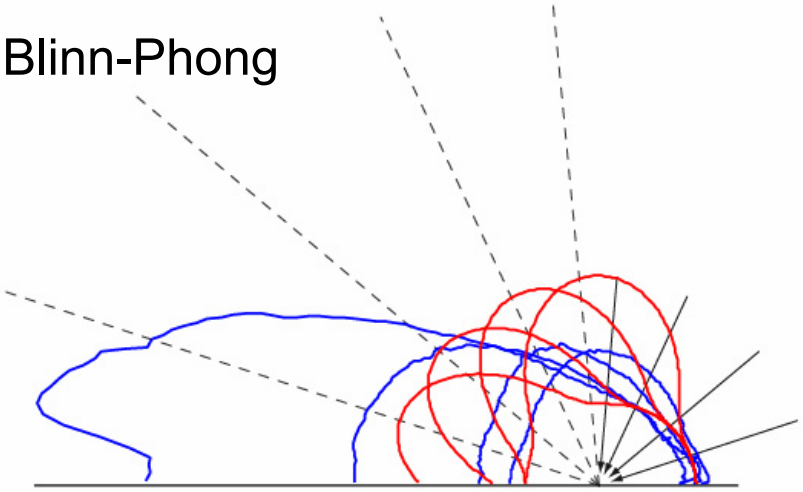


Blinn-Phong



Material – Dark blue paint

Dark blue paint

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Data

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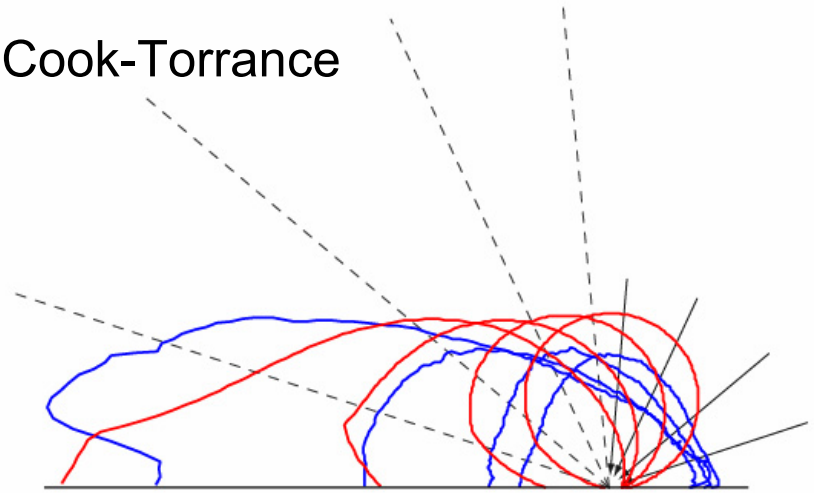
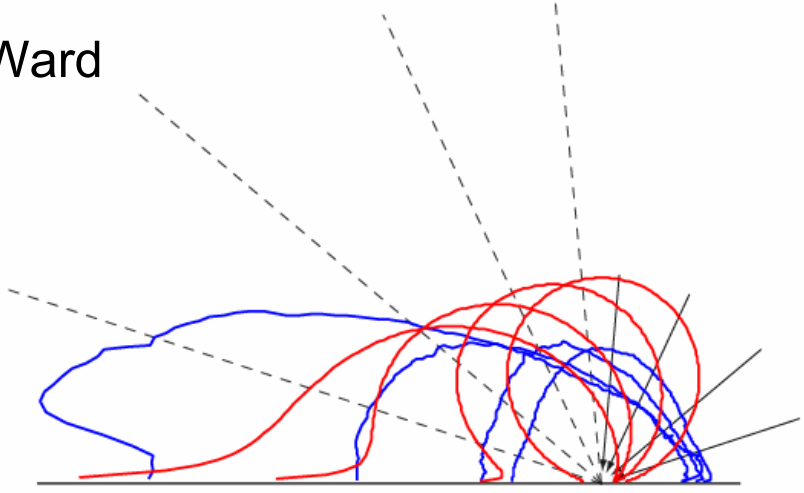
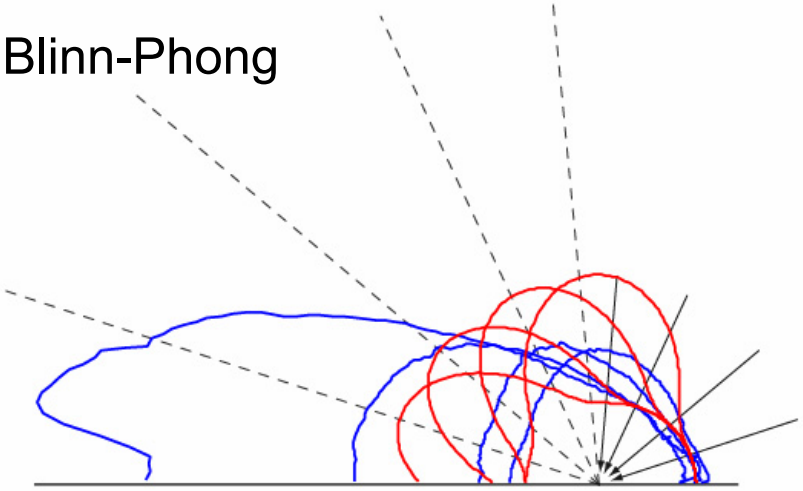
Cook-Torrance



Ward



Blinn-Phong



Material – Dark blue paint

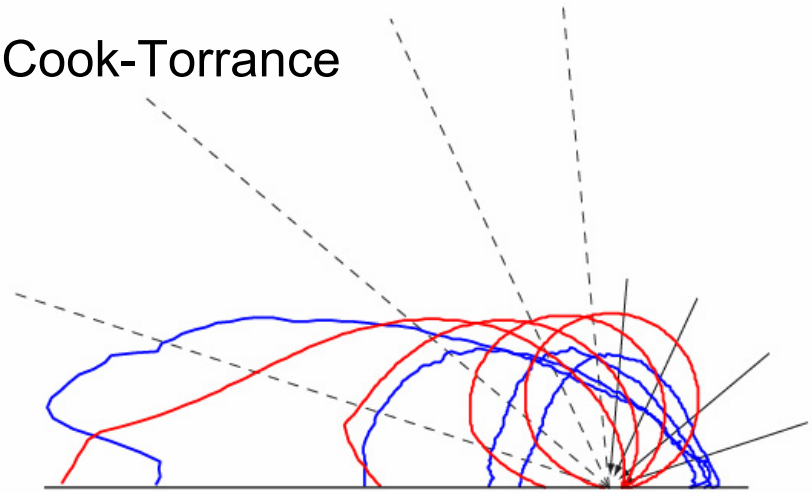
Dark blue paint

Fitted model

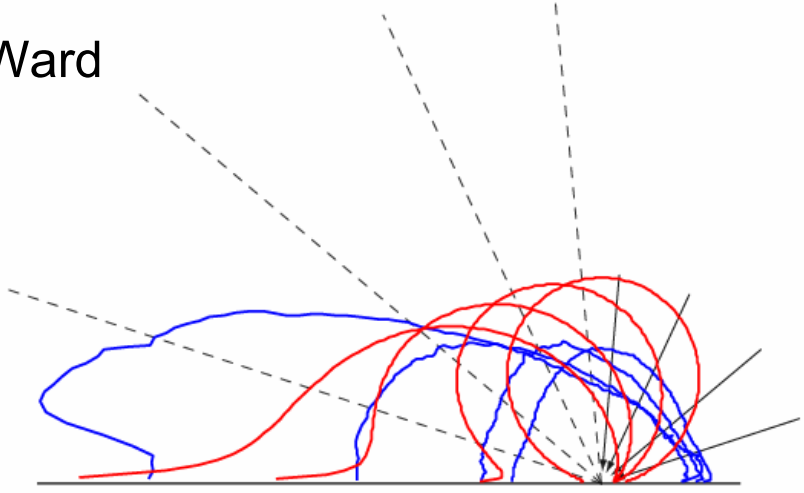
Data

SIGGRAPH2004

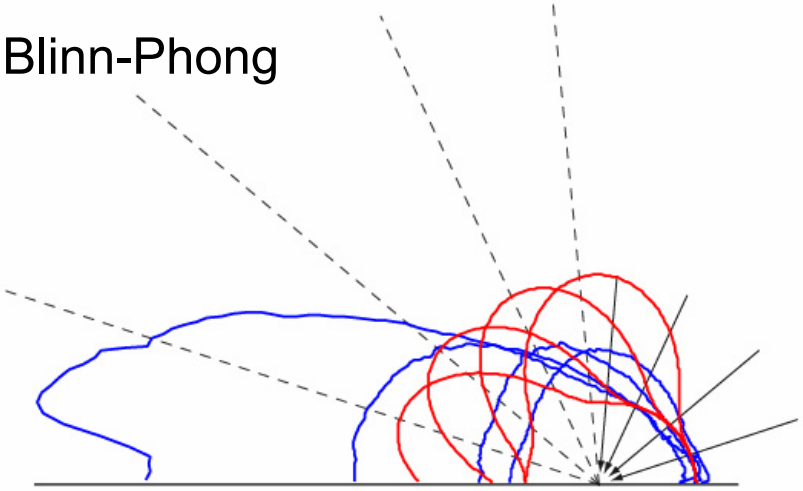
Cook-Torrance



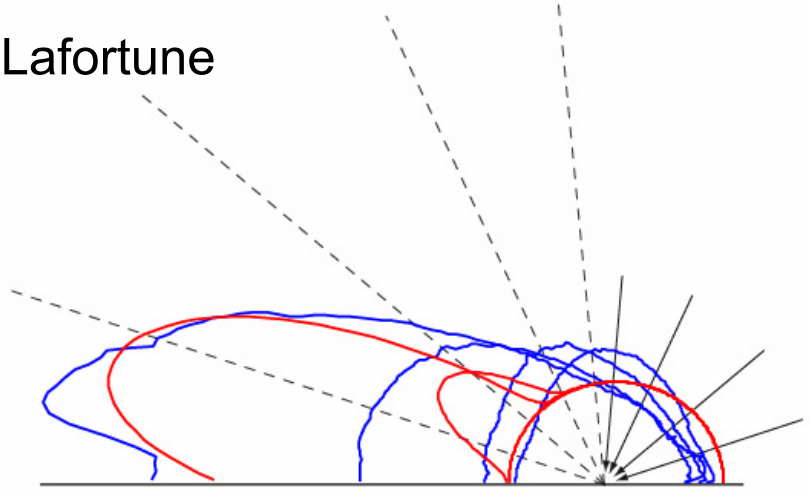
Ward



Blinn-Phong



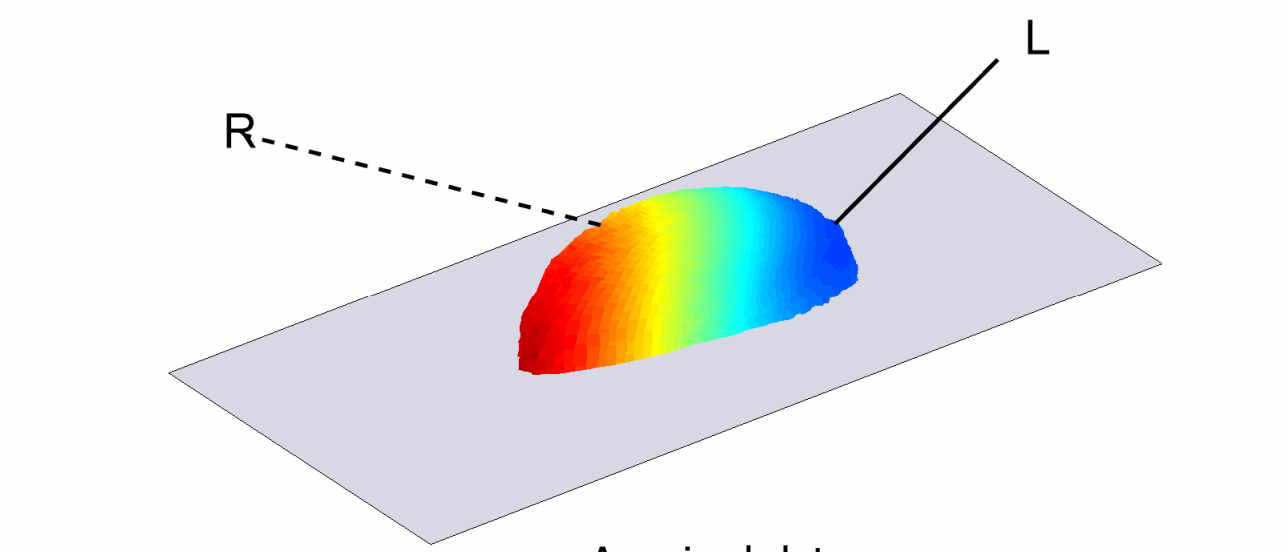
Lafortune



Material – Dark blue paint

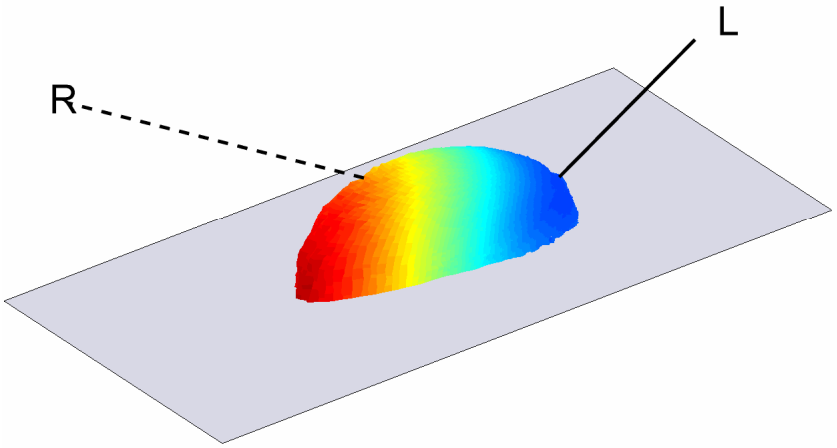
Dark blue paint

- Hemispherical plot for a fixed incoming angle
  - False color correspond to value of the BRDF

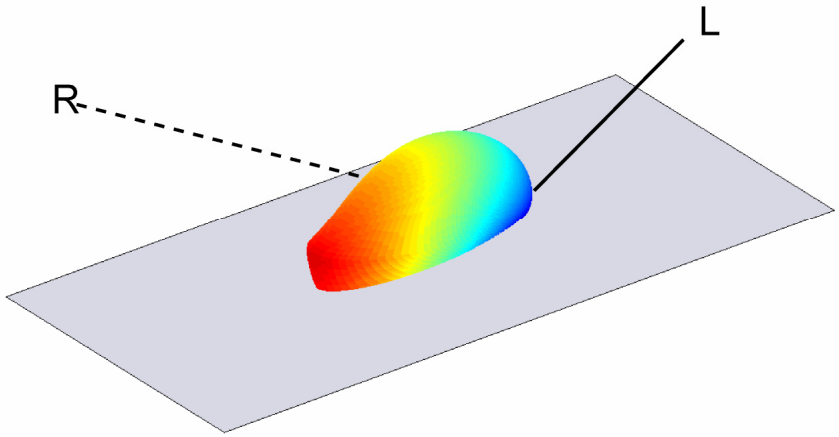


Acquired data

Dark blue paint

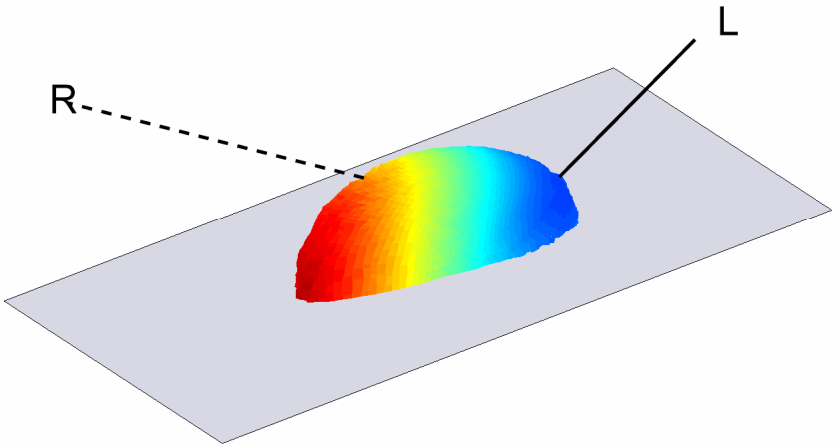


Acquired data

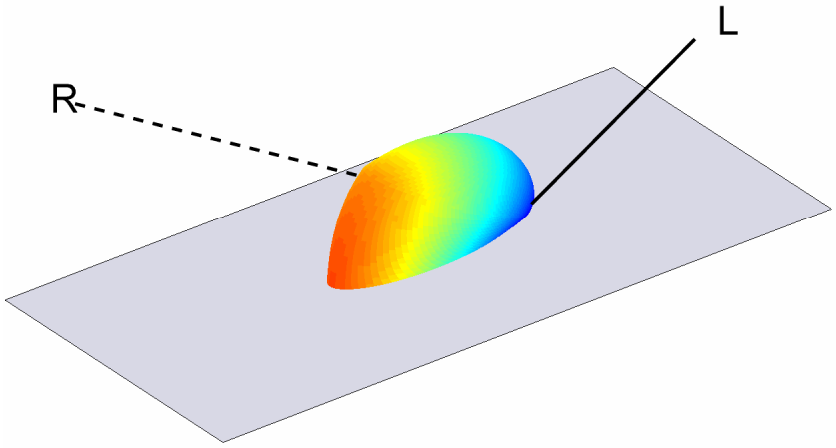


Cook-Torrance

Dark blue paint

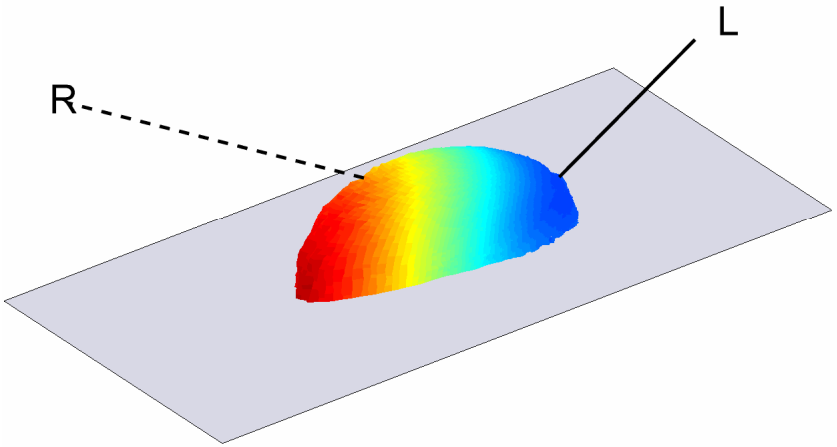


Acquired data

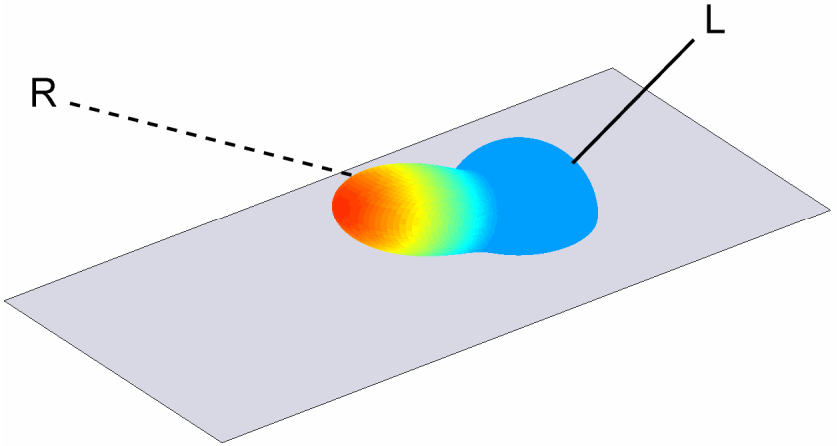


Ashikhmin

Dark blue paint



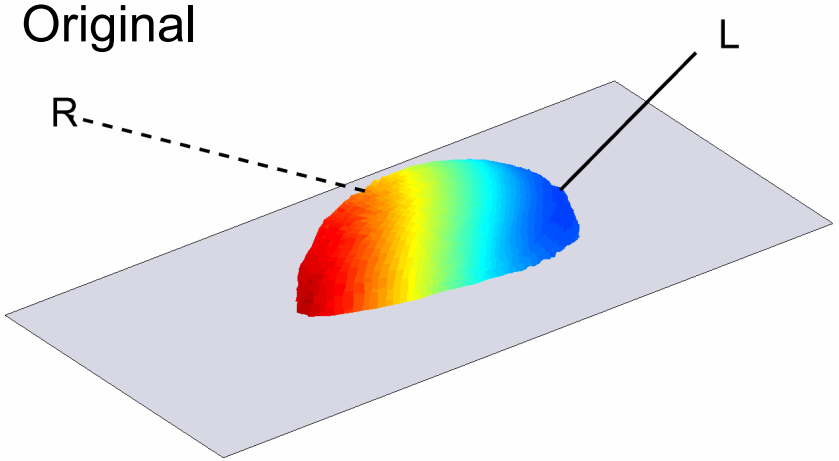
Acquired data



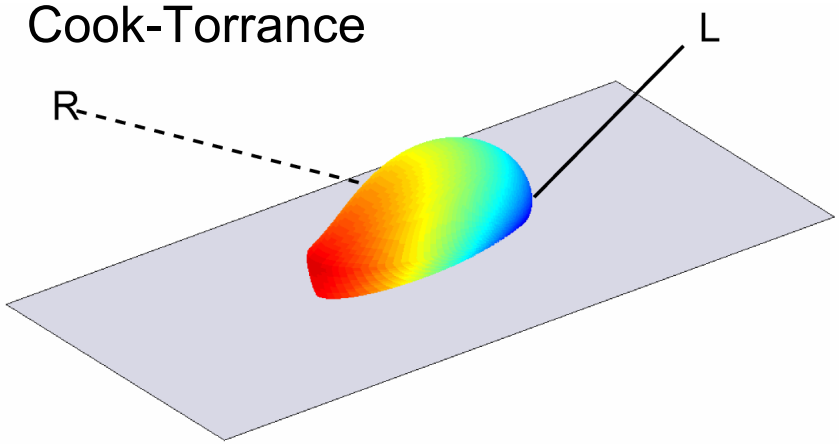
Lafortune

Dark blue paint

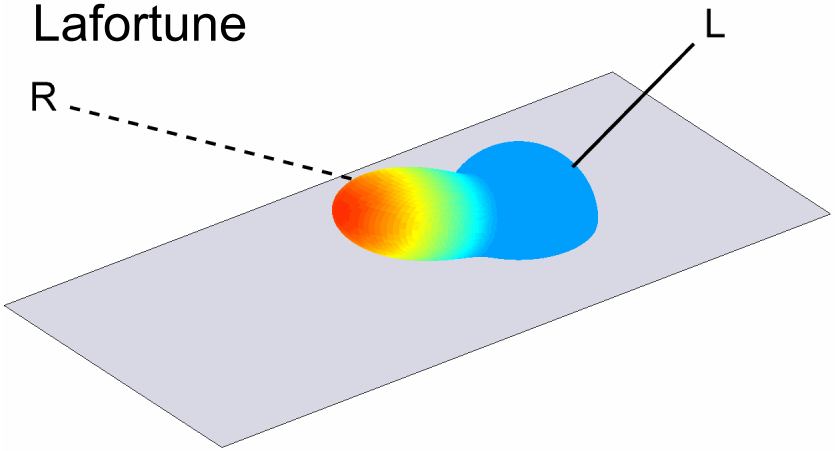
Original



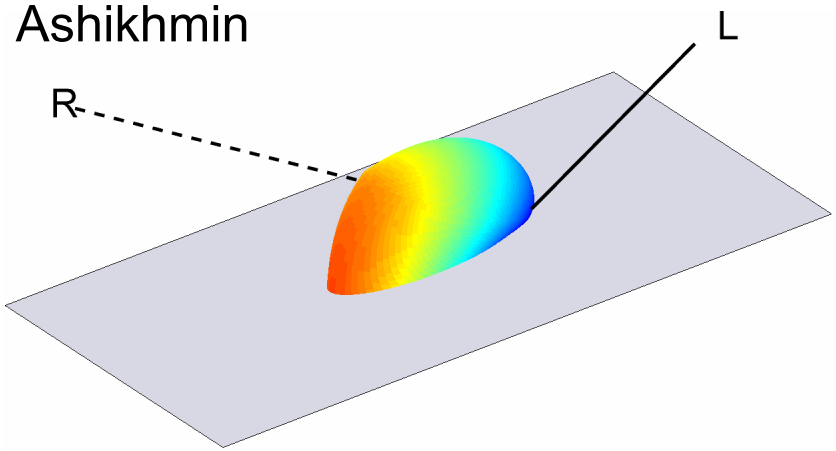
Cook-Torrance



Lafortune



Ashikhmin



Material – Dark blue paint

Observations

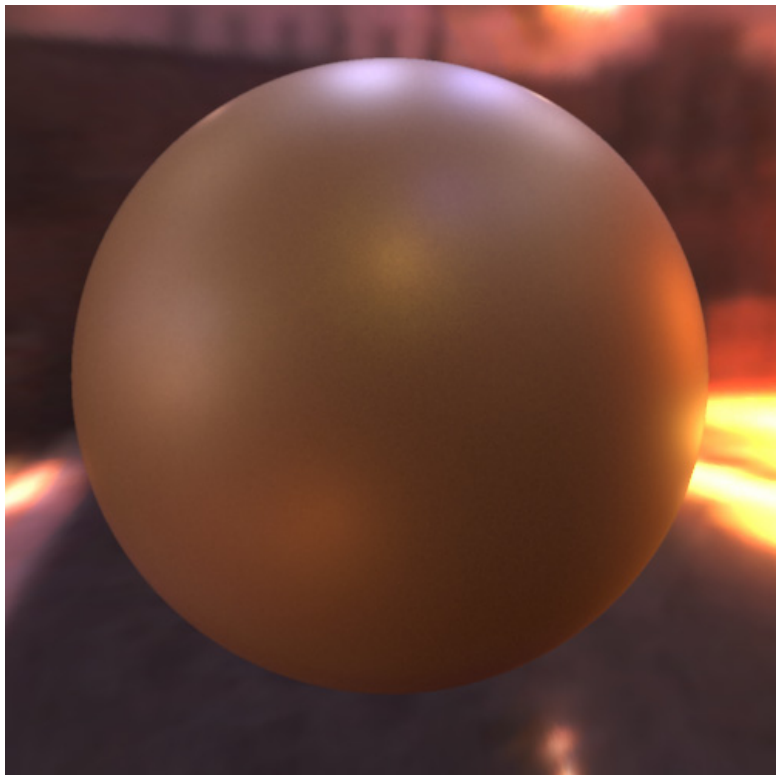
- Cook-Torrance, Ashikhmin
  - Consistently outperform the other models
- Lafortune
  - High discrepancy near grazing angle
  - Shape of lobe very different
- Ward, Blinn-Phong
  - unable to reproduce Fresnel effect

Analysis

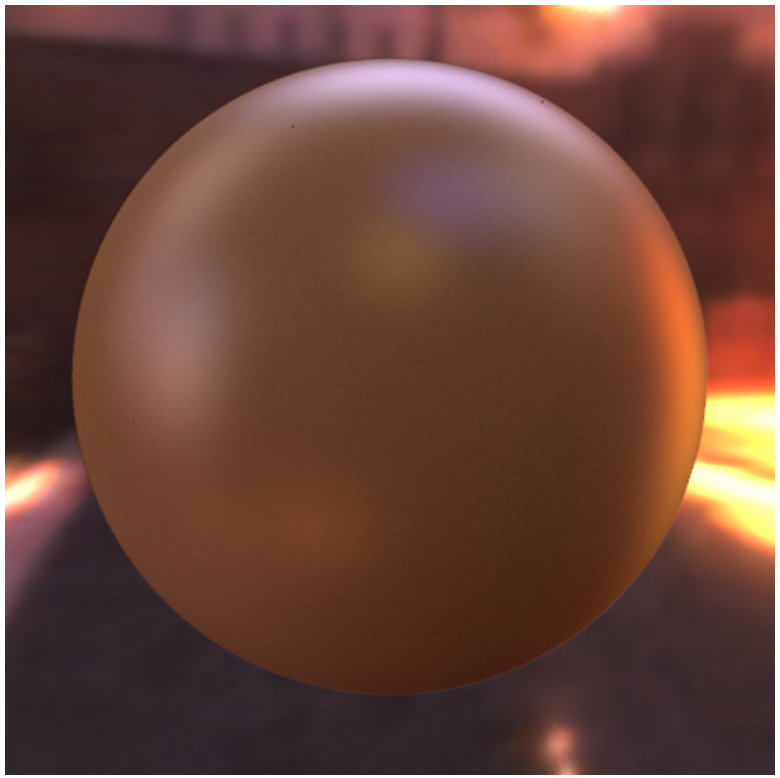
- Lafortune model
  - Very popular
    - Simple, inexpensive to evaluate
    - Handle phenomena like off-specular reflection, retroreflection
    - importance sampling friendly

Analysis

- Lafortune model
  - High discrepancy near grazing angle



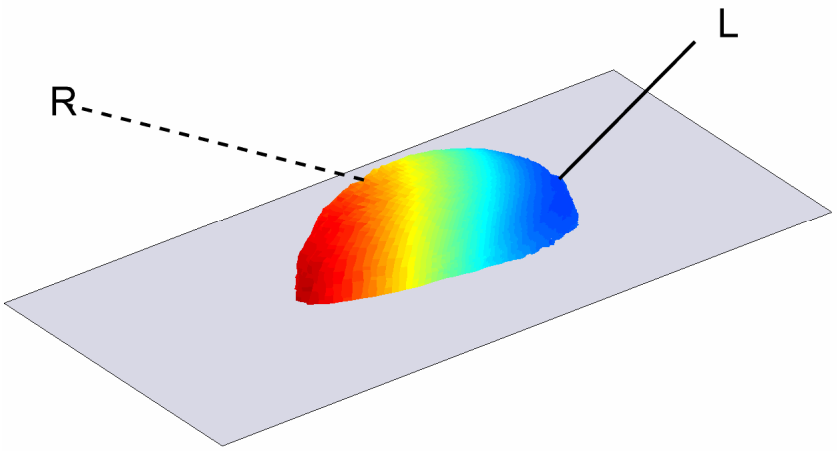
Acquired data – gold paint



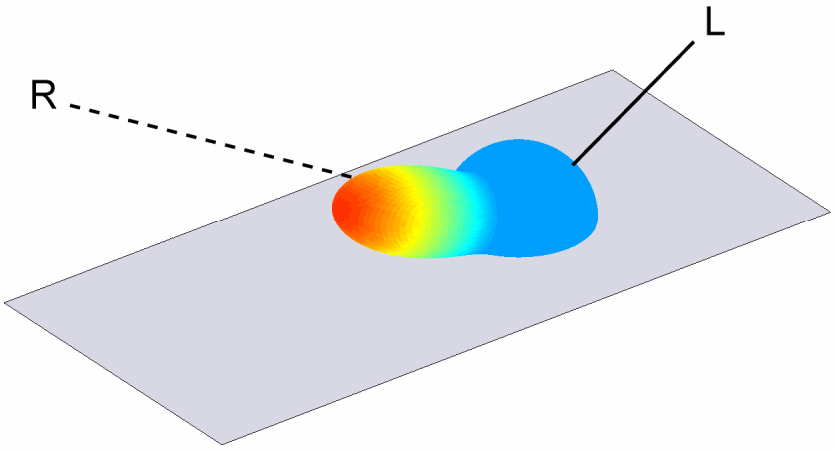
Lafortune fit

Analysis

- Lafortune model
  - High discrepancy near grazing angle



Acquired data



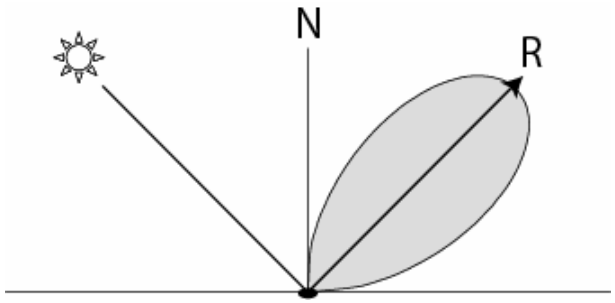
Lafortune

WHY?

Lobe definition

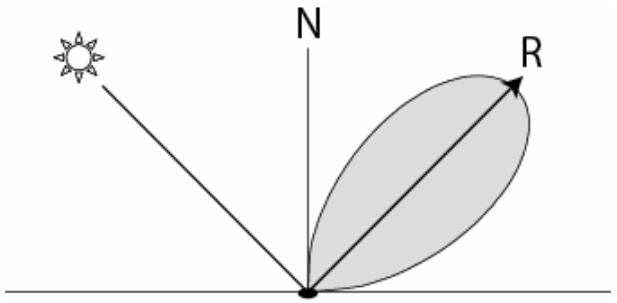
SIGGRAPH2004

- Peak at mirror direction

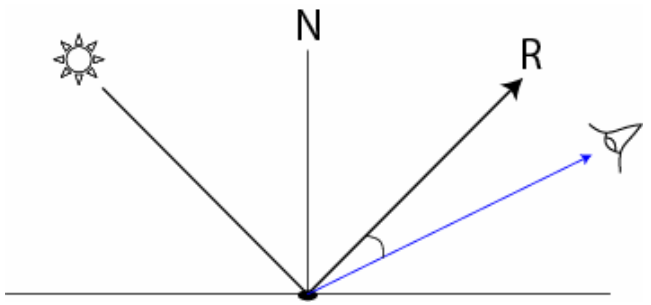


Lobe definition

- Peak at mirror direction

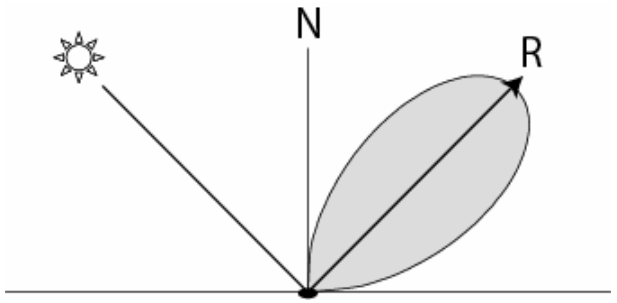


  - Mirror-vector, View-vector
    - Phong, Lafortune*

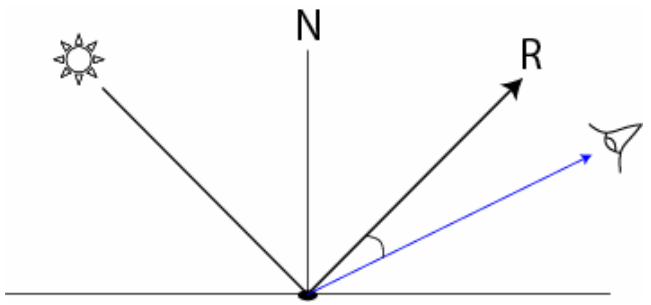


Lobe definition

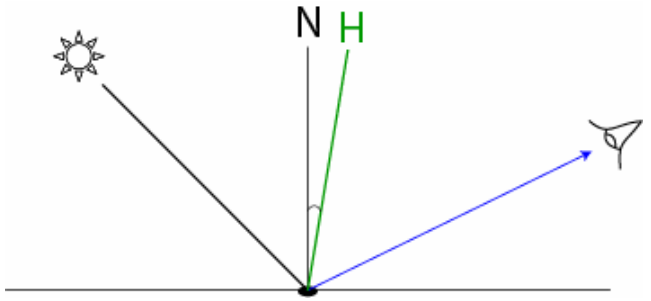
- Peak at mirror direction



  - Mirror-vector, View-vector
    - Phong, Lafortune*

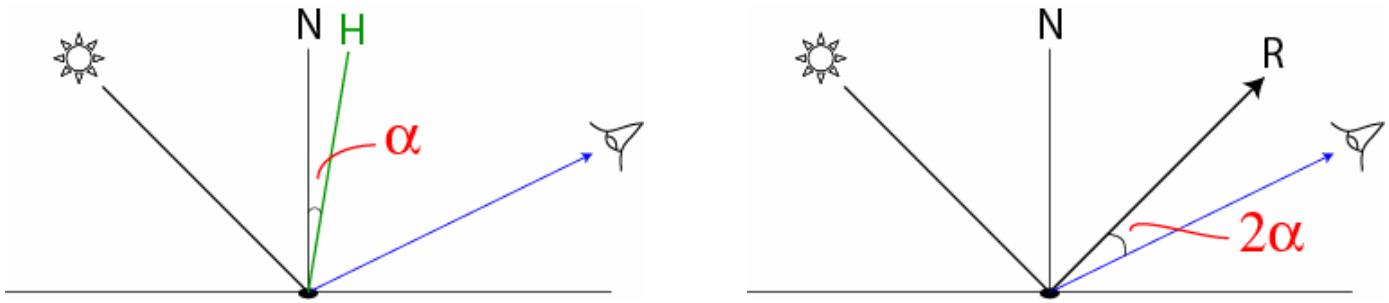


  - Half-vector, Normal
    - All other models



Lobe definition

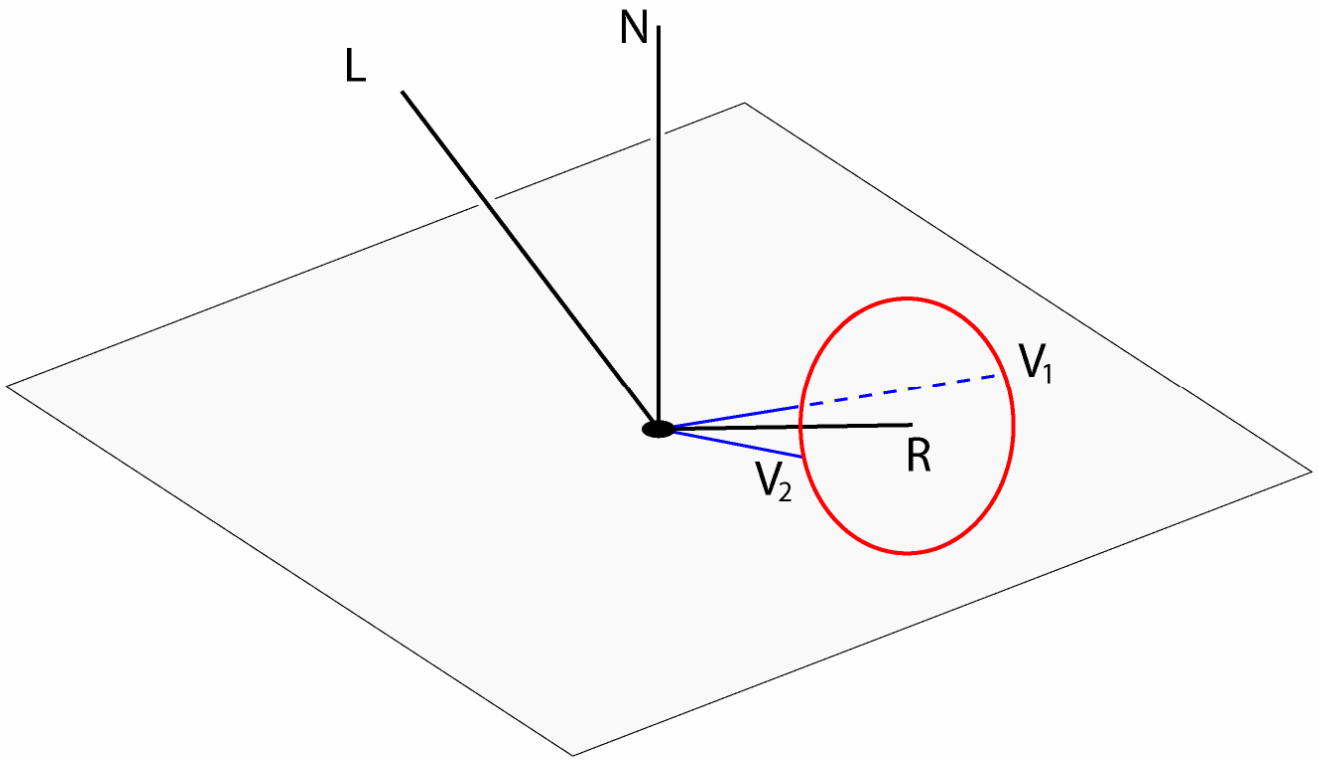
- In the incidence plane, the angle is different by a factor of 2.



- Outside the incidence plane, the relation is not as simple

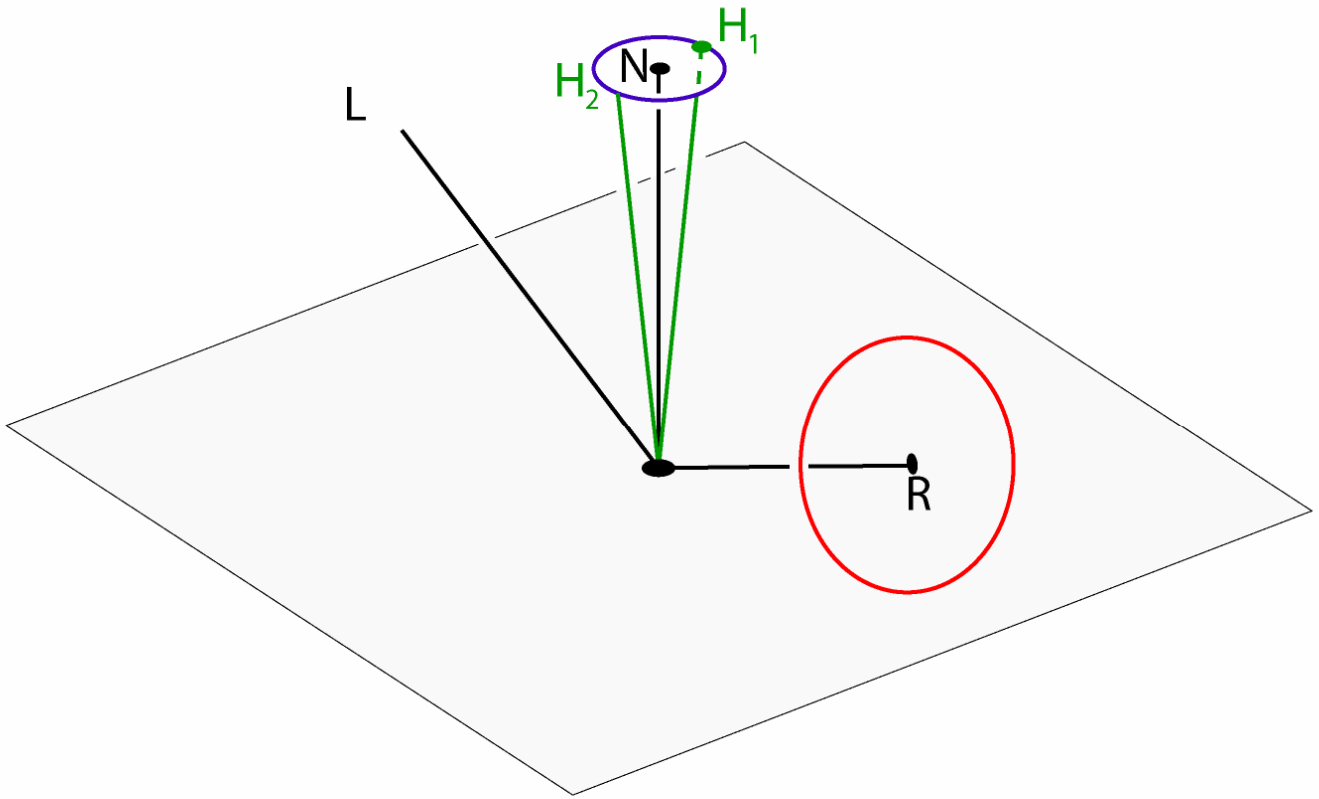
Mirror lobe (V,R)

- Red circle: set of directions V_i with constant angle from R (mirror vector)



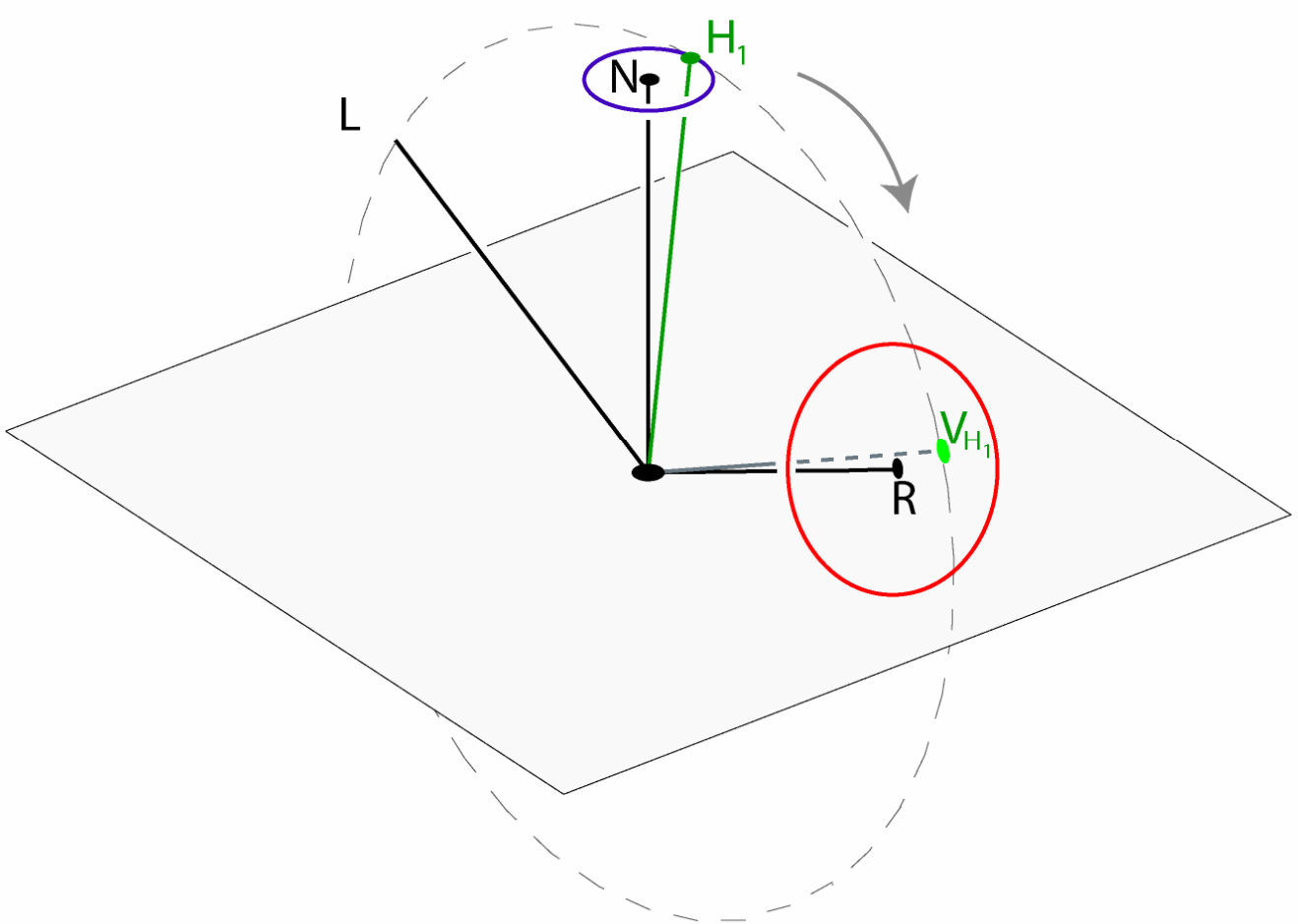
Half vector lobe (H,N)

- Blue circle: set of half vectors H_i with constant angle from N (normal)



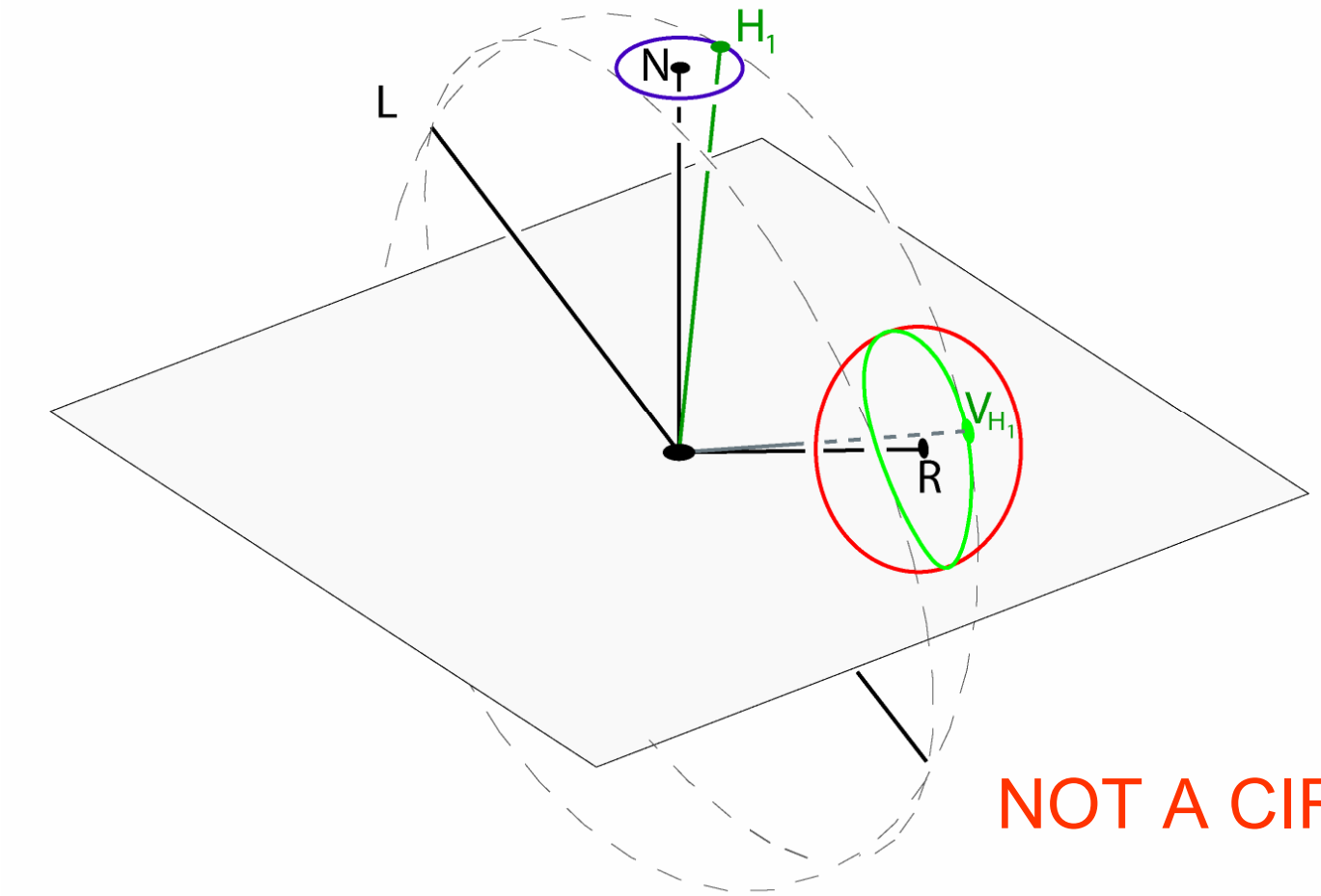
Half vector lobe (H,N)

- Remapping half-vector H_1 to the corresponding outgoing direction V_{H1}



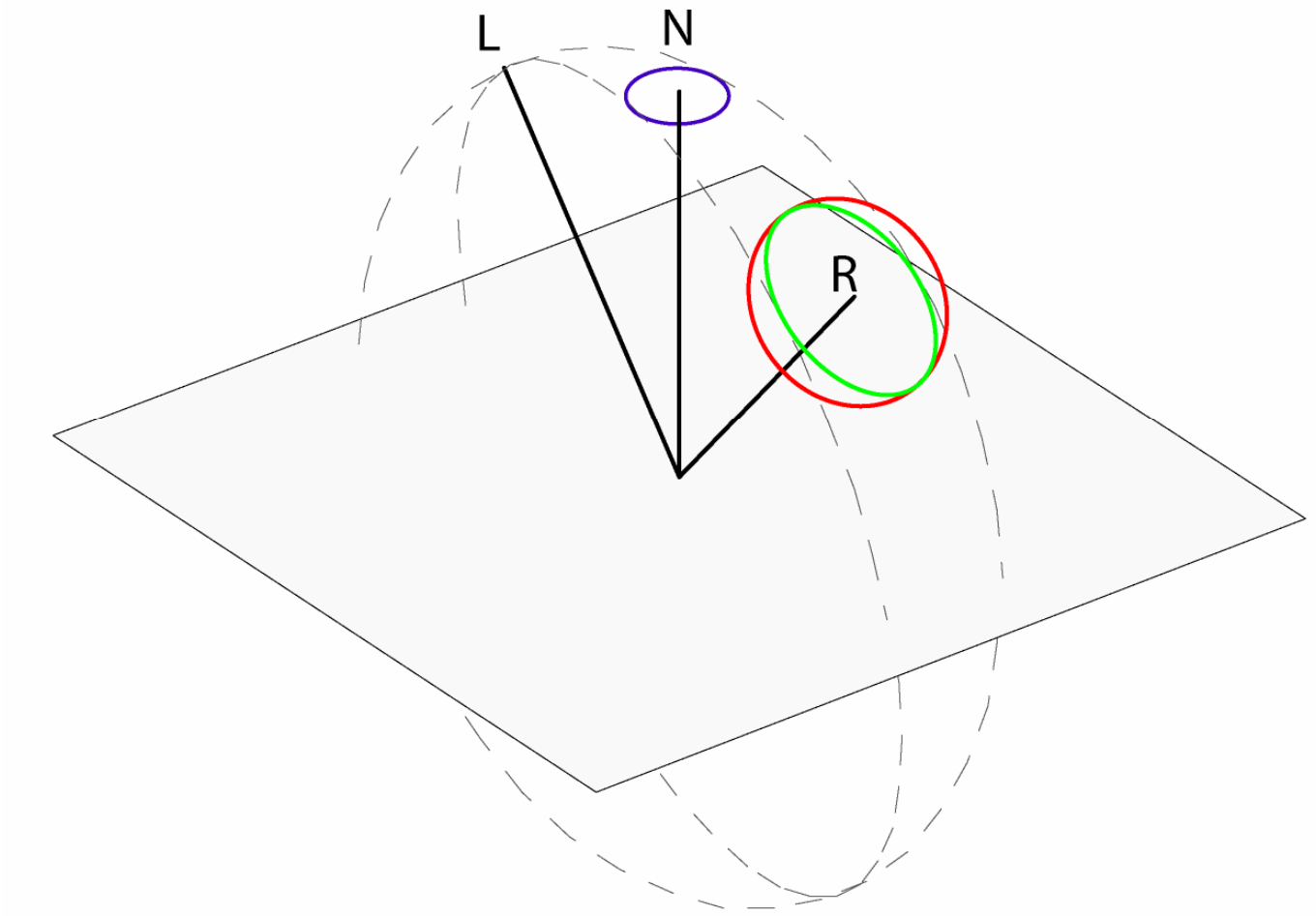
Lobe Comparison

- Green contour: set of half-vectors remapped to outgoing directions



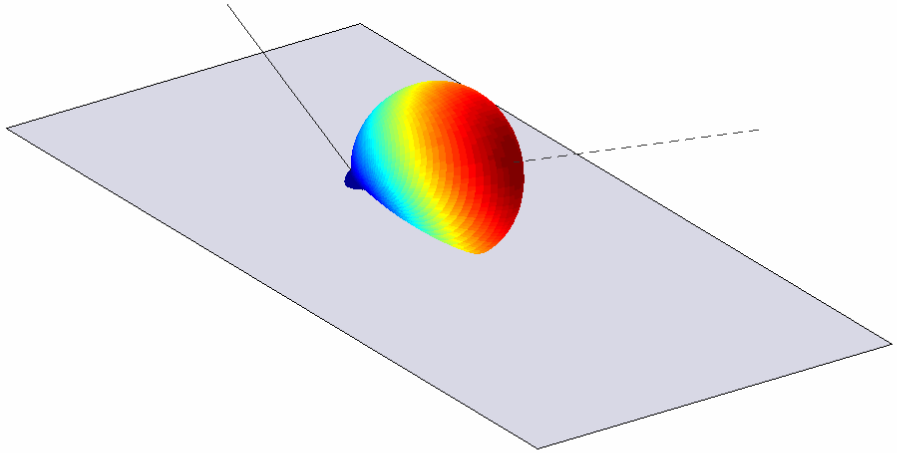
Lobe Comparison

- Shape of green contour is dependent on L

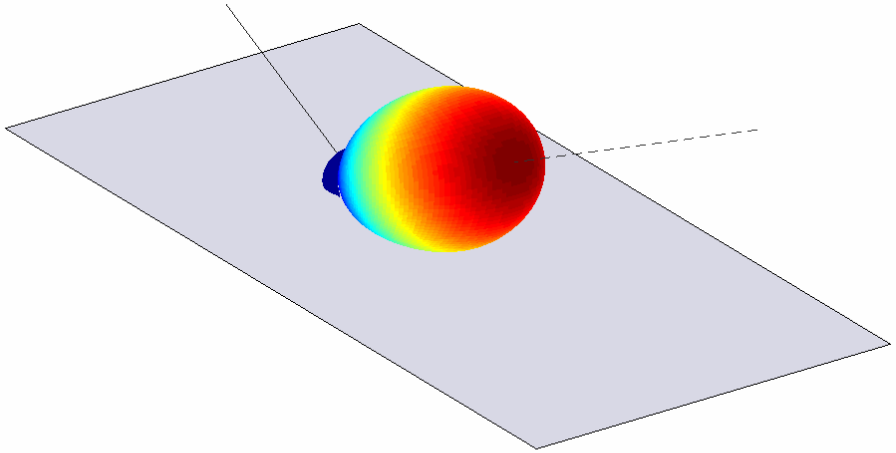


Lobe Comparison

- Full lobe



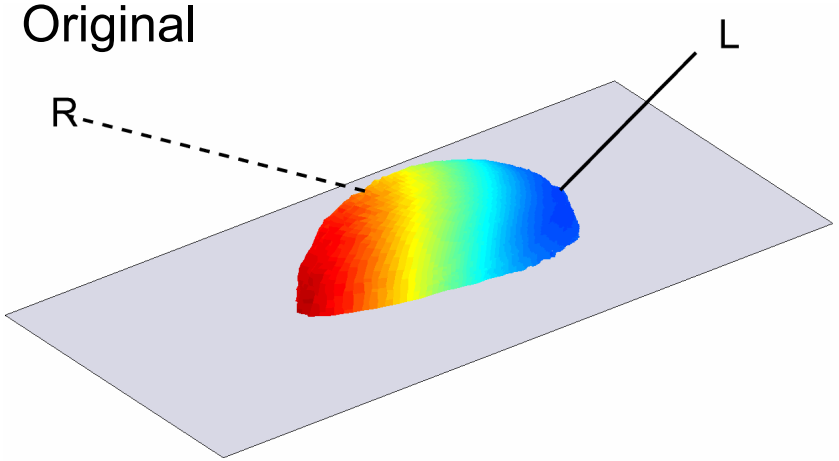
Half vector lobe



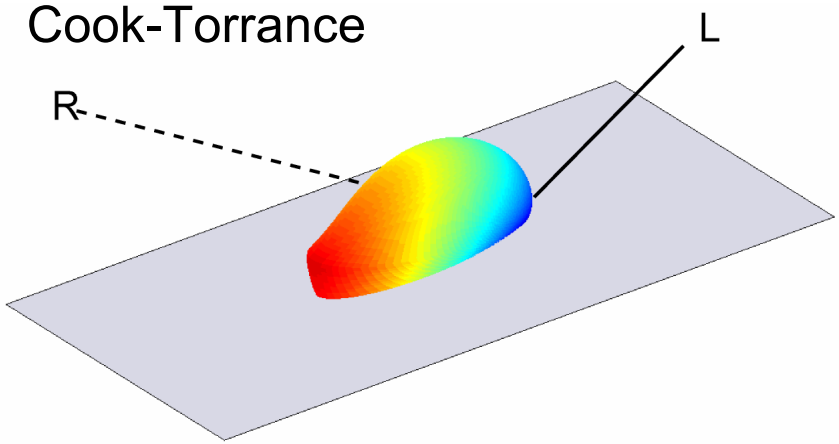
Mirror lobe

Dark blue paint

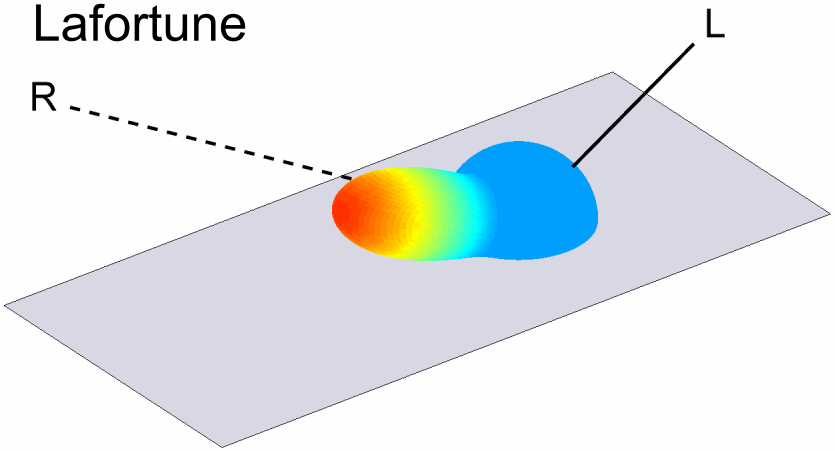
Original



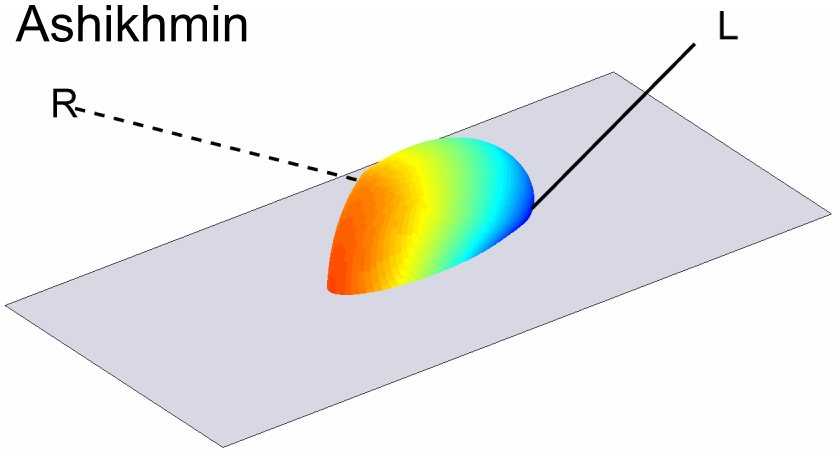
Cook-Torrance



Lafortune



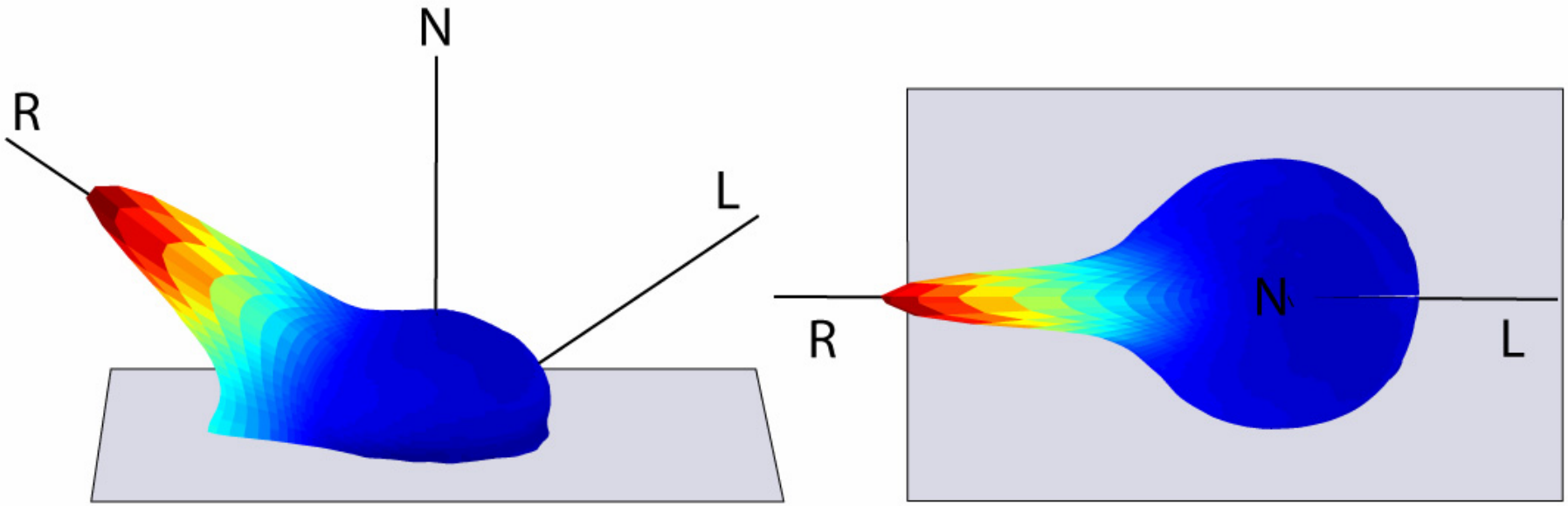
Ashikhmin



Material – Dark blue paint

Half vector lobe

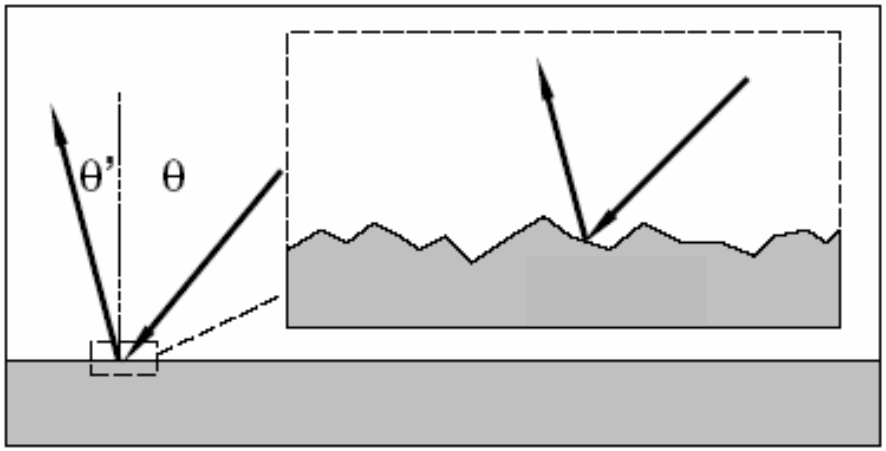
- Consistent with what we observe in the dataset.



Example: Plot of "PVC" BRDF at 55° incidence

Microfacet theory

- [Torrance & Sparrow 1967]
  - Surface modeled by tiny perfect mirrors
  - Value of BRDF at (L,V)
    - # of mirrors oriented halfway between L and V
  - BRDF naturally represented by function of H



[Shirley 97]

Microfacet theory

- [Torrance & Sparrow 1967]
  - Surface modeled by tiny perfect mirrors
  - Value of BRDF at (L,V)
    - # of mirrors oriented halfway between L and V
  - BRDF naturally represented by function of H

- Shape of the mirror lobe cannot be explained with any microfacet distribution

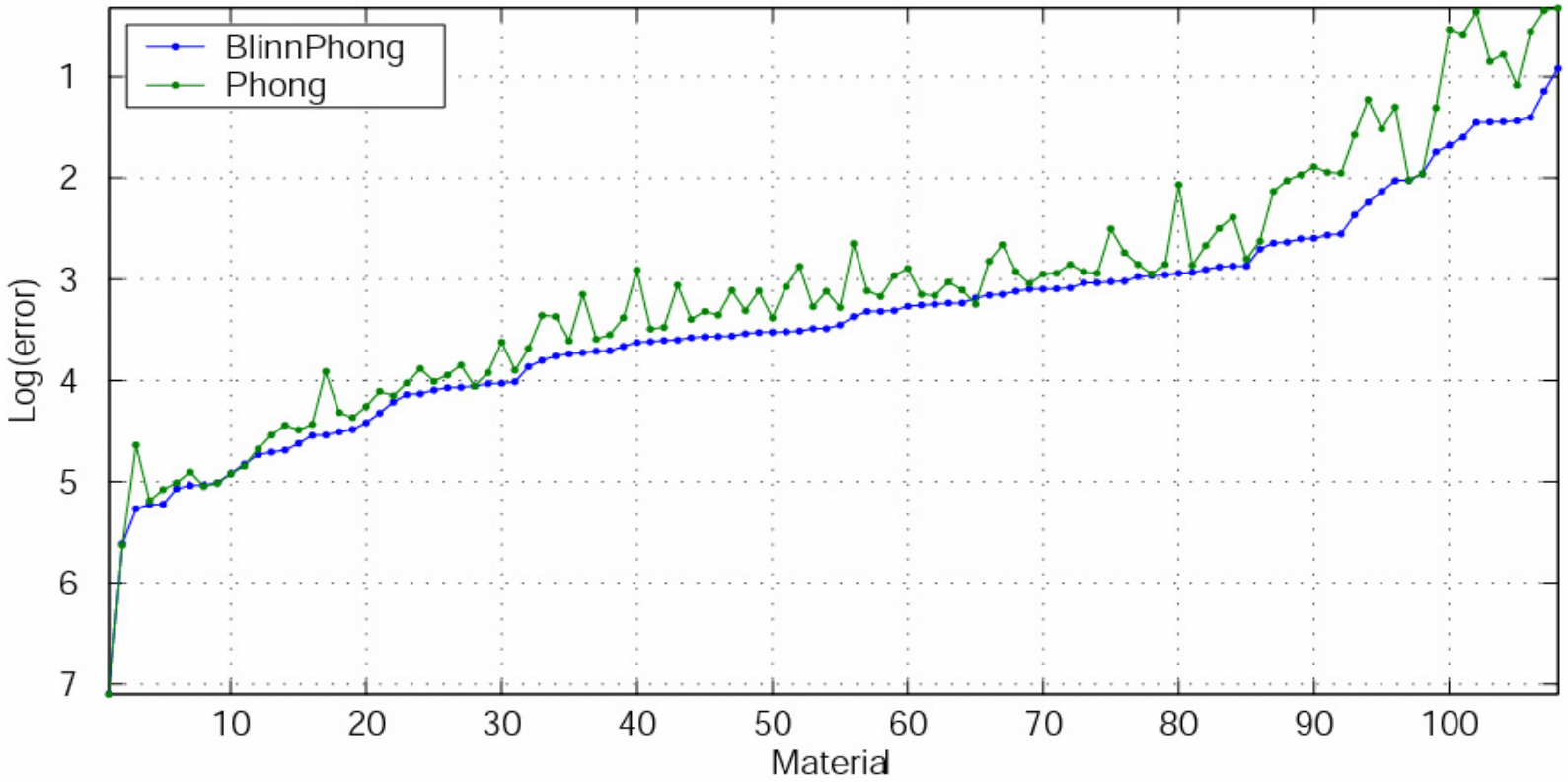
Phong vs Blinn-Phong

- Blinn uses half vector lobe instead of mirror lobe in the original model [1977]

Phong vs Blinn-Phong

SIGGRAPH2004

- Blinn uses half vector lobe instead of mirror lobe in the original model [1977]
- Lower numerical error in nearly all cases!



Conclusion

- Half vector lobe better than mirror lobe
- Fresnel effect is important
- Cook-Torrance and Ashikhmin models match real data quite well

Future Work

- Anisotropic materials
- Gain insight by grouping materials into classes

Questions?