Appearance of Interfaced Lambertian Microfacets

using STD Distribution

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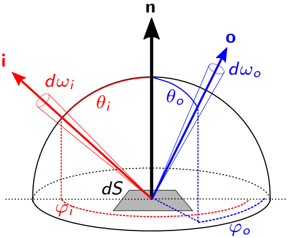
BRDF Models



$$L(\mathbf{i},\mathbf{o},\mathbf{n}) = \frac{d^2\phi_o(\mathbf{i},\mathbf{o})}{dS\cos\theta_o d\omega_o}$$

$$f(\mathbf{i},\mathbf{o},\mathbf{n}) = \frac{dL(\mathbf{o},\mathbf{n})}{dE(\mathbf{i},\mathbf{n})}$$

- Many existing models [Phong,Ward,CT82,ON94,Ash00,Jak14,Wu15,Bel17,etc.]
  Only few parameters, more or less intuitive and easy to control
  Some are designed specifically for fitting parameters
- Some of them aim designed for physically-based applications
  (Energy conservation and reciprocity)
  ⇒ Microfacet-based models often employed

Microfacet Representation

General Equation [ON94,Walt07]:

$$f(\mathbf{i},\mathbf{o},\mathbf{n}) = \int_{\Omega_+} \frac{|\mathbf{im}|}{|\mathbf{in}|} f^{\mu}(\mathbf{i},\mathbf{o},\mathbf{m}) \frac{|\mathbf{om}|}{|\mathbf{on}|} D(\mathbf{m}) G(\mathbf{i},\mathbf{o},\mathbf{m}) d\omega_m. \tag{1}$$

⇒ *All microfacets may contribute*

⇒ *Rough surfaces imply multiple light reflections*

Simplifies with specular microfacets f^{μ} [TS67,CT82,Walt07]:

$$f(\mathbf{i},\mathbf{o},\mathbf{n}) = \frac{F(\mathbf{i},\mathbf{h})D(\mathbf{h})G(\mathbf{i},\mathbf{o},\mathbf{h})}{4|\mathbf{in}||\mathbf{on}|}, \tag{2}$$

⇒ *Only one microfacet orientation can contribute*

⇒ *Multiple light reflections are ignored*

Many authors have discussed:

- Relationships between D and GAF [TS67,Ash00,SB,Heitz,etc.]
- Energy conservation with specular microfacets [Kel01,TVCG17]
- Multiple scattering [Heitz,TVCG17]

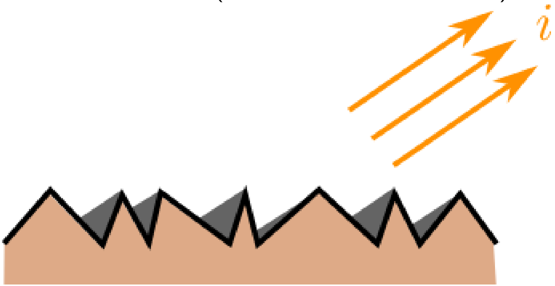
Microfacet Representation

- Playing with f^{μ} offers a large panel of different materials.

Microfacet Representation

- Playing with f^{μ} offers a large panel of different materials.
- Geometrical Attenuation Factor (GAF).

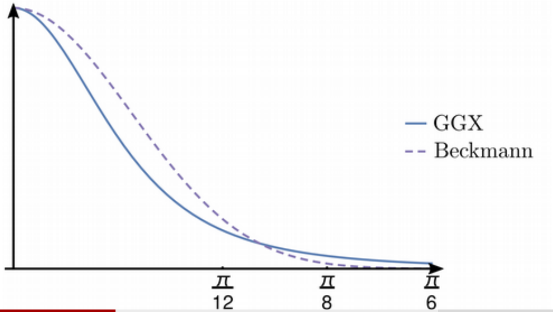
Torrance-Sparrow (V-cavity profile)
Smith-Bourlier (Uncorrelated microfacets)



Microfacet Representation

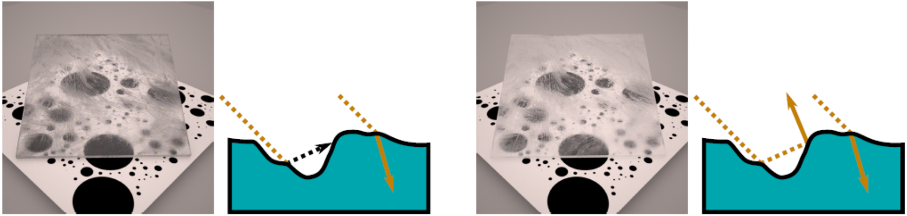
- Playing with f^{μ} offers a large panel of different materials.
- Geometrical Attenuation Factor (GAF).
- Normal Distribution Functions.

Beckmann distribution
GGX or Trowbridge-Reitz



Microfacet Representation

- Playing with f^{μ} offers a large panel of different materials.
- Geometrical Attenuation Factor (GAF).
- Normal Distribution Functions.
- Multiple scattering between microfacets.

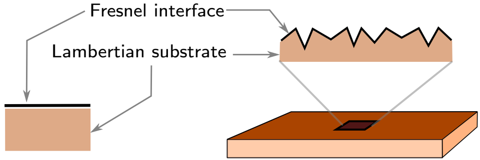


(image from [Heitz16])

Interfaced Lambertian (IL) Model [TVCG17]

Several observations can be made:

- The glossy term increases according to incidence angle
- Thus, a constant Lambertian term is not adapted to energy conservation
- Solution: Rough Lambertian background covered with a flat Fresnel interface



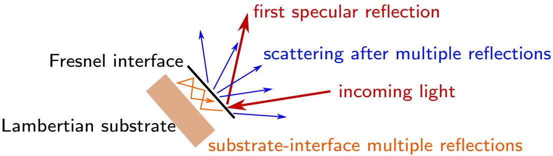
Lambertian interfaced single microfacet

Lambertian interfaced microfacet distribution

Light transmission at interface
Multiple scattering under interface

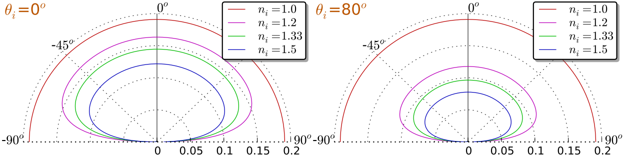
$$\frac{1}{\pi n_i^2} T(\mathbf{i},\mathbf{m}) T(\mathbf{o},\mathbf{m}) \frac{K_d}{(1 - K_d r_i)},$$

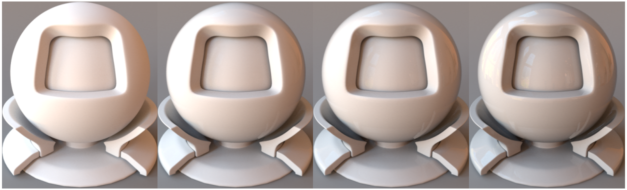
r_i for multiple scattering (analytical cf. [TVCG17])



Flat IL Material

- Flat surface: Analytical representation, including multiple light scattering
- Body term decreases according to incidence angles, and specularity
- Decreases also at grazing observation angles





$n_i = 1$ $\quad$ $n_i = 1.2$ $\quad$ $n_i = 1.33$ $\quad$ $n_i = 1.5$

Rough IL Material

The general BRDF equation should be integrated, with:

$$f(\mathbf{i},\mathbf{o},\mathbf{n}) = \int_{\Omega_+} \frac{|\mathbf{im}|}{|\mathbf{in}|} \left[f_s^{\mu}(\mathbf{i},\mathbf{o},\mathbf{m}) + f_b^{\mu}(\mathbf{i},\mathbf{o},\mathbf{m}) \right] \frac{|\mathbf{om}|}{|\mathbf{on}|} D(\mathbf{m}) G(\mathbf{i},\mathbf{o},\mathbf{m}) d\omega_m \quad (3)$$

- The first integral corresponding to f_s corresponds to the glossy term

$$f_s(\mathbf{i},\mathbf{o},\mathbf{n}) = \frac{F(\mathbf{i},\mathbf{m}) D(\mathbf{m}) G(\mathbf{i},\mathbf{o},\mathbf{m})}{4|\mathbf{in}||\mathbf{on}|},$$

- The second term f_b has no analytical solution

Monte Carlo for the rendering Equation:

$$L_o(x,\mathbf{o},\mathbf{n}) = L_e(x,\mathbf{o},\mathbf{n}) + \int_{\Omega_+} L_i(x,\mathbf{i},\mathbf{n}) f(\mathbf{i},\mathbf{o},\mathbf{n}) |\mathbf{in}| d\omega_i, \quad (4)$$

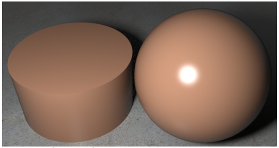
where f is given by Equation 3, which includes

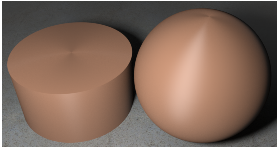
$$f_b^{\mu}(\mathbf{i},\mathbf{o},\mathbf{n}) = \frac{1}{\pi n_i^2} T(\mathbf{i},\mathbf{m}) T(\mathbf{o},\mathbf{m}) \frac{K_d}{(1 - K_d r_i)} \quad (5)$$

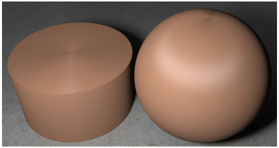
Rough IL Material

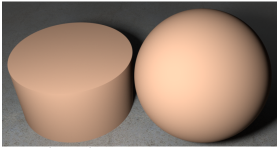
Solution: use Monte Carlo process again.

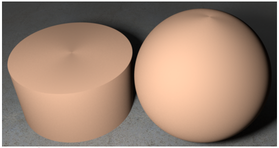
- Importance sampling of one microfacet for the body term
- Slightly increases noise (since increases integral dimension)
- But allows to handle multiple scattering between microfacets [Heitz16,TVCG17]


isotropic $n_i = 1.5$, $\sigma = 0.1$


aniso. $n_i = 1.5$, $\sigma_x = 0.2$, $\sigma_y = 0.6$


aniso. $n_i = 1.5$, $\sigma_x = 0.6$, $\sigma_y = 0.2$


isotropic $n_i = 1.0$, $\sigma = 0.1$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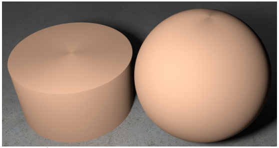

aniso. $n_i = 1.0$, $\sigma_x = 0.6$, $\sigma_y = 0.2$

$\Rightarrow$ *Inherently accounts for anisotropy, given anisotropic distributions*

Appearance

General model, accounts for:

- Flat Lambertian ($\sigma = 0.0, n_i = 1.0$)
- Rough Lambertian ($n_i = 1.0$), with backscattering
- Rough dielectric mirrors ($K_d = 0.0$)
- Rough interfaced Lambertian (general case)

$\Rightarrow$ *Illustrated on next slide*

An approximate model is proposed in [TVCG17], with:

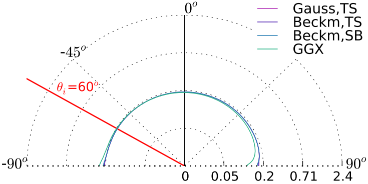
- Beckmann and Gauss distributions
- Torrance-Sparrow's GAF

$\Rightarrow$ *Makes it possible to use with interactive applications and fitting*

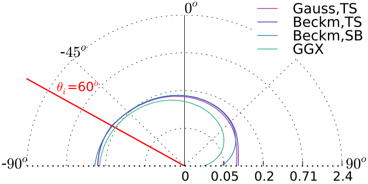
Note that:

- Surface and substrate roughnesses are the same
- Light scattering between microfacets should be handled

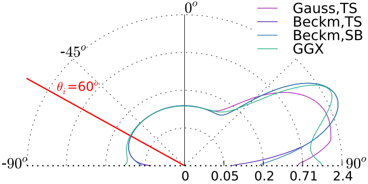
IL BRDF lobes



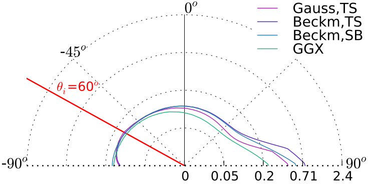
(a) $n_i = 1.0, \sigma = 0.1$



(b) $n_i = 1.0, \sigma = 0.6$



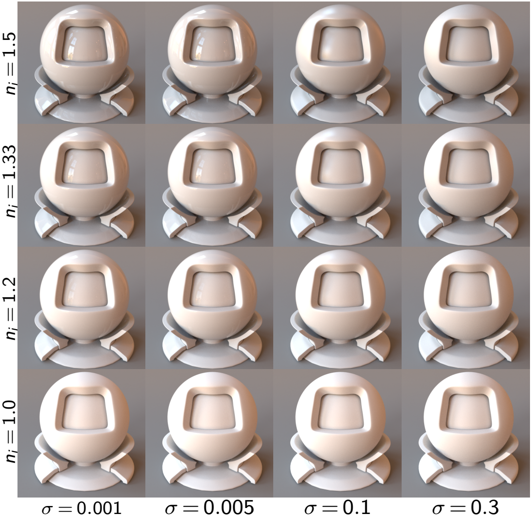
(c) $n_i = 1.5, \sigma = 0.1$



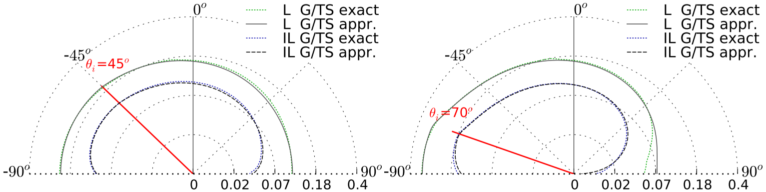
(d) $n_i = 1.5, \sigma = 0.6$

Distributions and GAFs for various values of n_i and σ, illustrated at $\theta_i = 60^o$ (log scale).

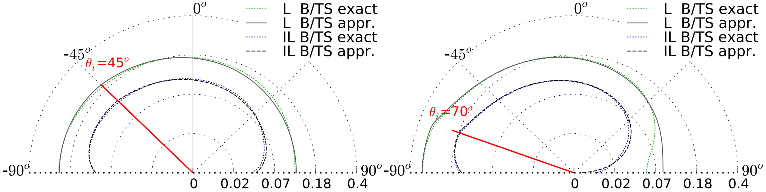
With Beckmann Distribution and Smith GAF



IL BRDF lobes: approximate model



(a) Gaussian distribution, with $n_i = 1.5$ and $\sigma = 0.6$



(b) Beckmann distribution, with $n_i = 1.5$ and $\sigma = 0.6$

Comparison between Monte Carlo BRDF estimation of Lambertian (L) and interfaced Lambertian (IL) materials and our approximate model, with Gaussian (G) and Beckmann (B) distributions, and Torrance-Sparrow (TS) GAF (log scale).

Discussion

- Management of metals (conductors) ?
  ⇒ *Nothing new [CT82], since almost no transmission*

- Generalization of approximate models ?
  ⇒ *much more complicated...*
  ⇒ *Approximation relies on both D and G*
  ⇒ *Our method extends [ON94], based on Gaussian/Beckman distributions*

- Generalization of distribution and GAF
  - Many existing distributions
  - Without analytical GAF and/or analytical importance sampling
    ⇒ *This presentation provides some results with STD (next slides)*

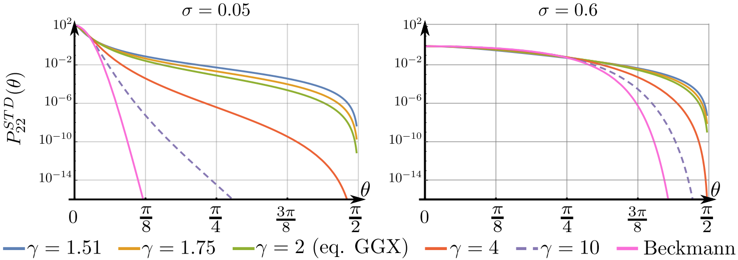
- Management of light scattering between microfacets
  - Two existing contributions: [Heitz16] with SB GAF; [TVCG17] with TS GAF
  - Path tracing implementation
    ⇒ *Both applied to STD and IL in this presentation*

Student's T-Distribution

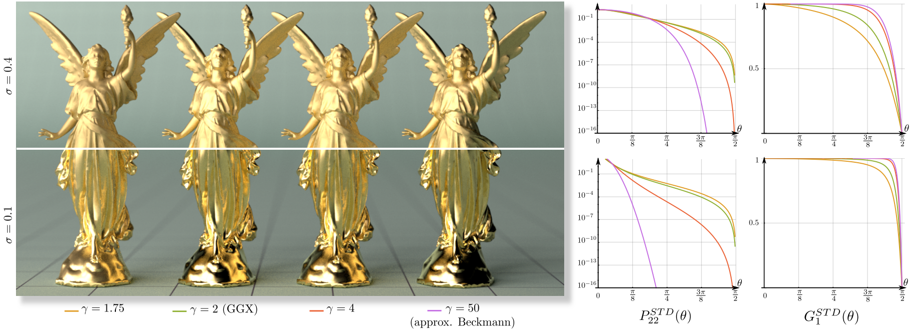
Introduced at EG 2017 [EG17]:

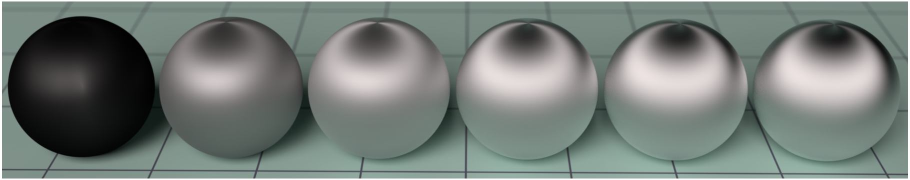
$$D^{STD}(m) = \frac{(\gamma - 1)^\gamma \sigma^{2\gamma - 2}}{\pi \cos^4 \theta_m \left((\gamma - 1)\sigma^2 + \tan^2 \theta_m\right)^\gamma} \quad (6)$$

- Inspired from GTR (Generalized Towbridge Reitz) [TR75,Walter07]
- Includes both GGX and Beckmann's distributions
- With analytical GAF formulation following the Smith's formulation
- With analytical importance sampling



Influence on appearance

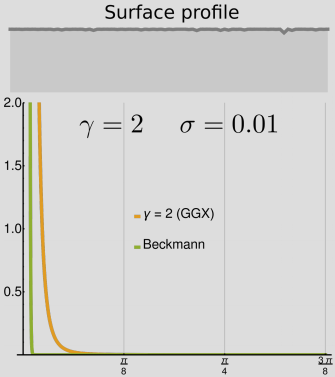




$\Rightarrow$ *Anisotropy also handled (rough aluminium in this case)*

Influence on appearance

Visual impact of STD



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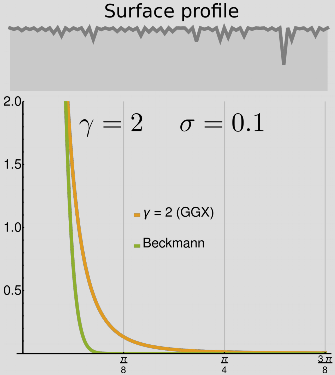

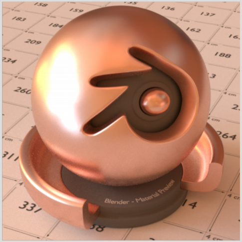

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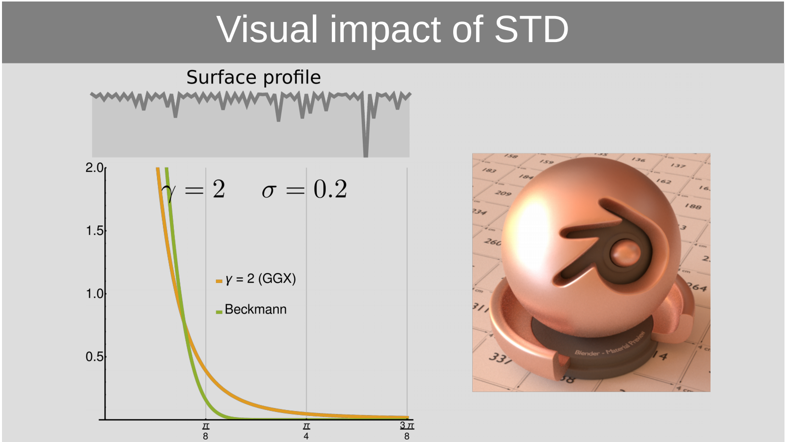

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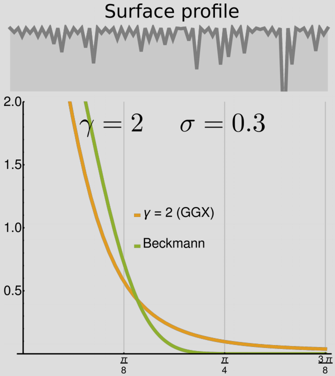

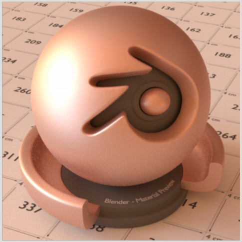

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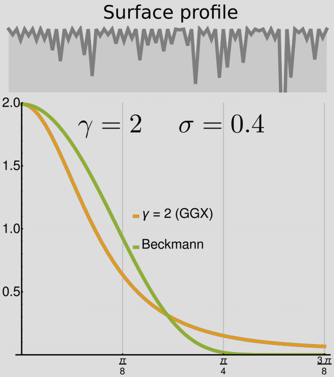

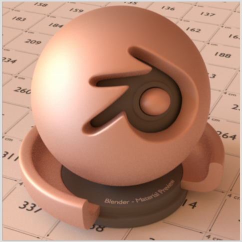

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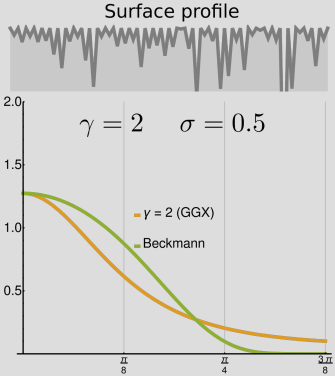

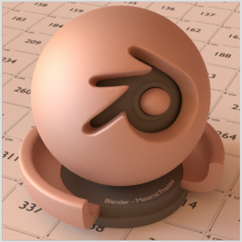

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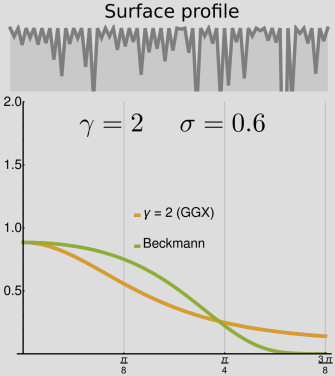

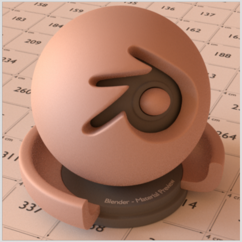

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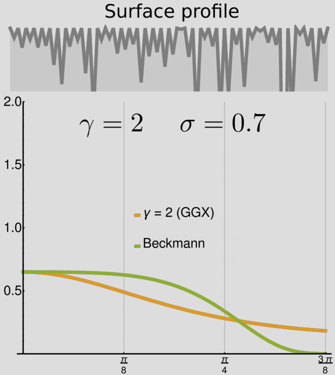

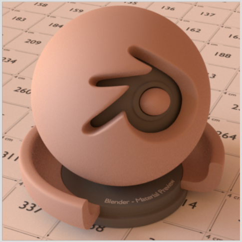

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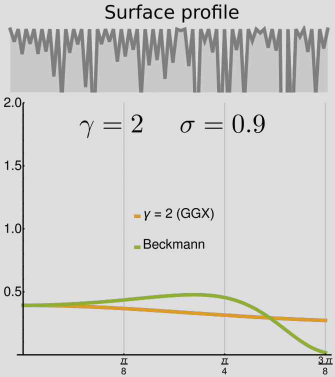

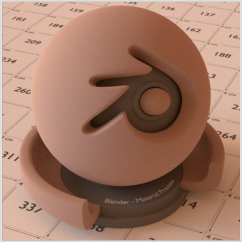

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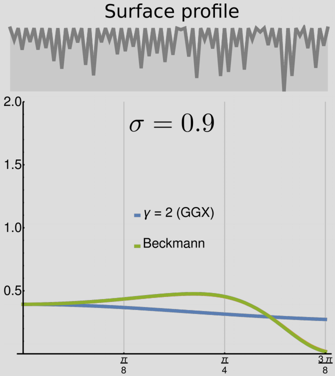

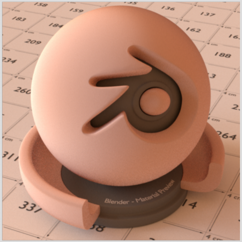

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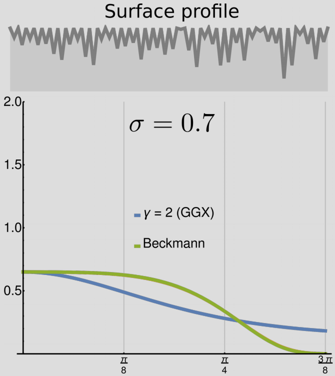

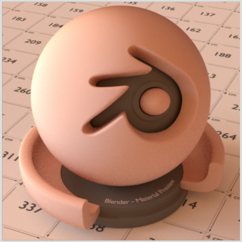

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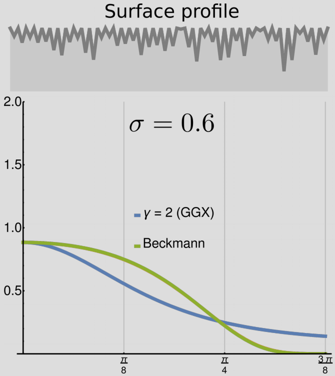

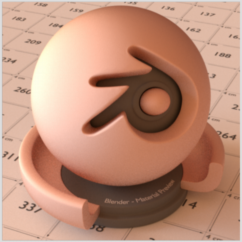

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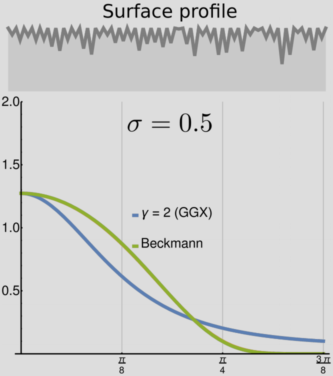

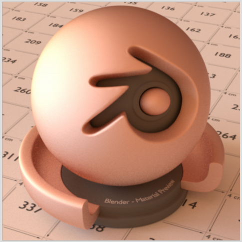

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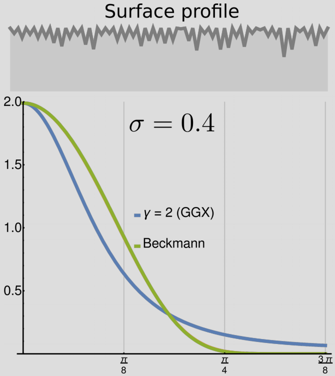

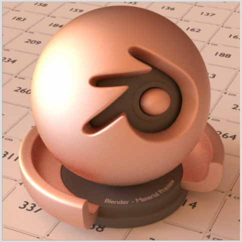

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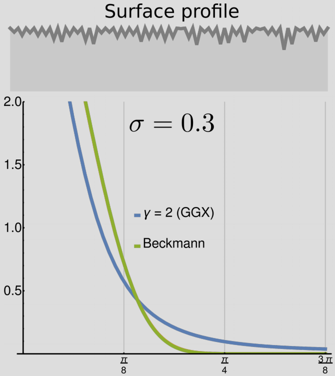
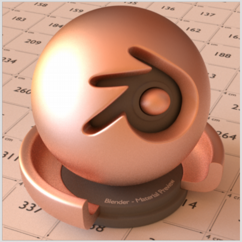
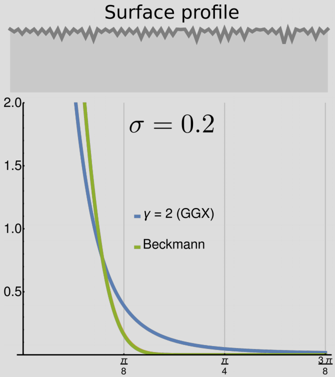
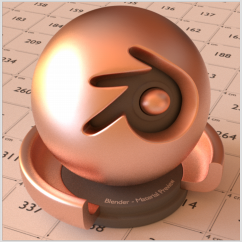




Influence on appearance

Visual impact of STD





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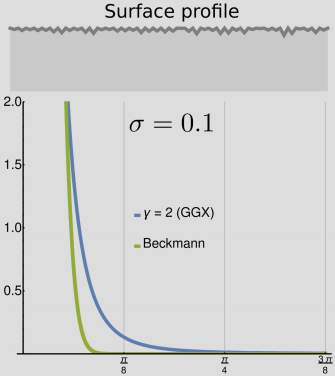

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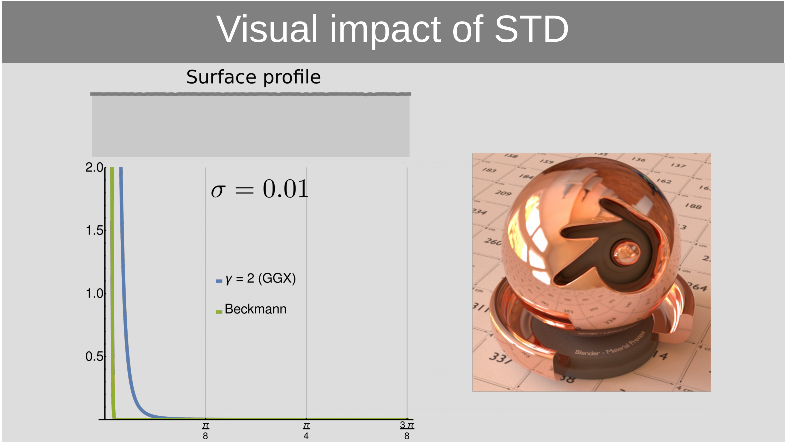

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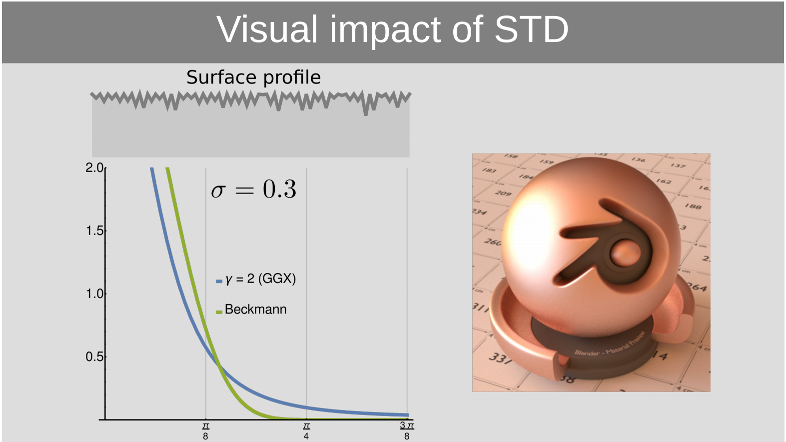

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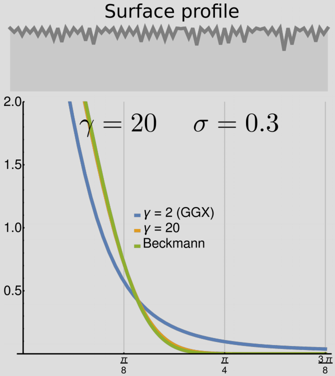

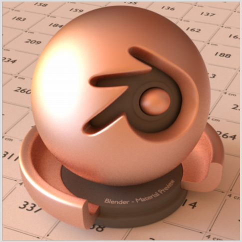

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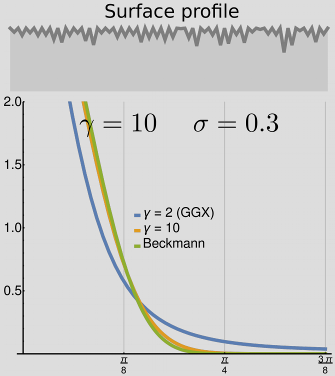

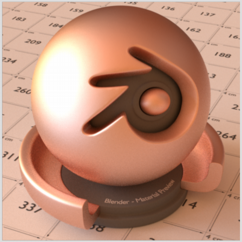

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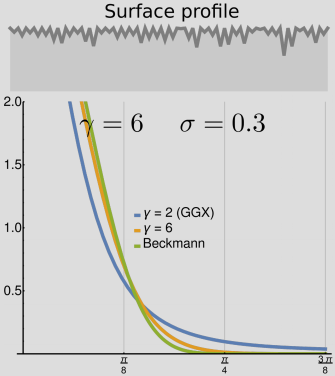

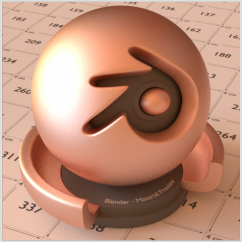

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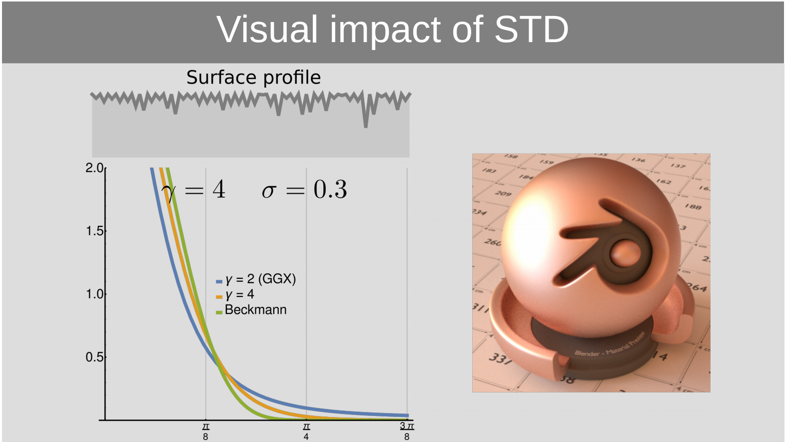

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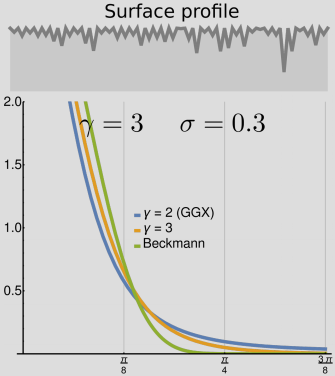

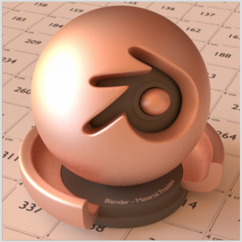

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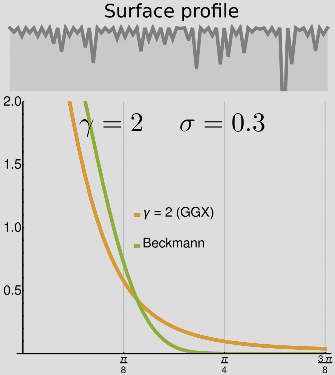

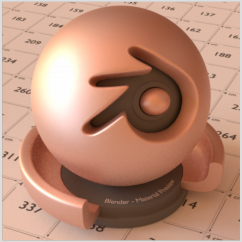

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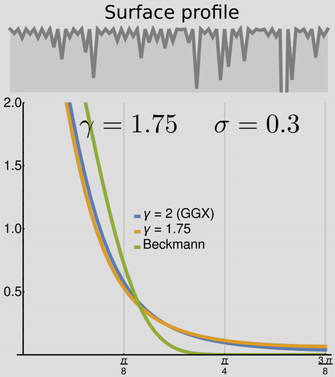

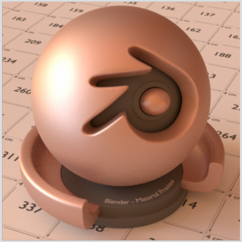

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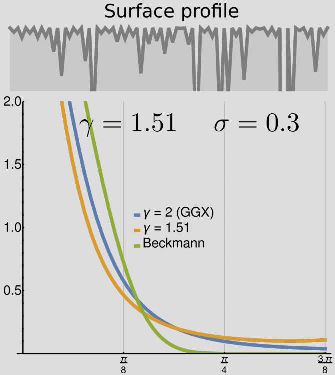
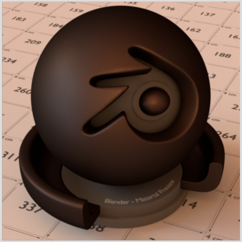


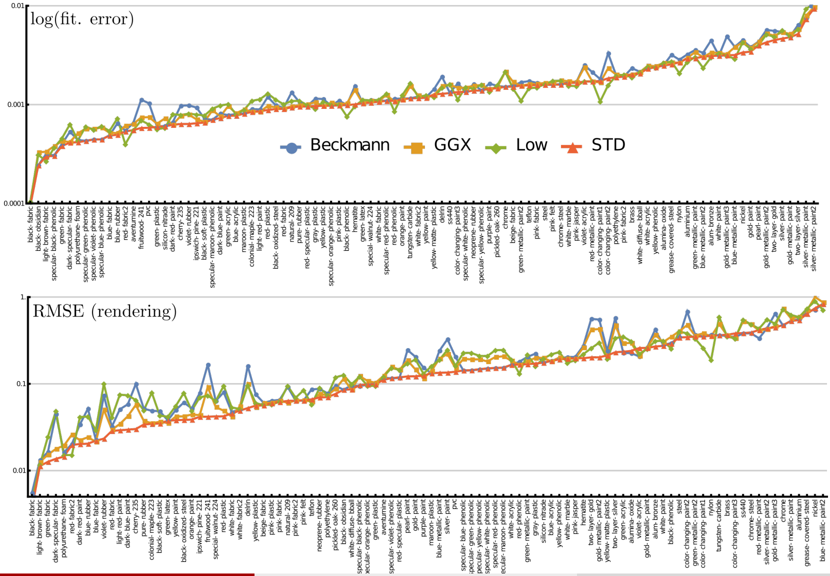


Discussion

Advantages of STD:

- Accurate control of roughness
- Interesting use for fitting (combines the advantages of GGX and Beckmann)

Fitting with STD



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- Accounts for a physical representation of body scattering
- Combines advantages of both
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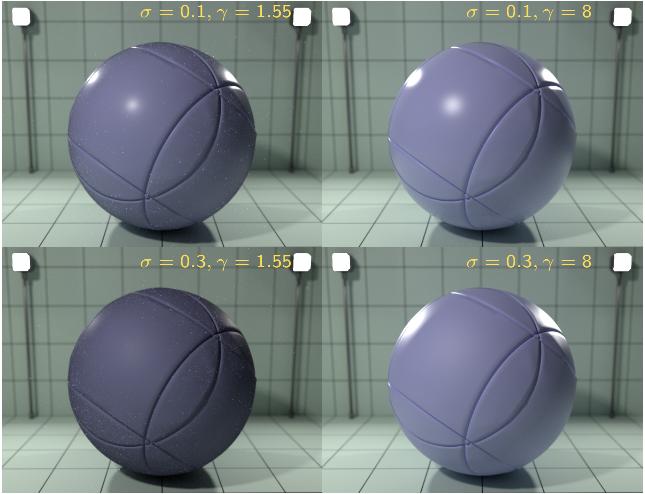
Implementation issues:

- Does not make any difference for IL
- Possible to include the combination in any Monte Carlo rendering system
- Also possible to handle multiple scattering

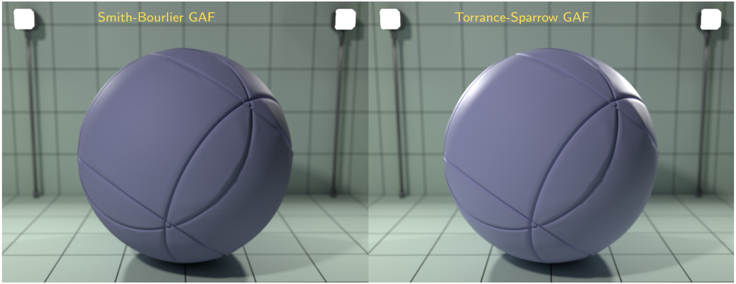
Influence on appearance

According to γ, with two different roughnesses σ (Smith GAF with $n_i = 1.5$):



Influence on appearance

When changing GAF ($\gamma = 1.75$, $n_i = 1.5$ and $\sigma = 0.7$):

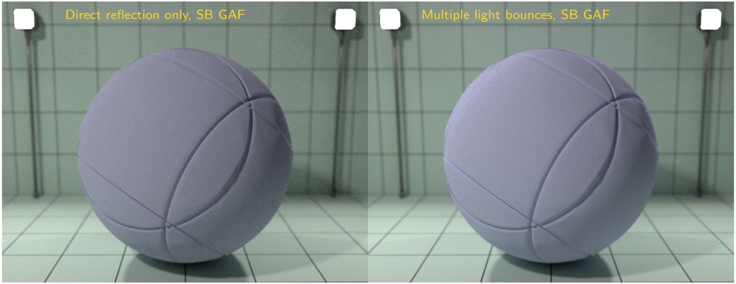


For grazing observation angles:

- Torrance-Sparrow's GAF tends to overestimate gloss [Heitz14]
- Glossy effects remain high despite increasing roughness

Influence on appearance

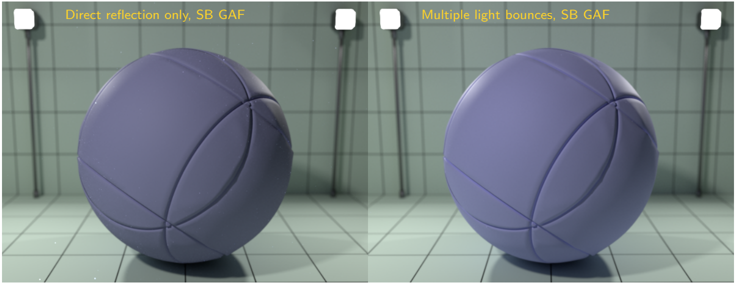
Comparisons with and without multiple scattering between microfacets:



- Rough Lambertian ($n_i = 1.0$)
- $\gamma = 8, \sigma = 0.7$
- Smith-Bourlier GAF

Influence on appearance

Comparisons with and without multiple scattering between microfacets:



- Interfacet Lambertian microfacets ($n_i = 1.5$)
- $\gamma = 1.75, \sigma = 0.5$
- Smith-Bourlier GAF

Conclusion and Future Work

STD with interfaced Lambertian microfacets:

- Physically based model
- Management of specular and body reflections
- Only few parameters
- Extends the range of rendered materials

Future work:

- Better STD importance sampling
  $\Rightarrow$ *What about Visible Normals Importance Sampling?*
- In depth fitting analysis
- Correlation between the interface and the substrate roughness in IL
- Any other idea ?