Visual appearance of industrial surfaces: *Haze and gloss*

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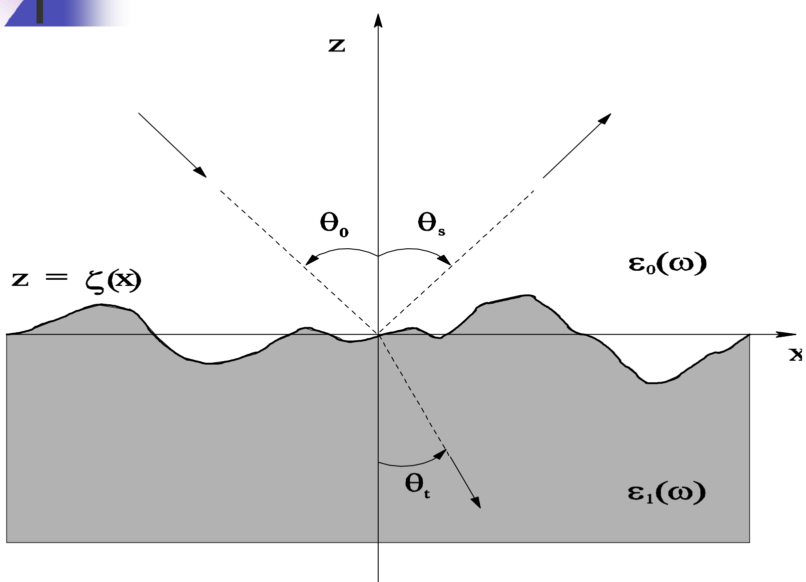
Motivation

- The industry quantifies the visual appearance of optical materials (*e.g.* haze and gloss)
- Materials are categorized according to their visual appearance and functional properties
  - Eg. reflector materials, food wrappings
- Science *does not* seem to "provide" the relevant quantities
  - the industry seems to use **haze** and **gloss** for this purpose
  - these quantities are not uniquely defined (industrial standards)

Plastic materials

Scattering Geometry



$q =$

σ	rms-roughness
a	correlation length

$$q = \sqrt{\varepsilon_m}\,\frac{\omega}{c}\sin\theta$$

$$\alpha_m(q) = \sqrt{\varepsilon_m \frac{\omega^2}{c^2} - q^2}$$

- Statistical description:
  - Height distribution
  - Correlation function: W

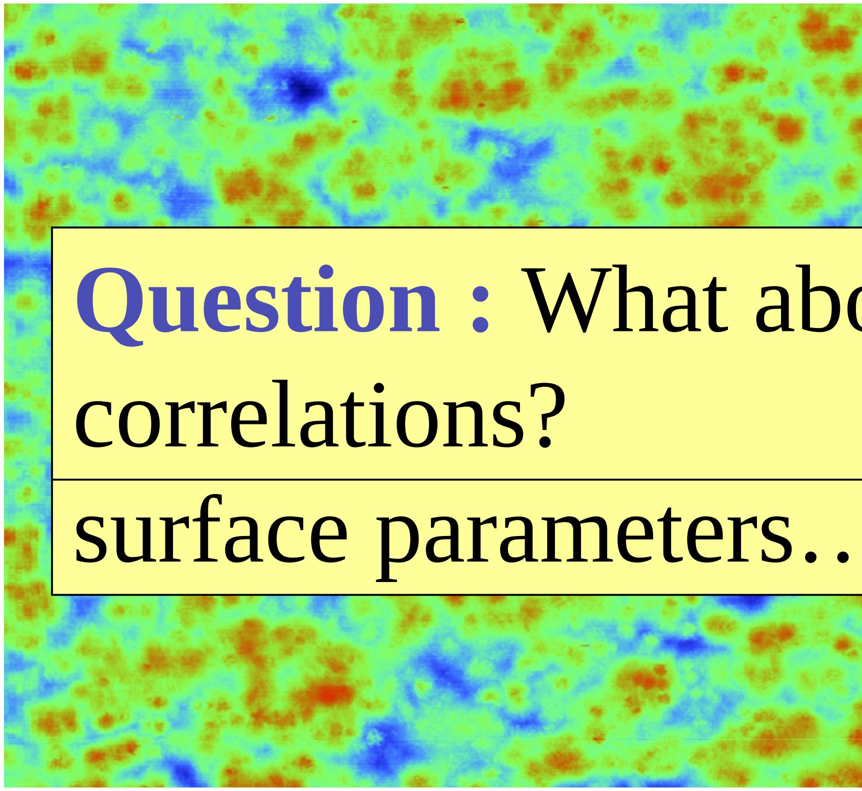
$$\langle \varsigma(x) \rangle = 0$$

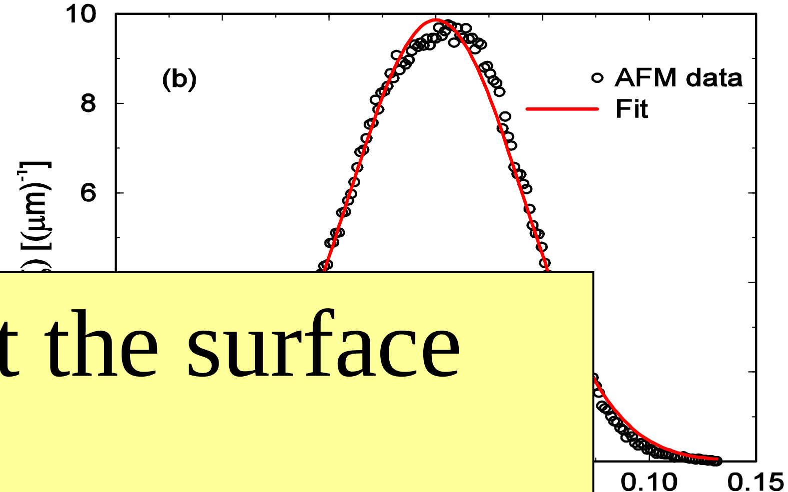
$$\langle \varsigma(x)\varsigma(x') \rangle = \sigma^2 W\left(|x - x'| \right)$$

- Power spectrum

$$g\left(|k| \right) = \int dx\, W\left(|x| \right) e^{ikx}$$

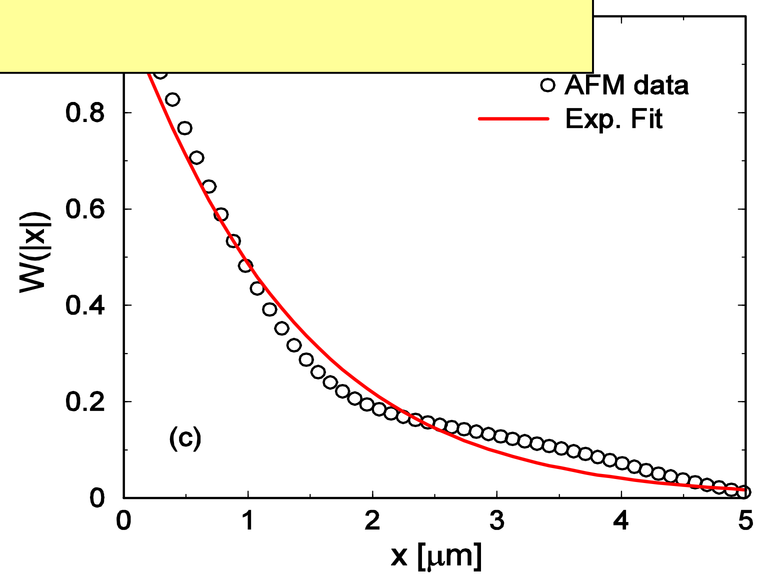
Example : Plastic material (LLDPE)





Question : What about the surface correlations?

surface parameters…?

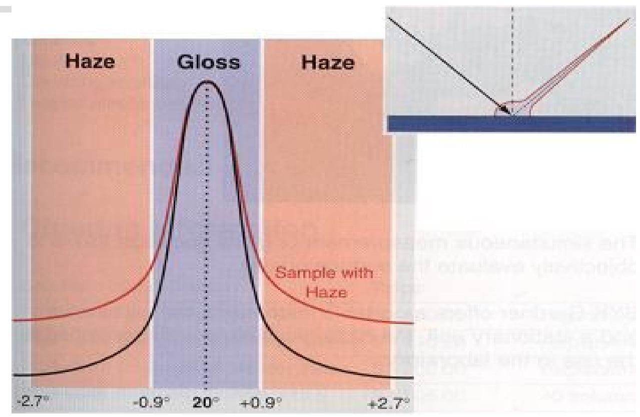


$$\sigma \approx 0.04\,\mu m$$

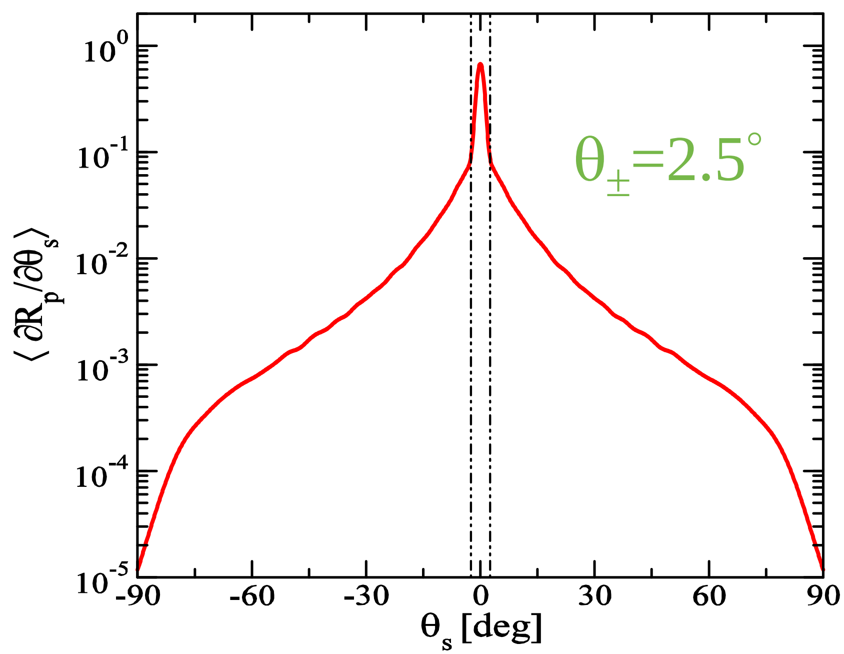
$$a \approx 1.3\,\mu m$$

Definitions : Haze and gloss

- No scientific definition exists
- Industrial standards
  - Gloss/haze meters
  - Reference material used
  - Different standards in eg. America and Europe
  - Wide- and narrow-angle gloss



- **Haze** measures how diffuse a material is
- **Gloss** measures how speckular it is



Definitions : Haze and gloss (cont.)

Haze (gloss) are defined as the fraction of the reflected/transmitted power that is reflected/transmitted outside(inside) an angular interval $\Delta\theta$ about the speckular direction.

- Simple considerations gives (diffuse field)

$$H(\theta_0) \propto \sigma^2 k^2$$

- Question : But how does haze depend on the height-height correlations along the surface?

Ref : Alexander-Katz and Barrera (1998).

Approximation to Haze

- Phase-perturbation theoretical result

$$H(\theta_{\cdot}) \approx 1 - \exp\left\{ -\sigma^2 \Lambda^2(k|k) \left(1 - G(a)\Delta q \cdots \right) \right\}$$

Question :

How good is this approximation?

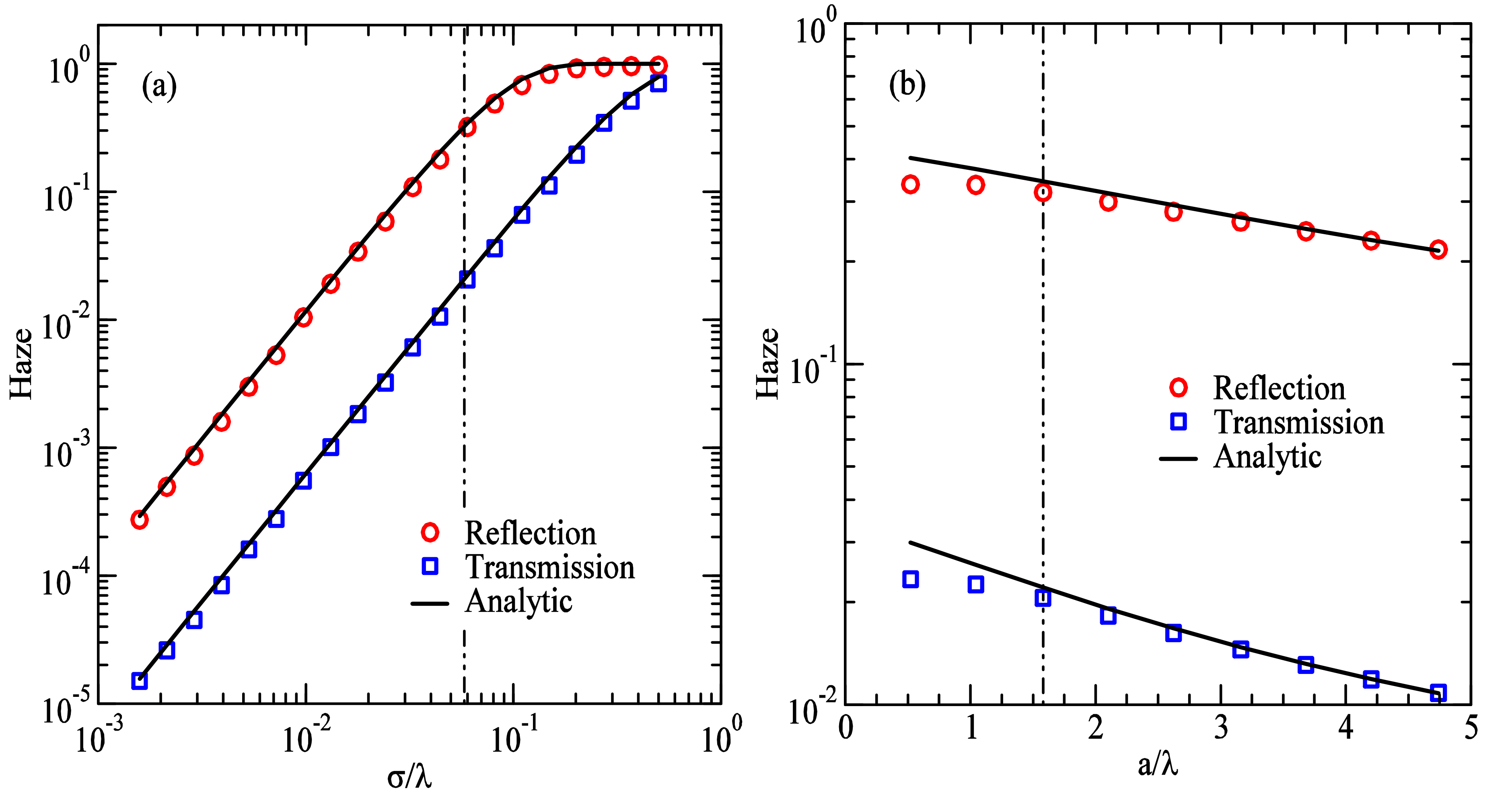
Power spectrum factor $\quad G(a) = \dfrac{1}{2\,\Delta q} \displaystyle\int_{-\Delta q}^{\Delta q} dq\, g\left(|q|\right)$

Momentum transfer : $\Lambda(k|k)$ (perpendicular); Δq (lateral)

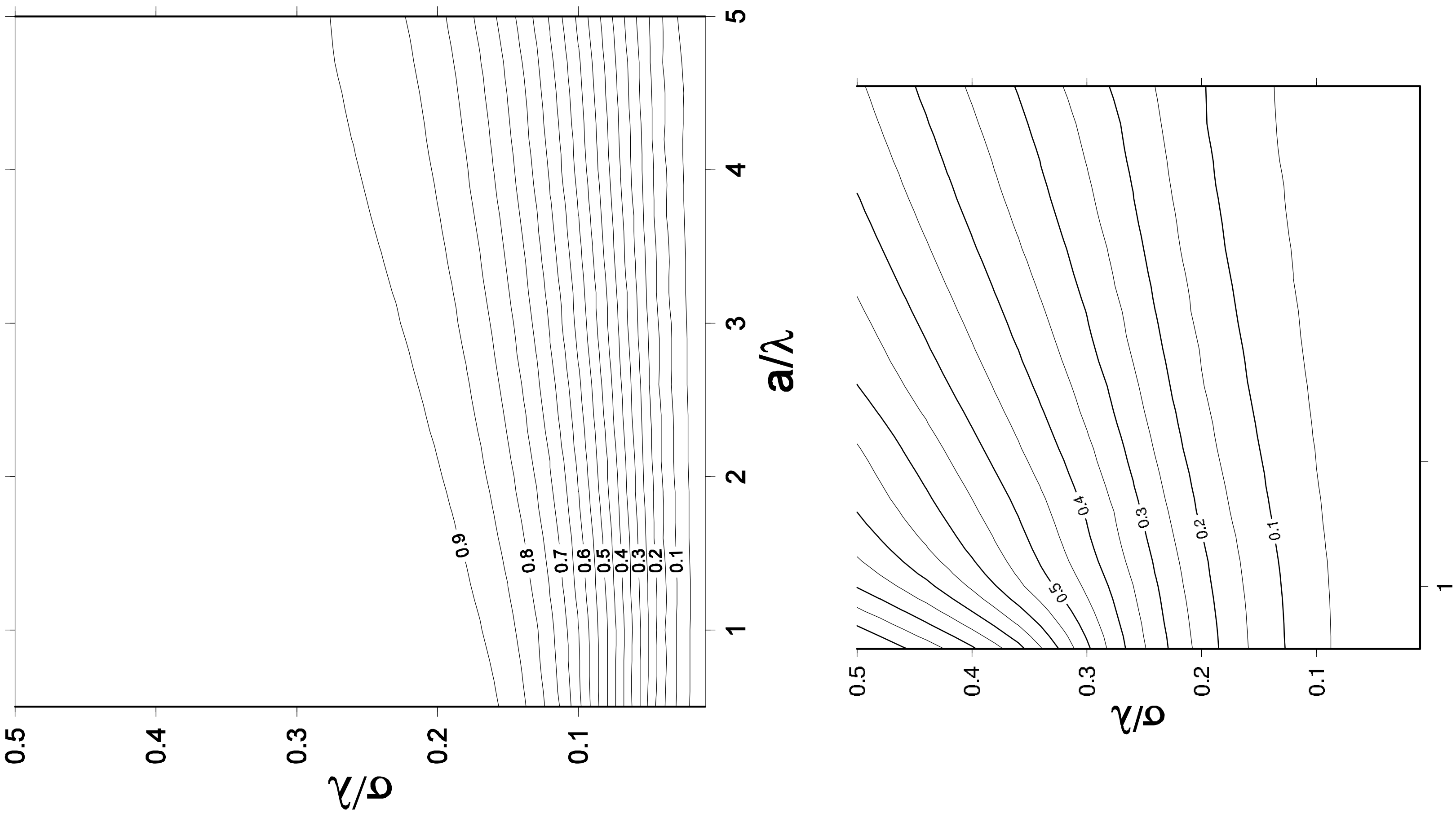
Reduced variables : $\sigma\Lambda(k|k)$ and $G(a)\Delta q$

Haze : Numerical results

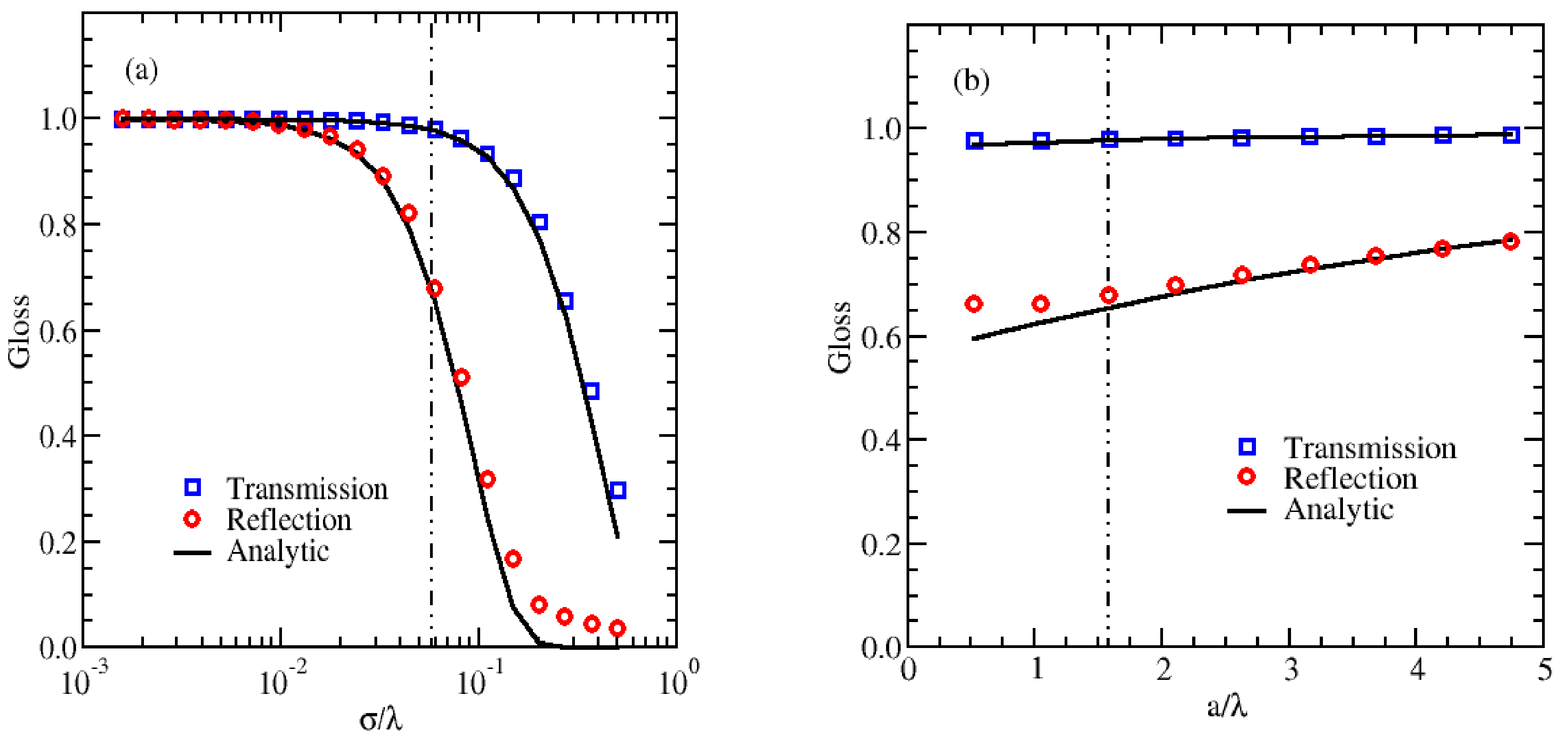
- Comparison to rigorous Monte Carlo simulations:



Haze : Numerical results (cont…)



Gloss : Numerical Results



Experimental results

- Measured haze of the plastic material discussed earlier

$$H(\theta_0 = 0) = 0.189$$

- Estimated from the analytic expression using the measured topography data $H_{1D}(0)=0.054$

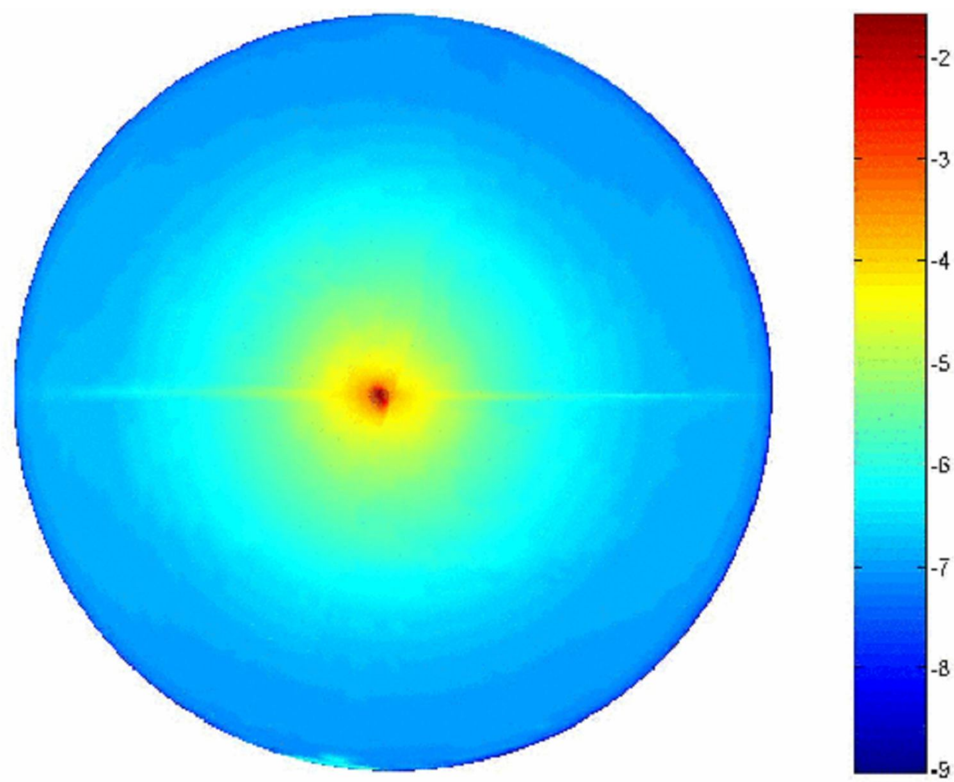
$$H' = \pi H_{1D}(0) = 0.170$$

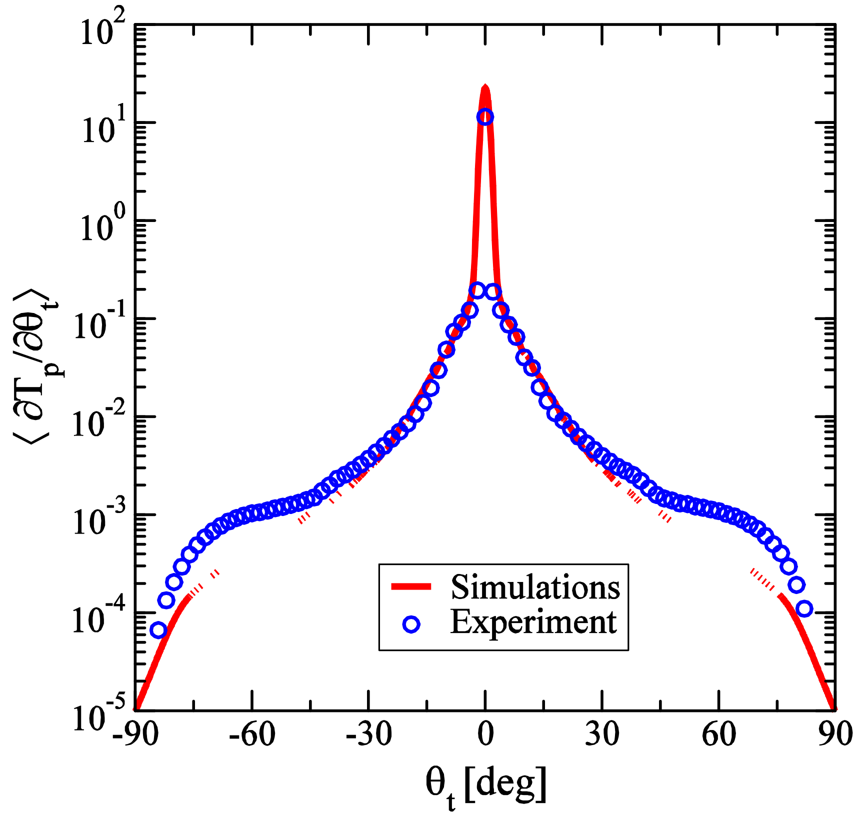
Conclusions

- Within the context of phase perturbation theory, we have derived an expression for haze and gloss
  - in terms of *reduced variables* $\sigma\Lambda(k|k)$ and $G(a)\Delta q$
  - explicitly shows the dependence on the power spectrum $g(|k|)$
- Accessed the accuracy of the approximation
  - good approximation over large regions of parameter space

Thank you for your attention

Scattering results





Measured roughness parameters used!
Film thickness d=50µm

The haze approximation "written out"

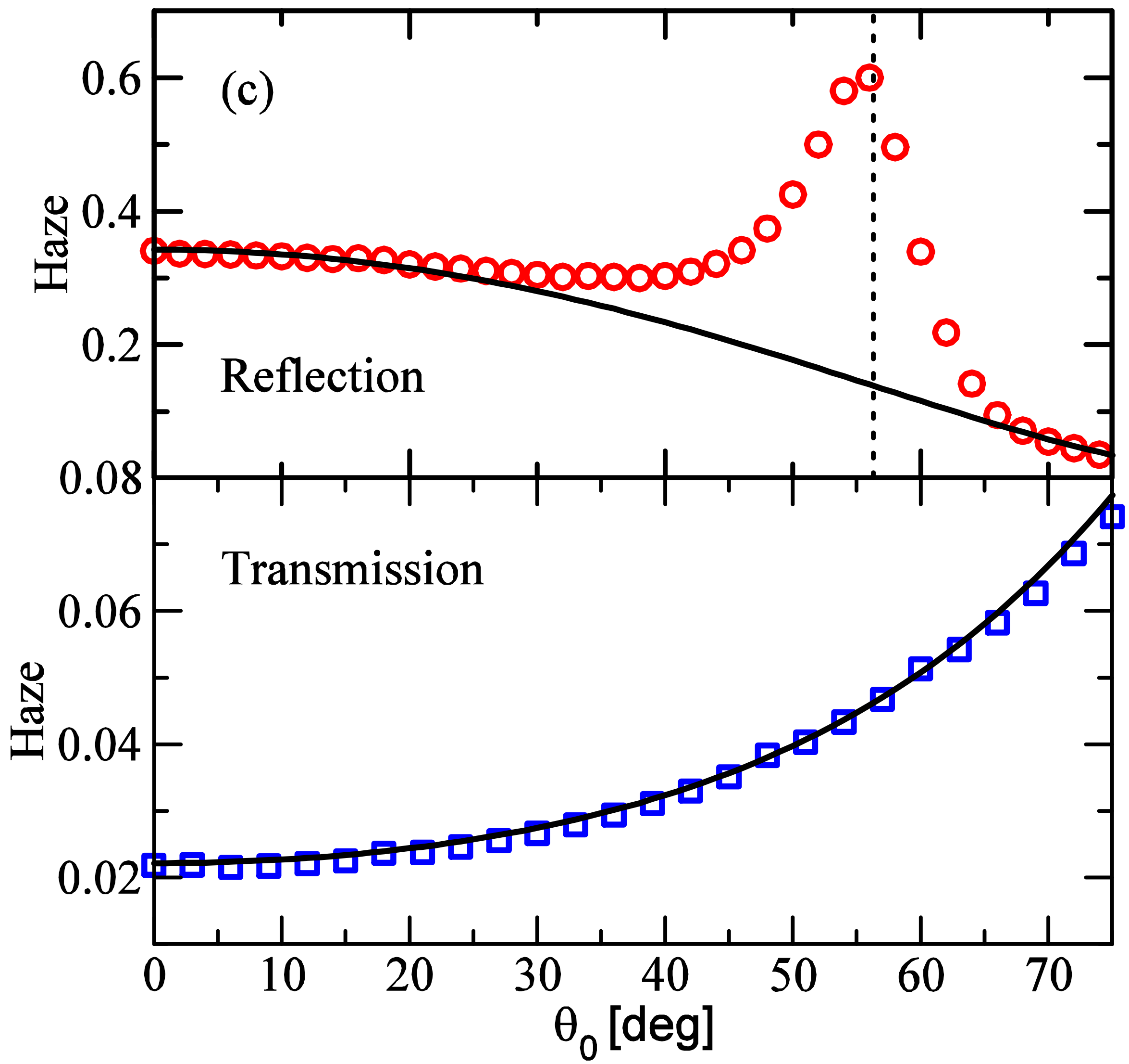
For completeness, the expressions for haze in terms of the "defining" quantities will be explicitly given. With Eqs. (16), (19c) and (24) one has for reflection

$$\mathcal{H}_s(\theta_0) \simeq 1 - \exp\left[-16\pi^2\varepsilon_0\left(\frac{\sigma}{\lambda}\right)^2\cos^2\theta_0\left\{1 - 2\sqrt{\varepsilon_0}\frac{\mathcal{G}(a)}{\lambda}\sin\Delta\theta\cos\theta_0\right\}\right], \tag{29a}$$

while in transmission the haze can be approximated by

$$\mathcal{H}_t(\theta_0) \simeq 1 - \exp\left[-4\pi^2\varepsilon_0\left(\frac{\sigma}{\lambda}\right)^2\left\{\sqrt{\frac{\varepsilon_1}{\varepsilon_0} - \sin^2\theta_0} - \cos\theta_0\right\}^2\left\{1 - 2\sqrt{\varepsilon_1}\frac{\mathcal{G}(a)}{\lambda}\sin\Delta\theta\sqrt{1 - \frac{\varepsilon_0}{\varepsilon_1}\sin^2\theta_0}\right\}\right]. \tag{29b}$$

In obtaining Eq. (29b) it has been used that for the specular direction (in transmission) $\cos\Theta_t = \sqrt{1 - (\varepsilon_0/\varepsilon_1)\sin^2\theta_0}$.



(c)
Reflection
Transmission
Haze
Haze
0.6
0.4
0.2
0.08
0.06
0.04
0.02
0
10
20
30
40
50
60
70
θ0 [deg]