DANISH NATIONAL SPACE CENTER

THE DANISH NATIONAL SPACECENTER IS A RESEARCH CENTER UNDER THE MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION

# Small d-spacing WC/SiC multilayers for future hard x-ray telescope designs

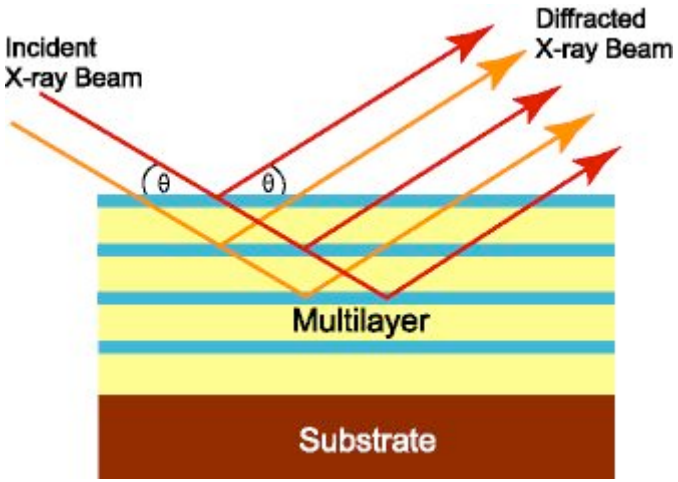
**C. P. Jensen, K. K. Madsen, F. E. Christensen**

**Danish National Space Center, Copenhagen, Denmark**

# Outline

- Reflectivity scans for WC/SiC
- Transverse scans WC/SiC
- Discuss optical constants for WC and SiC
- Telescopes up to 250 keV

# Multilayers

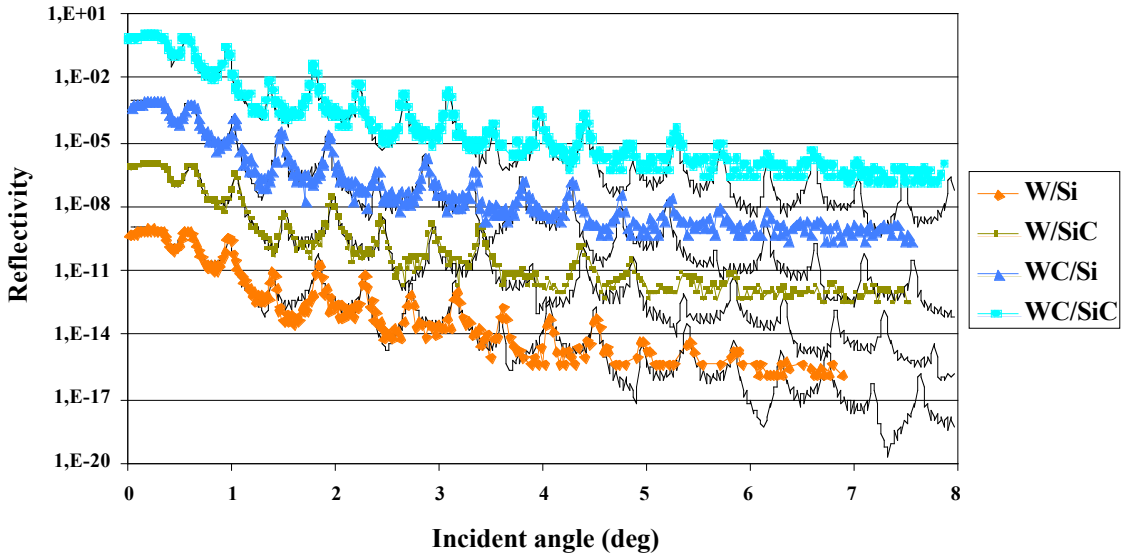



**Diffuse interface**

**Sharp rough interface**

DANISH NATIONAL SPACE CENTER

# Reflectivity scan with d-spacings around 9.5 nm




| | d-spacing (nm) | Γ | σ (nm) |
|---|---|---|---|
| W/Si | 9.85 | 0.32 | 0.33 |
| W/SiC | 9.10 | 0.37 | 0.28 |
| WC/Si | 9.35 | 0.41 | 0.28 |
| WC/SiC | 10.05 | 0.37 | 0.23 |

# Scatter

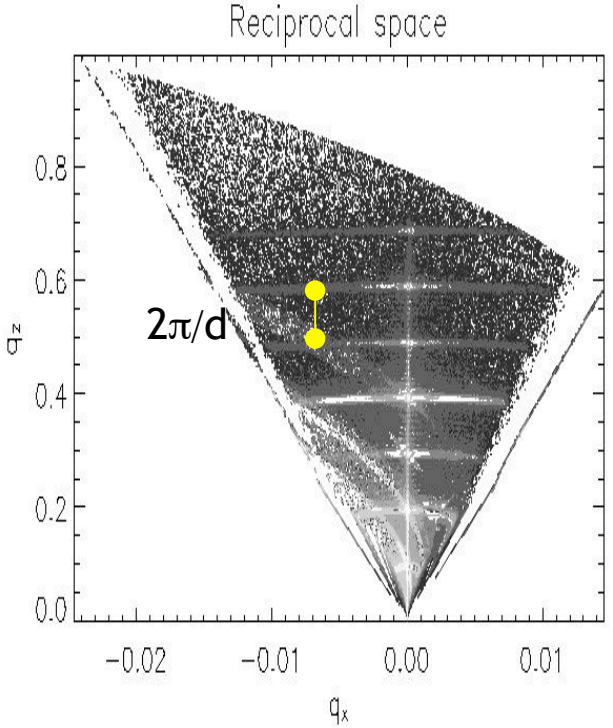
## Distorted Wave Born Approximation

### Roughness correlation:

$$\sigma = \sqrt{\sigma_d^2 + \sigma_r^2}$$

$\sigma_r$ : real roughness

$\sigma_d$: interfacial diffusion




$$\sigma_r = \sqrt{\sigma_{ucorr}^2 + \sigma_{corr}^2}$$

$\sigma_{corr}$ : correlated roughness

$\sigma_{ucorr}$: uncorrelated roughness ; $\sigma_{ucorr} \cong 0$

### Self-affine surface (Sinha *et al*):

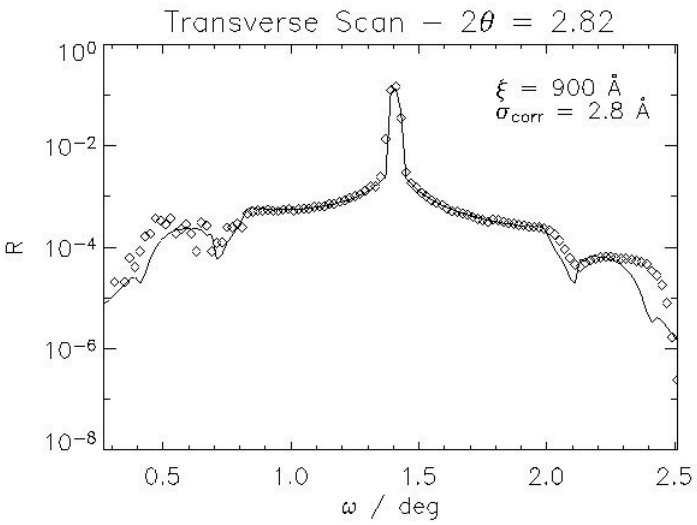
$$\langle h(r-R)\,h(r)\rangle = \sigma_{corr}^2 \exp\left\{-\left(|R|/\xi\right)^{2h}\right\}$$

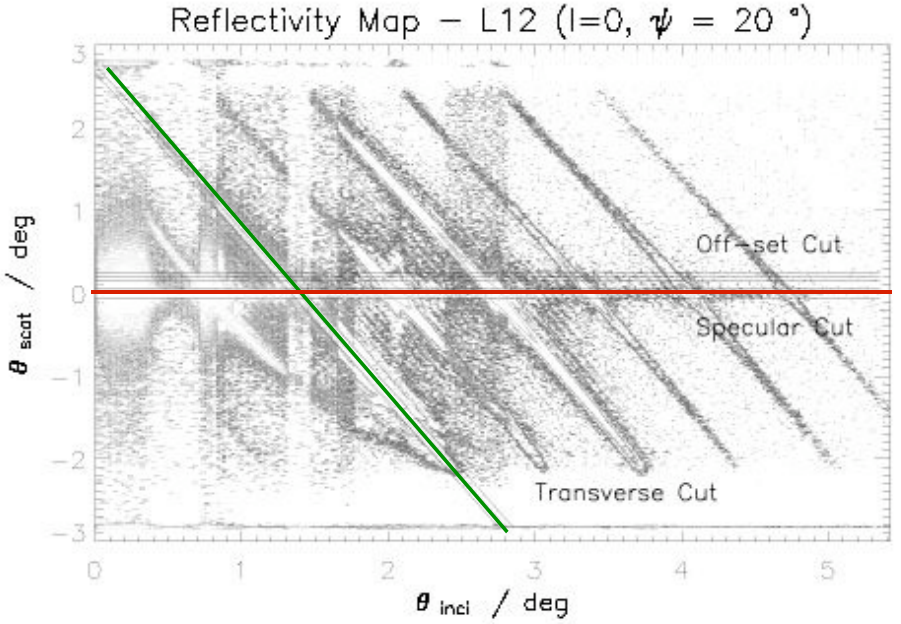
h: fractal exponent $0 < h \leq 1$

$\xi$: correlation length

# Scan types

- **2D-map**
- **Specular scan**
- **Transverse scan**



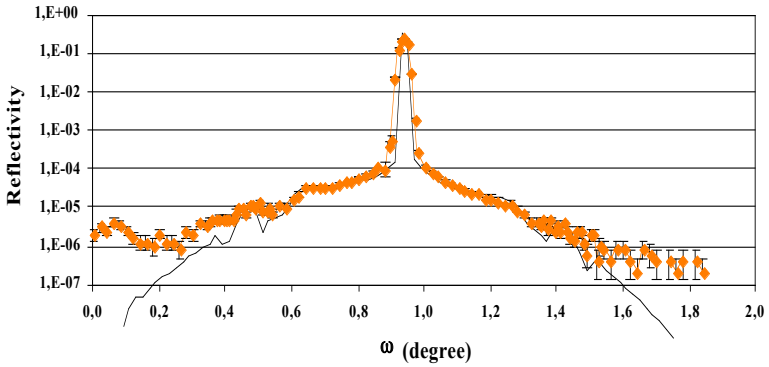



DANISH NATIONAL SPACE CENTER

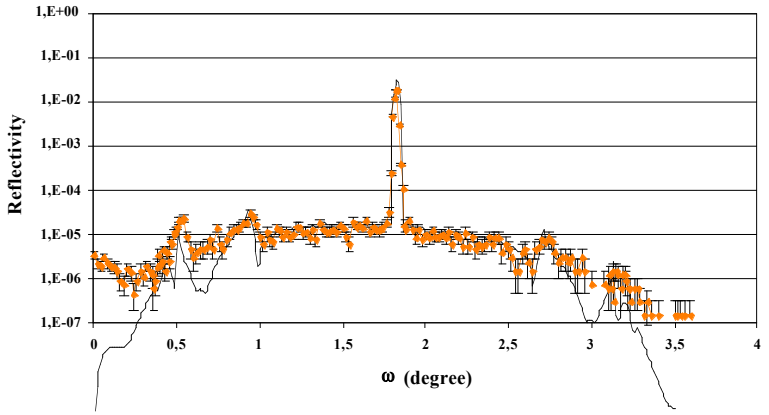
# Transverse scans

| Sample | ????deg | ? (nm ?10) | h (?0.1) | $?_{corr}$ (nm ?0.01) | $?_{d}$ (nm ?0.03) | $??_{corr}^2+?_{d}^2$ (nm ?0.033) |
|---|---|---|---|---|---|---|
| W/Si | 3.6 | 20 | 0.25 | 0.25 | 0.20 | 0.32 |
| W/SiC | 3.9 | 10 | 0.20 | 0.15 | 0.25 | 0.29 |
| WC/Si | 3.9 | 10 | 0.15 | 0.12 | 0.20 – 0.25 | 0.23 – 0.28 |
| WC/SiC | 3.6 | 10 | 0.16 | 0.12 | 0.15 | 0.19 |

**2. order peak for WC/SiC**

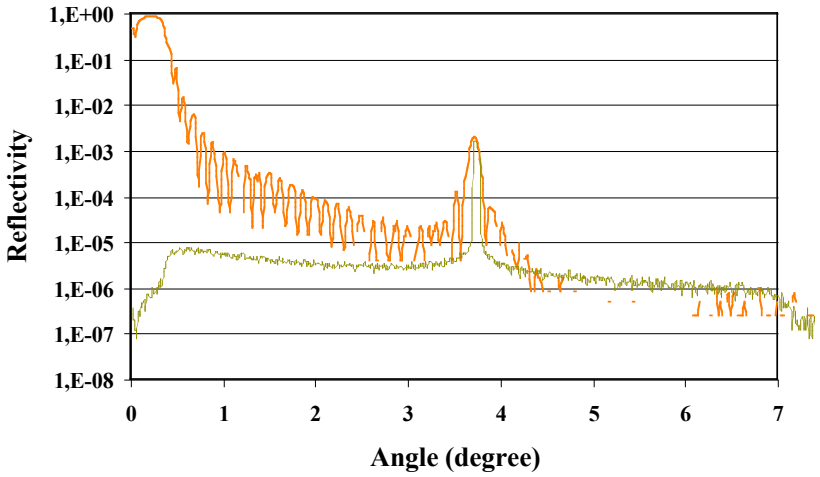



**4. order peak for WC/SiC**

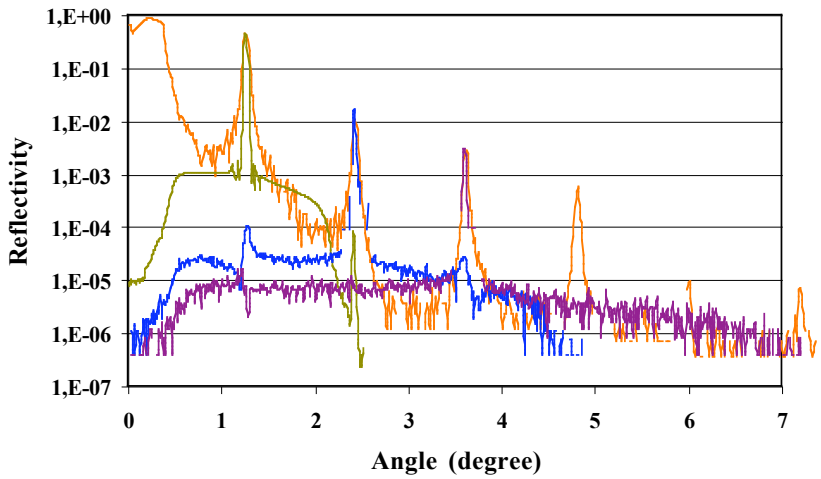


# Specular and transverse scans

**d-spacing 1.19 nm**

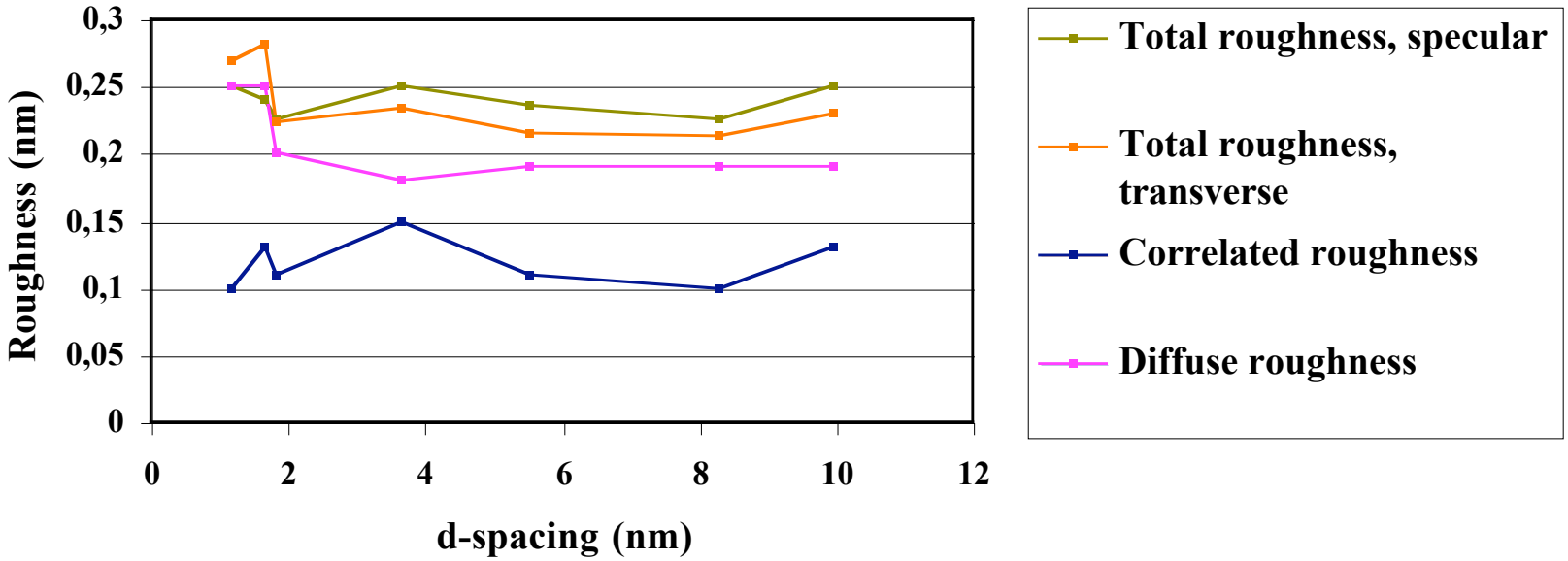



**d-spacing 3,67 nm**



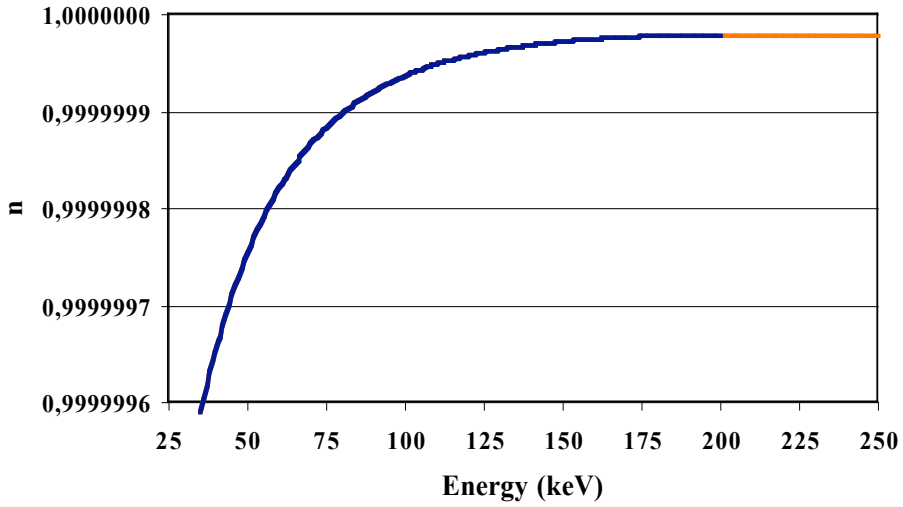
DANISH NATIONAL SPACE CENTER

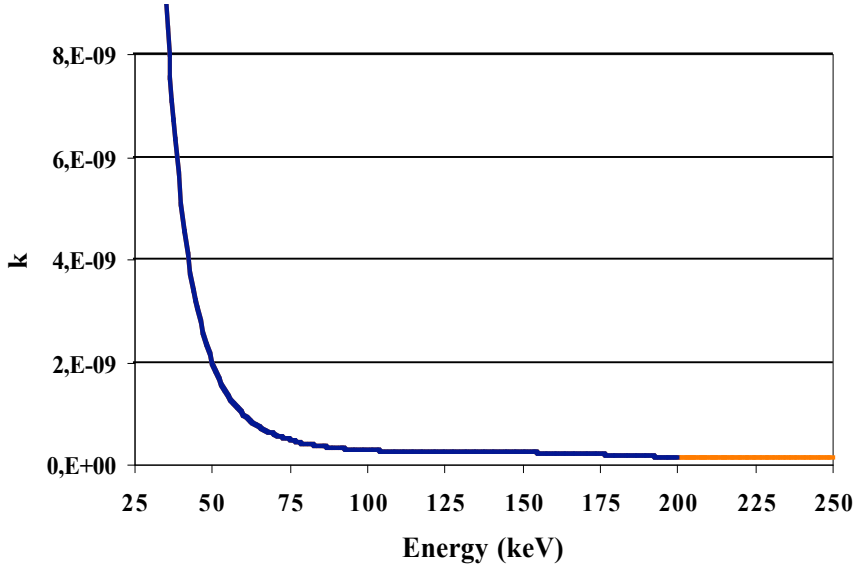
# Roughness for WC/SiC multilayer



DANISH NATIONAL SPACE CENTER

# Optical constants SiC



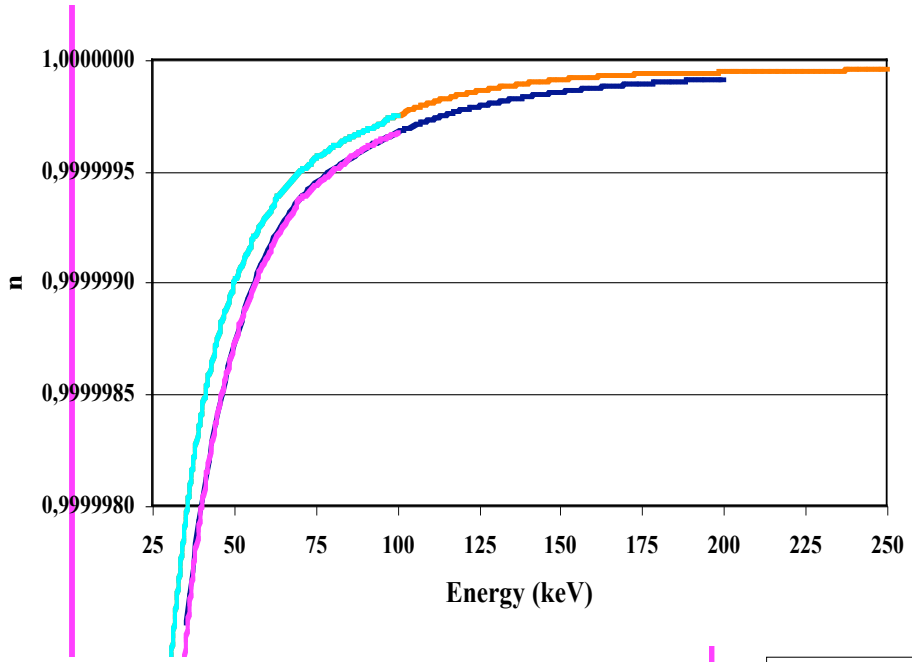



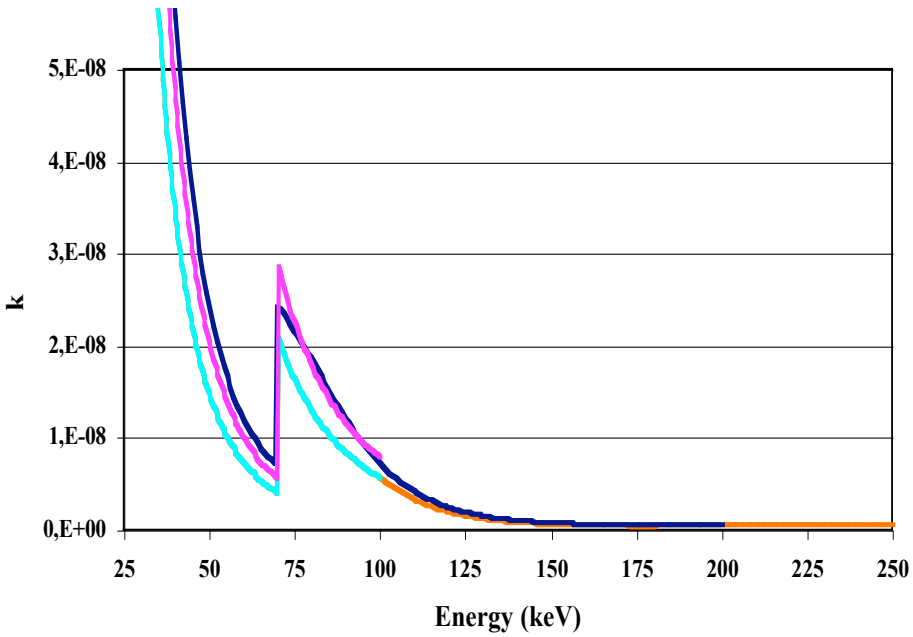

SiC Windt experimental

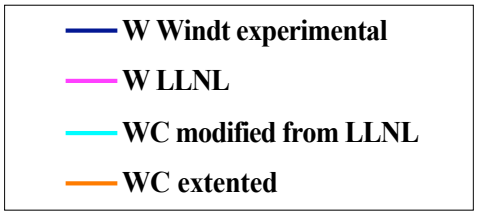
SiC extented

DANISH NATIONAL SPACE CENTER

# Optical constants WC



# Multilayer optimization

Power law thickness profiles:

$$D_i = \frac{a}{(b+i)^c}$$

- **Constants a and b are uniquely determined by Dmin and Dmax**
- **For a given max and min graze angle for a group Dmin and Dmax are determined by the Bragg equation:**

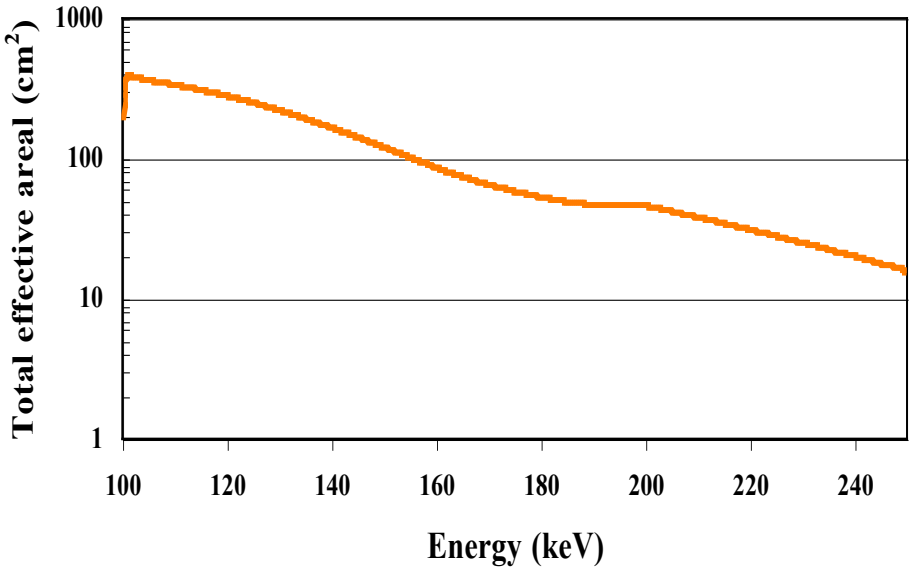
$$D = \frac{hc}{2E\sin\theta}$$

- **Multilayer recipes are optimized over:**
- **number of bilayers** **N**
- **high Z fraction** **Γ**
- **power law index** ***c***

DANISH NATIONAL SPACE CENTER

# Design based on a XEUS like configuration

| | |
|---|---|
| **Focal length** | **50 m** |
| **R** | **255-365 mm** |
| **Inci. angles** | **1.27 – 1.85 mrad** |
| **# shells** | **109** |
| **Shell thickness** | **0.2 mm** |
| **Primary mirror L** | **400 mm** |
| **Energy range** | **100 – 250 keV** |
| **Substrate** | **Si** |
| **Material combination** | **WC/SiC** |




$D_{min}$ range = 1.7nm – 1.4 nm

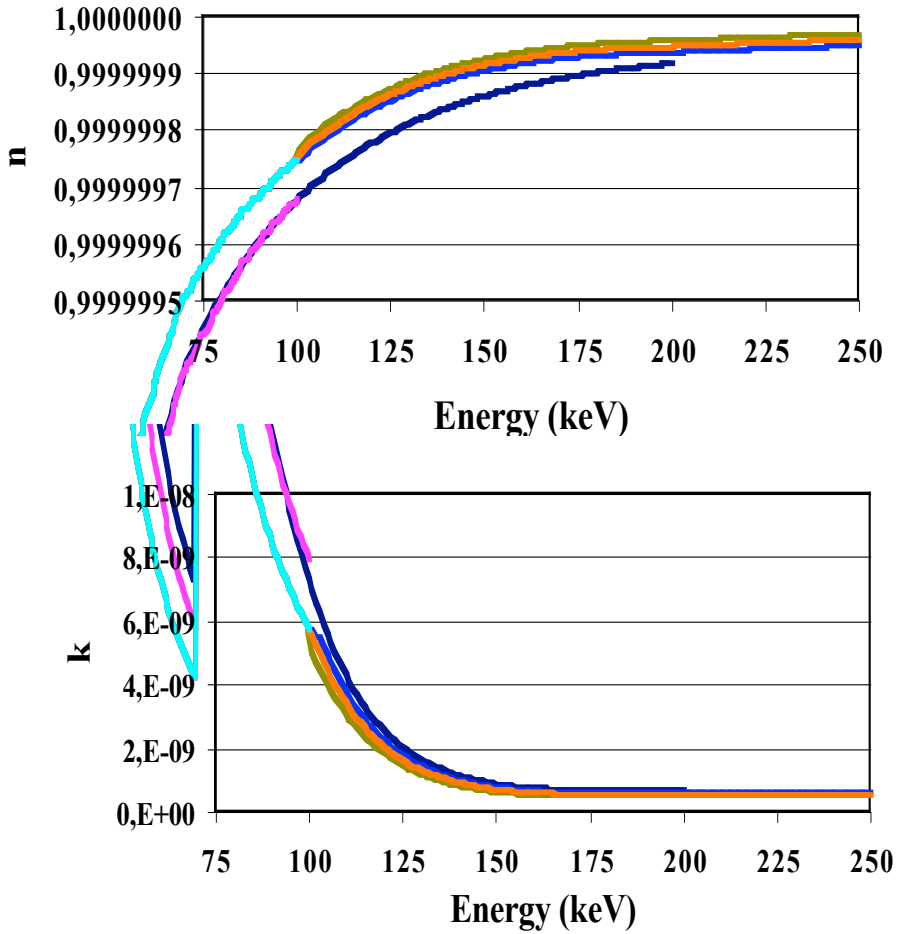
N = 1000 bilayers

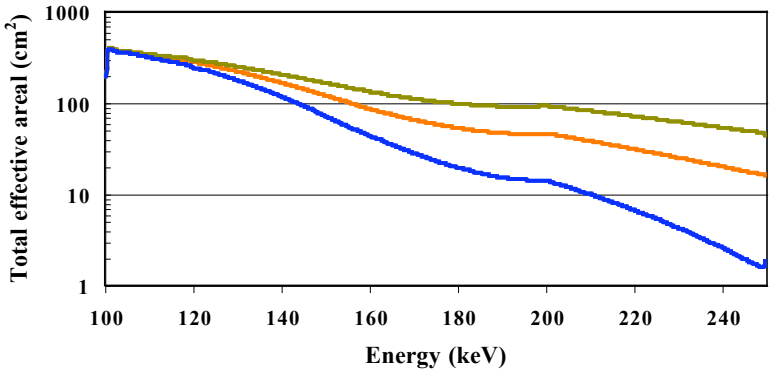
Γ range = 0.43 – 0.44

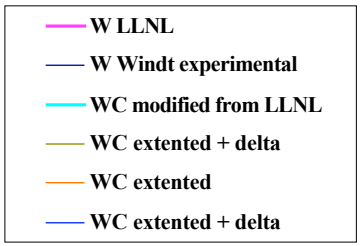
C = 0.260- 0.390

DANISH NATIONAL SPACE CENTER

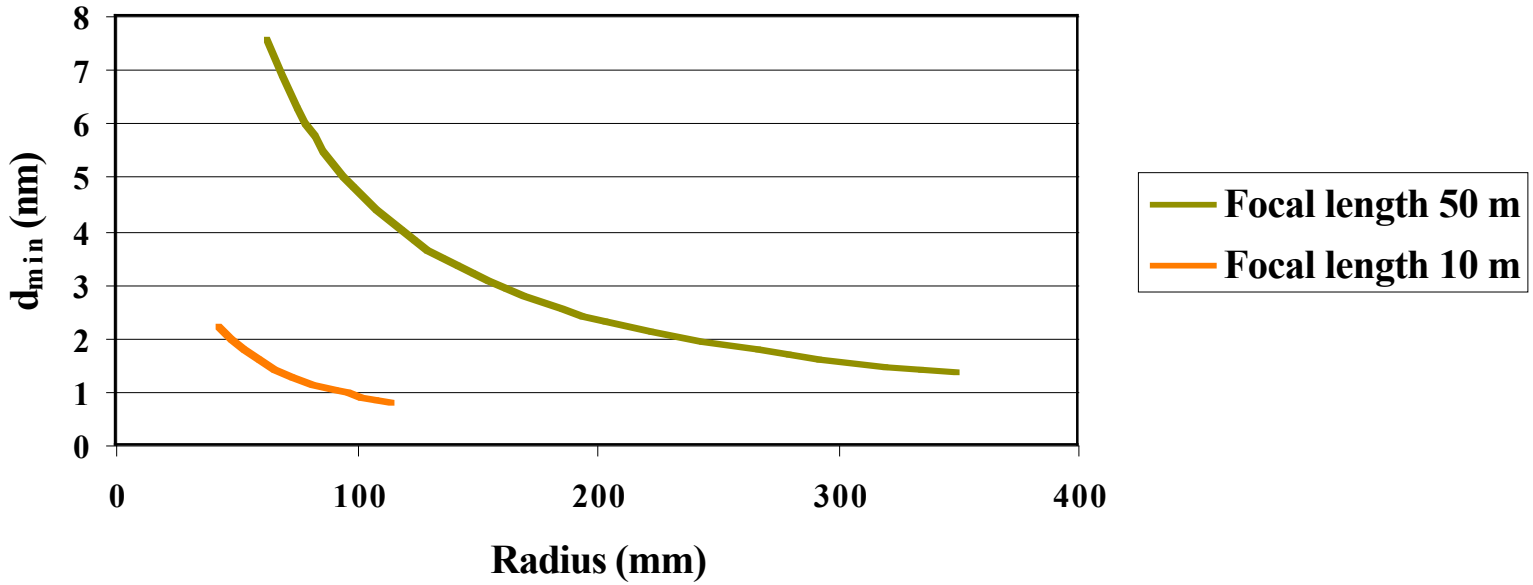
# Optical constants for WC



# $D_{min}$ for $E_{max}$ = 250 keV



# Summery

- Demonstrated very thin WC/SiC multilayer
- Shown problems caused by unknown optical constants

- Thin coatings can be used for:
  - Large radius telescopes with long focal length
  - High energy telescopes with short focal length
  - Telescope looking at small band at high energy

DANISH NATIONAL SPACE CENTER

# Hard x-ray focusing telescopes

| | Launche | Energy max (keV) | Coatings | Focullength (m) |
|---|---|---|---|---|
| NuSTAR | 2009 | 80 | Pt/SiC<br>W/SiC | 9 |
| Constalation-X | ~2015 | 70 | | |
| XEUS | ~2020 | 30 | | 50 |
| NEXT | ~200? | 80 | Pt/SiC | |

DANISH NATIONAL SPACE CENTER

# Stability of WC/SiC coating over time