Modeling Surface Roughness

Marian Harrison

R. Steven Turley

My Question:

How do different length scales of roughness affect the reflectance of a mirror?

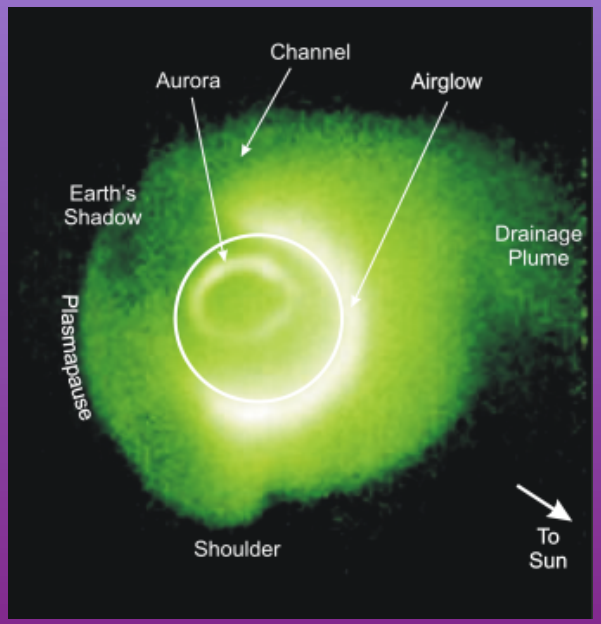
- **Height**
- **Integral**

Applications

Thin films and Extreme Ultra Violet Radiation

- **Space imaging**
  - **Mirror on IMAGE satellite**

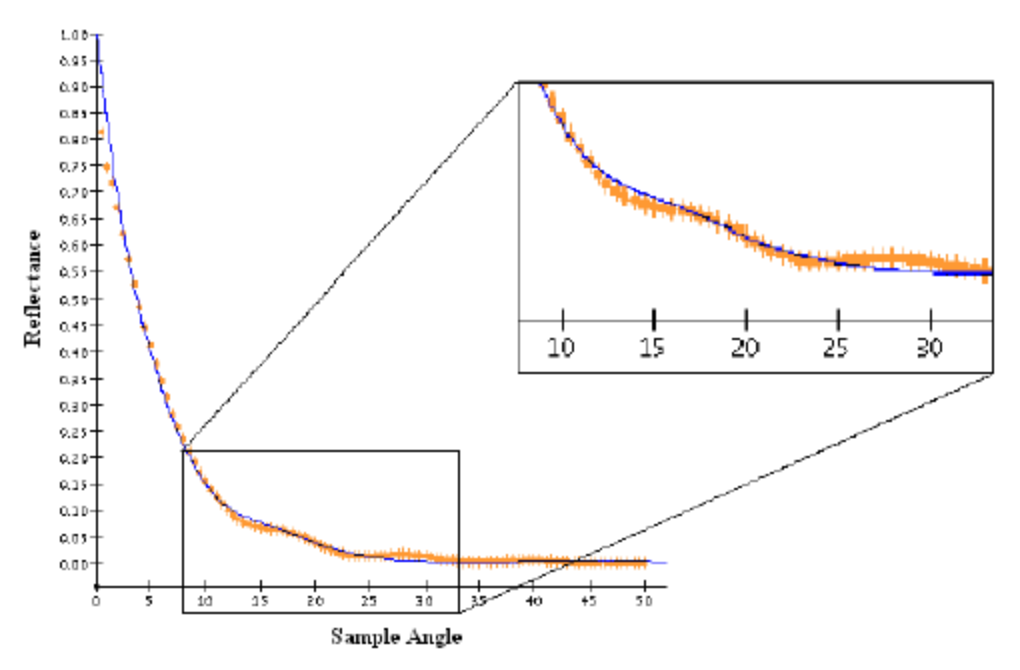
    Two helium emission lines
  - **Seeing into Stars**



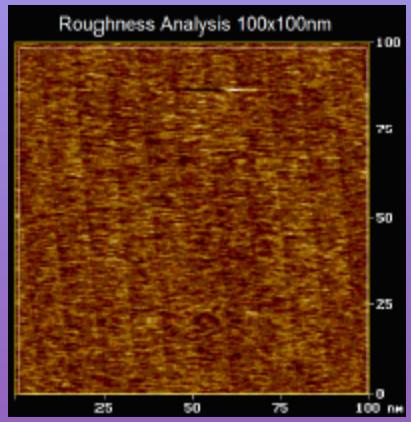
Outline

- **Basic Ideas**
- **Program**
- **Surfaces**
- **Results**

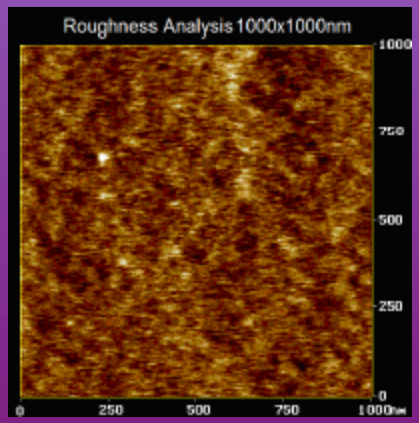
How does roughness affect our thin film measurements?



Fitting our data

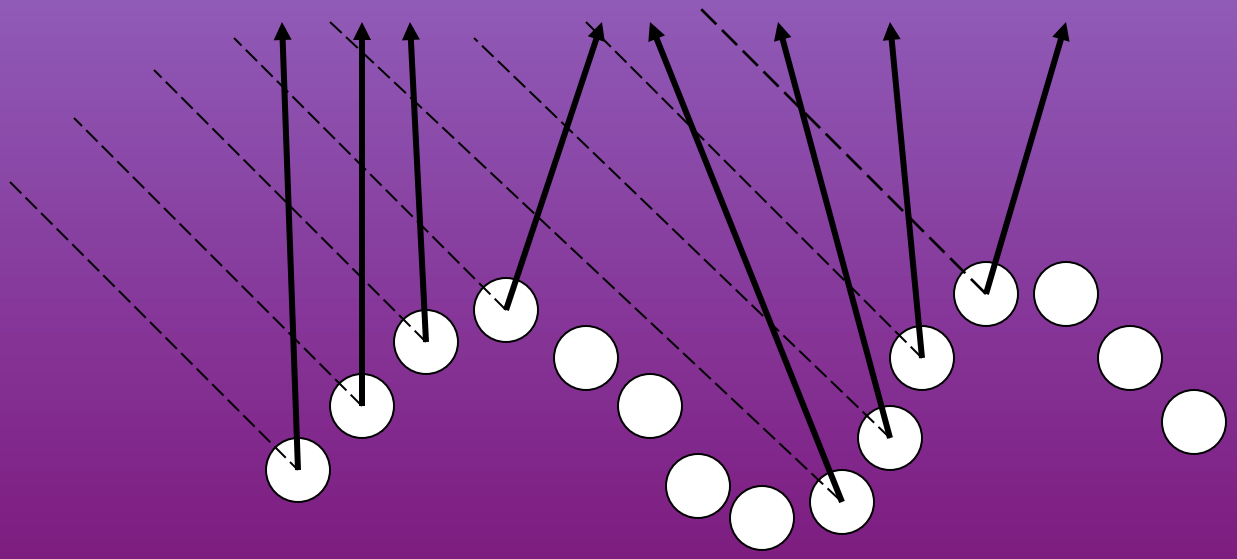


Rough Surfaces

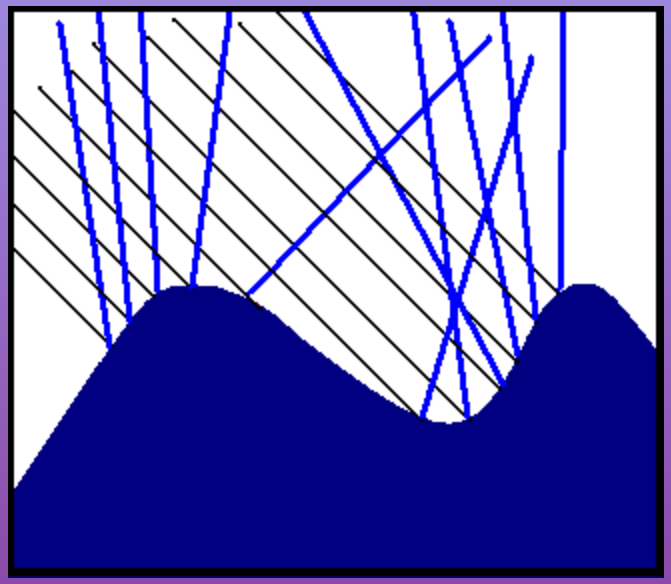


How does roughness affect our thin film measurements?

- **In the beginning:**
  - **Individual atoms**



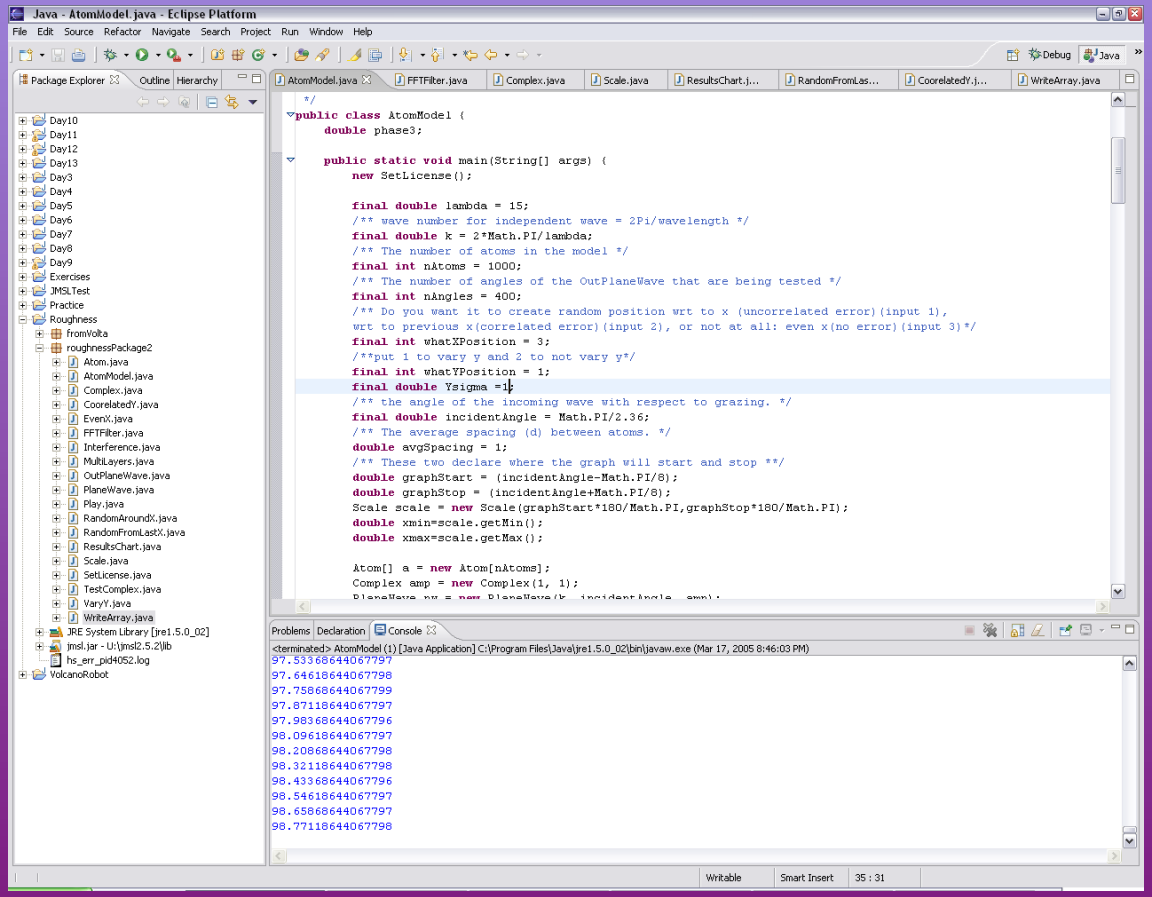
How does roughness affect our thing film measurements?



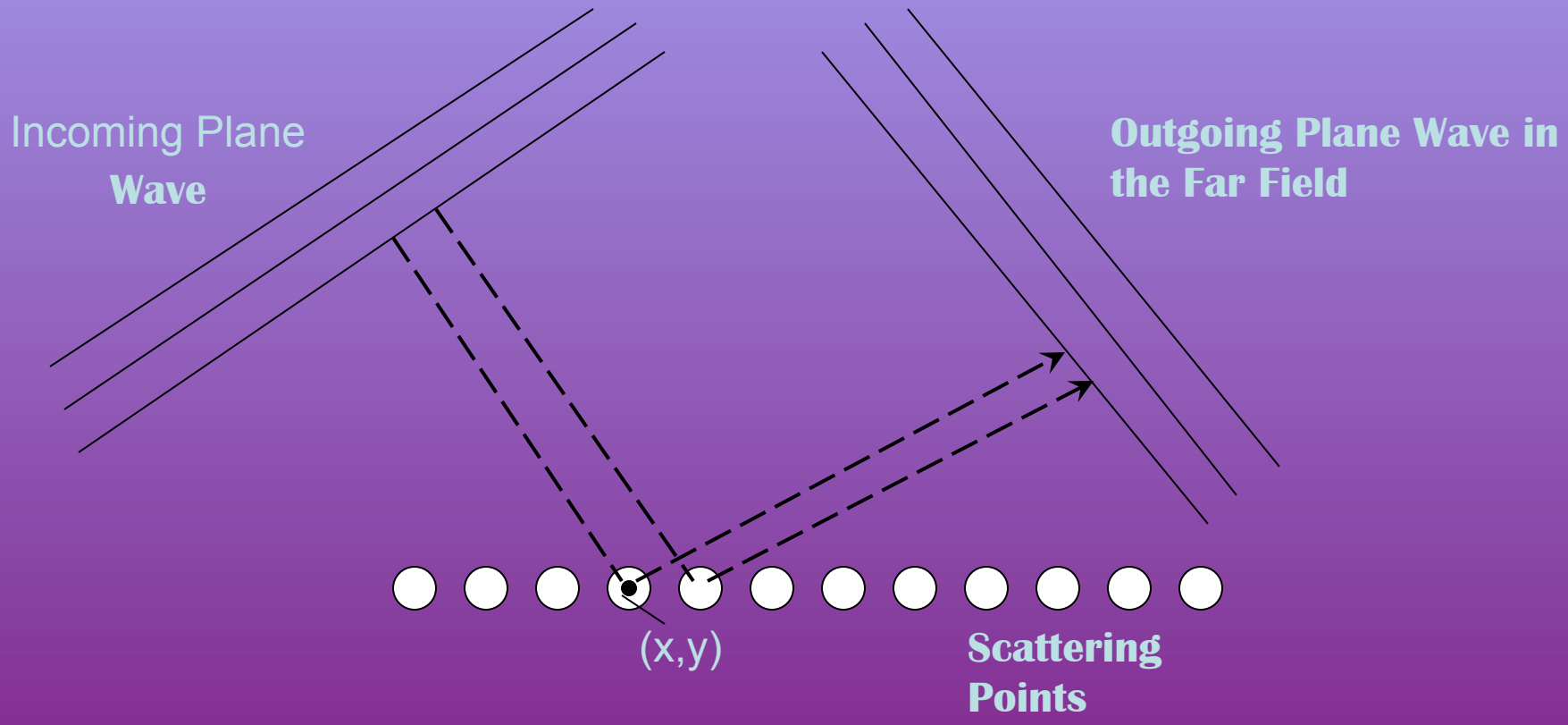
- **At the end:**
  - **Surface of "Huygen dots"**

The Method

- **Created a Java program**



Basic Idea

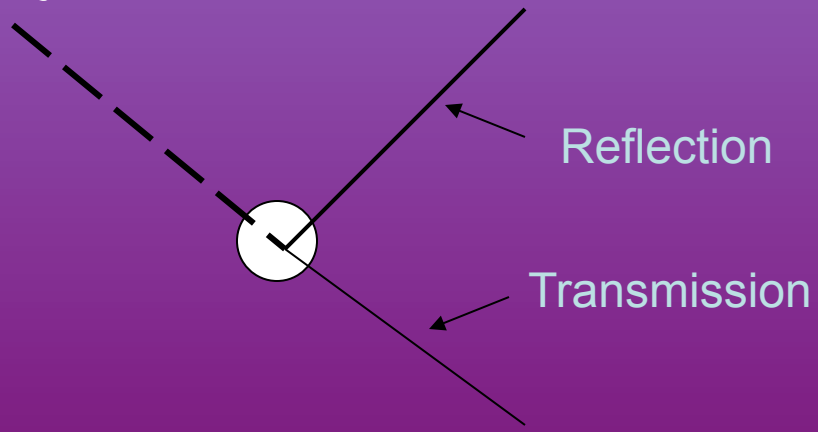

Incoming Plane
Wave
Outgoing Plane Wave in
the Far Field
(x,y)
Scattering
Points

The Program

Assumptions

- **S shaped radiation**

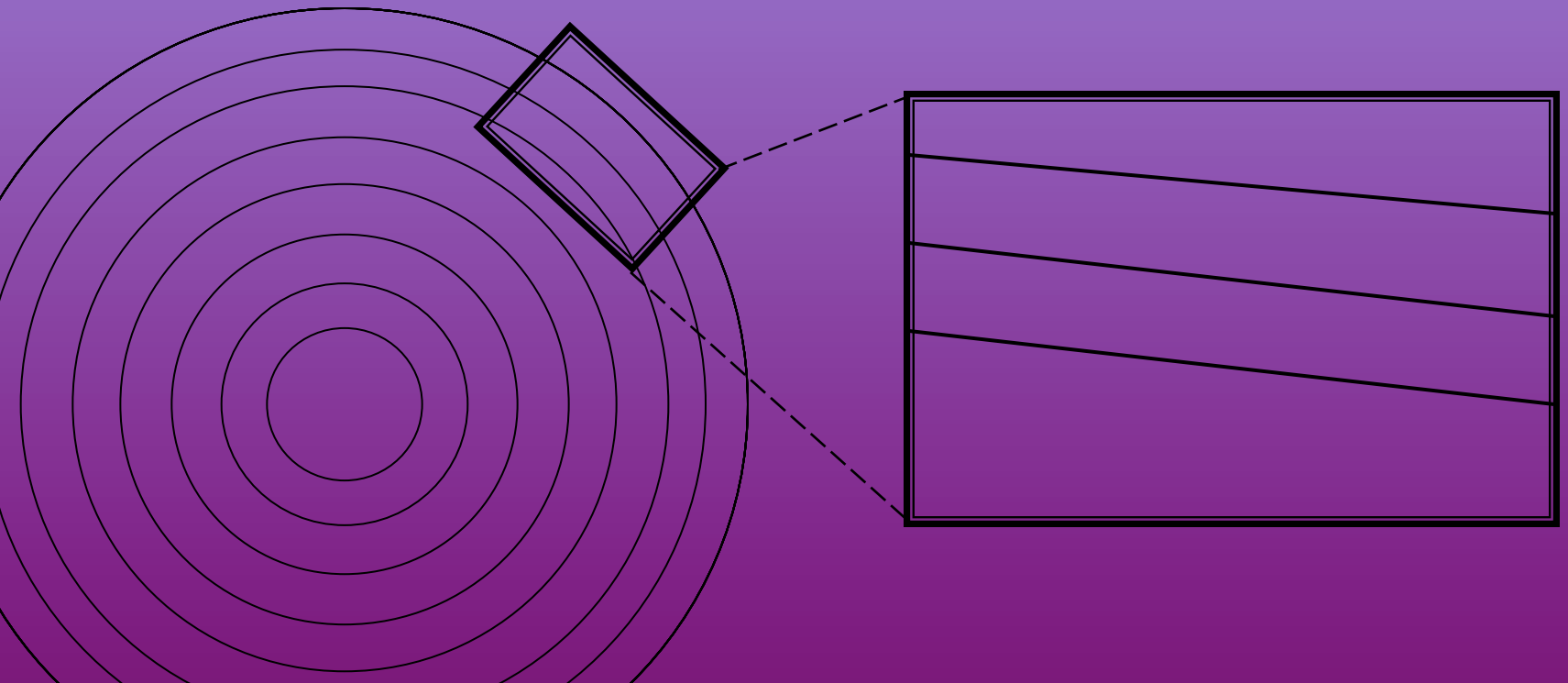
- **Looking only at reflection**



The Program

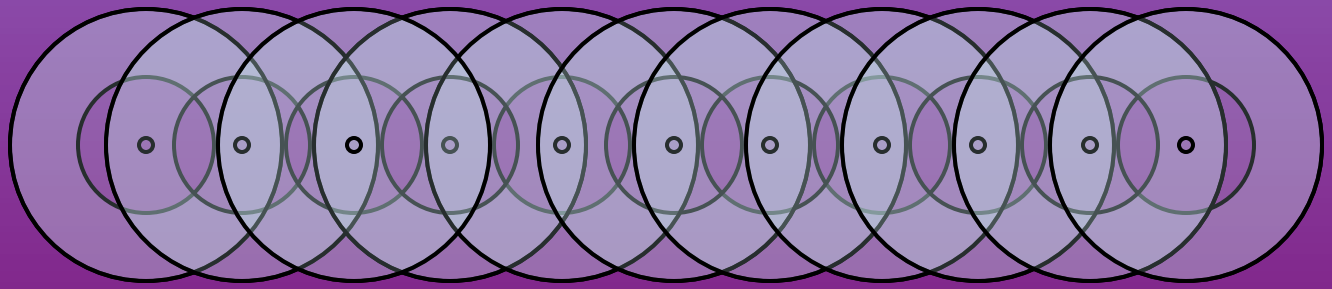
Assumptions

- **Rows of atoms are in a vacuum**
- **Looking at the wave in the far field**



The Program
Assumptions

- **Single frequency radiation**
- **No phase shift upon reflection**
- **Reflection off a scattering point is not affected by another point's radiation**



The Program

Math

♪

- **Phase**

$$\phi = \vec{k} \cdot \vec{x}$$

- **Electric Field**

$$E = E_0 e^{-i\phi}$$

The Program

Method - Overview

1) **Create a row of scattering points**
2) **Calculate the phase at each point**
3) **Calculate the electric field**
4) **Add all the fields from all the atoms**
5) **Compute the Intensity**
6) **Repeat for many angles**
7) **Calculate height and integral**

The Program

Surfaces

-Create an array of gaussian random numbers

-Multiply by a scaling factor

-Fourier Transform

-Apply filter

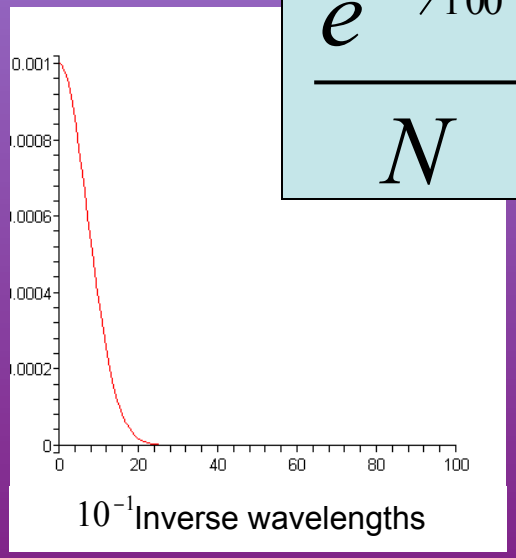
-Inverse Fourier Transform

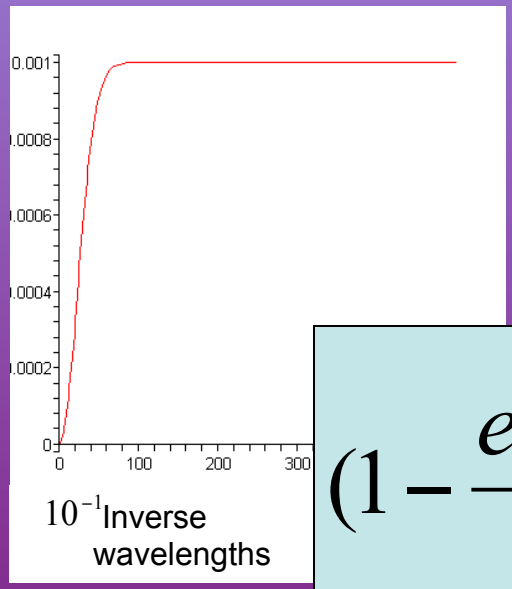
The Program

Surfaces

Filters: Multiply the Fourier Transform by:

$$\frac{e^{-x^2/100}}{N}$$

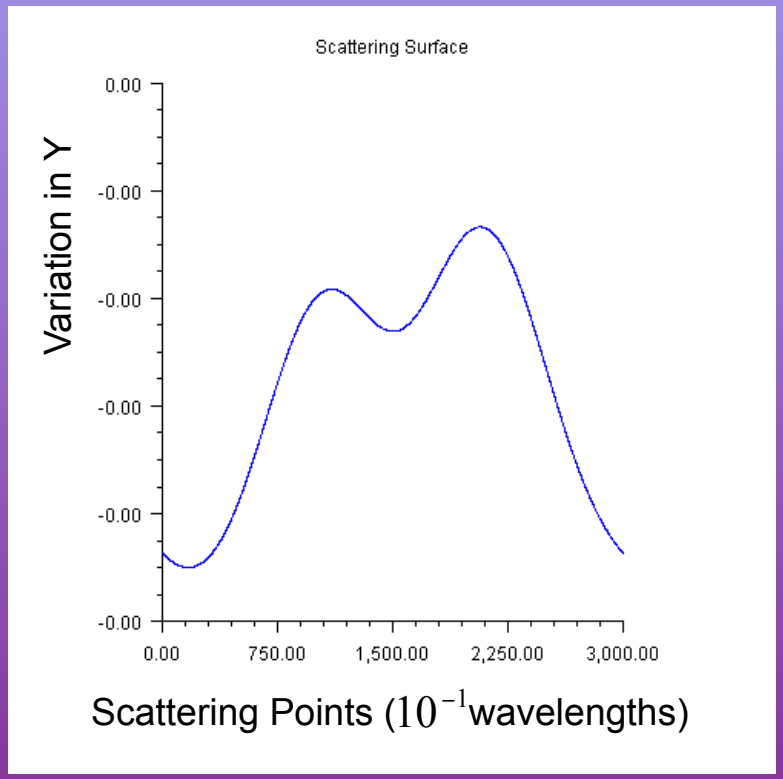




$$(1-\frac{e^{-x^2/100}}{N})$$

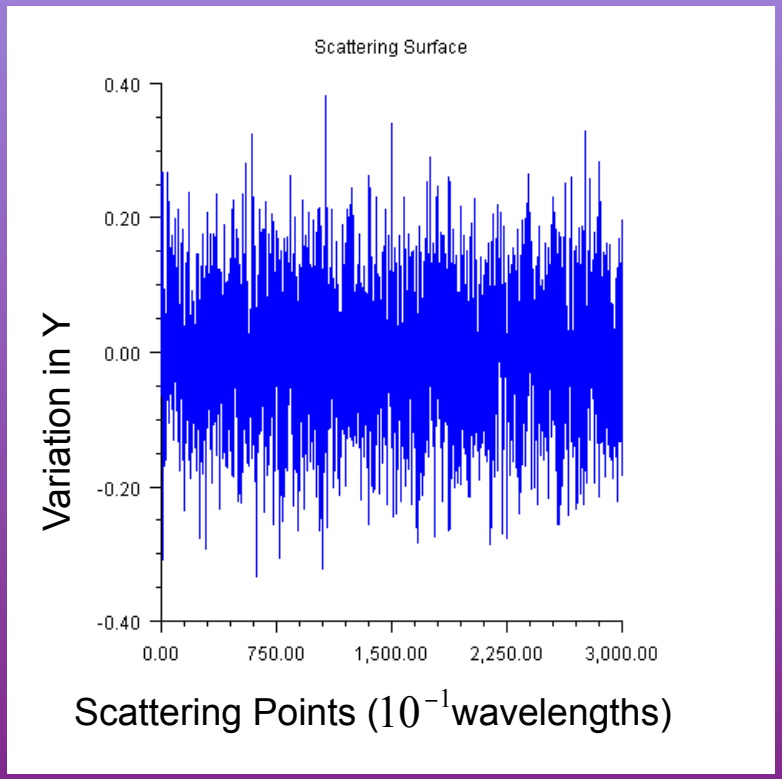
The Program

Surfaces



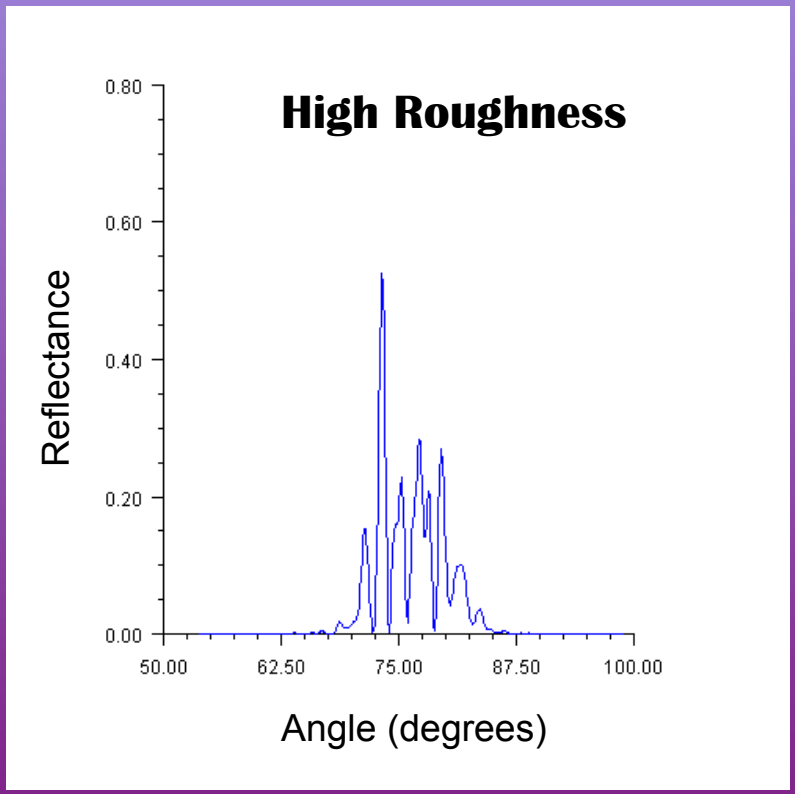
Low Pass Filtered Surface♪

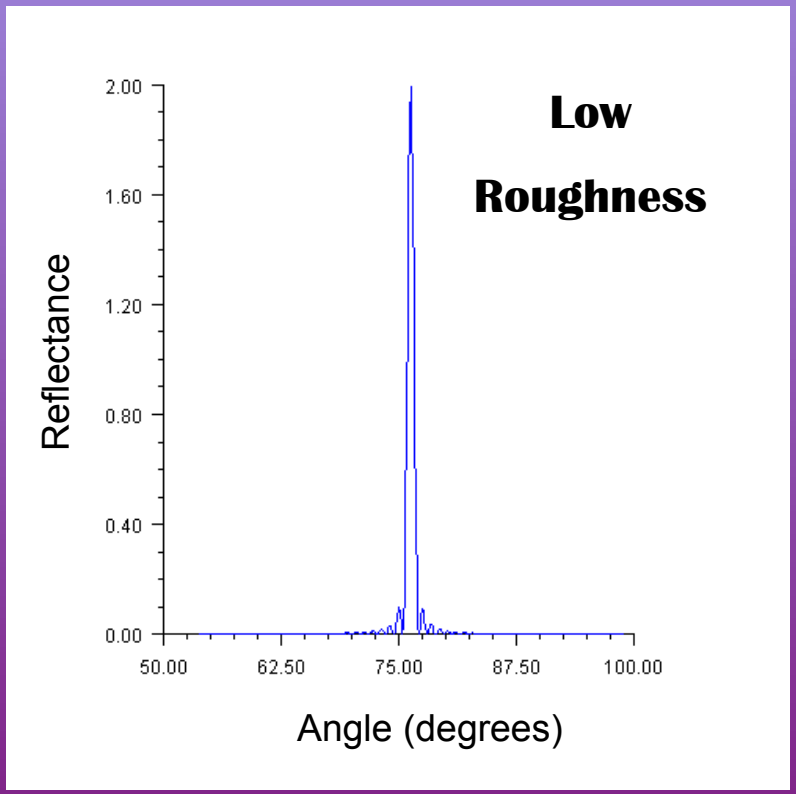
High Pass Filtered Surface♪



Results

Reflection Peaks





Results

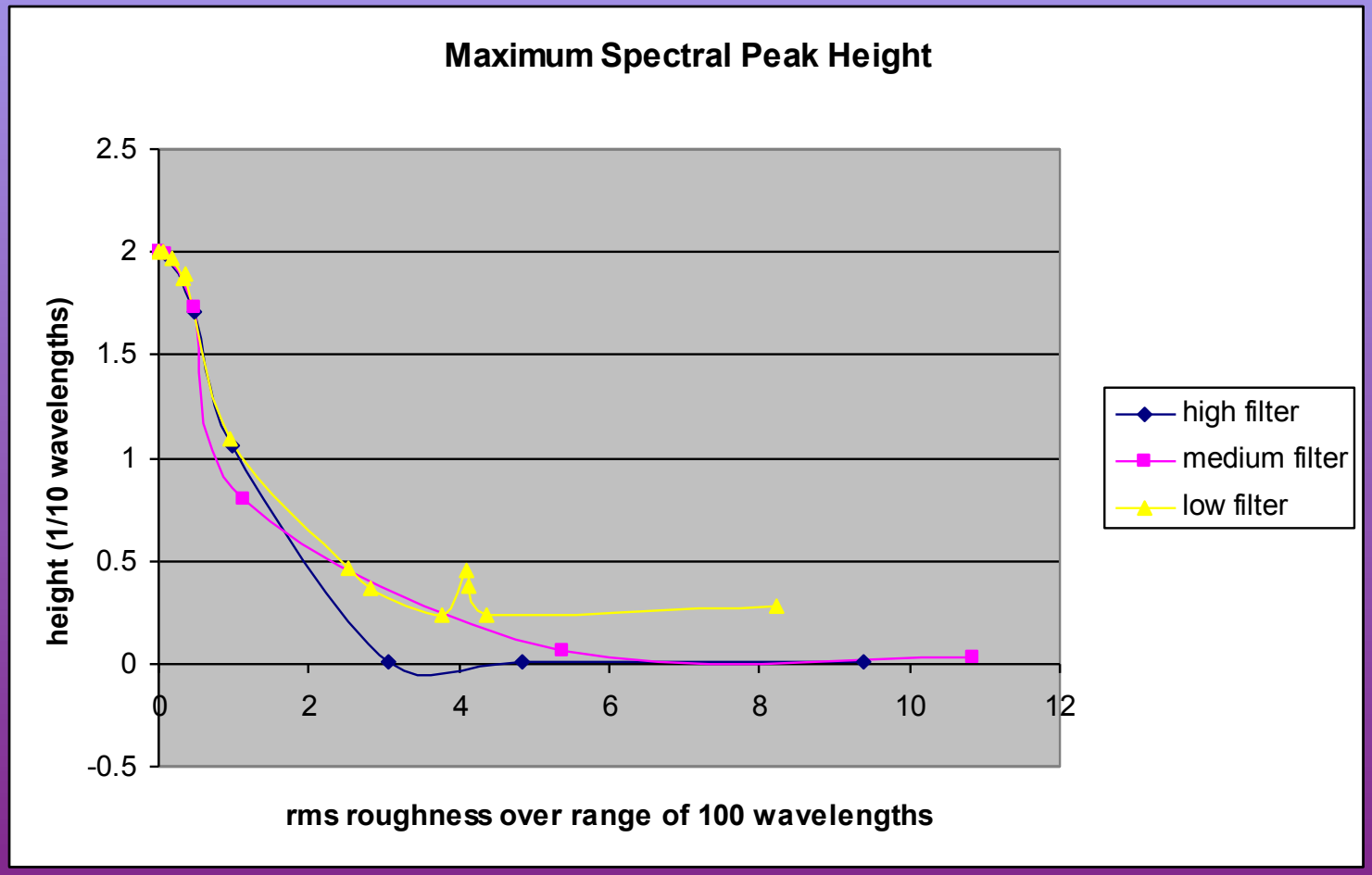
Reflection Peaks

- **Reasons for peaks**

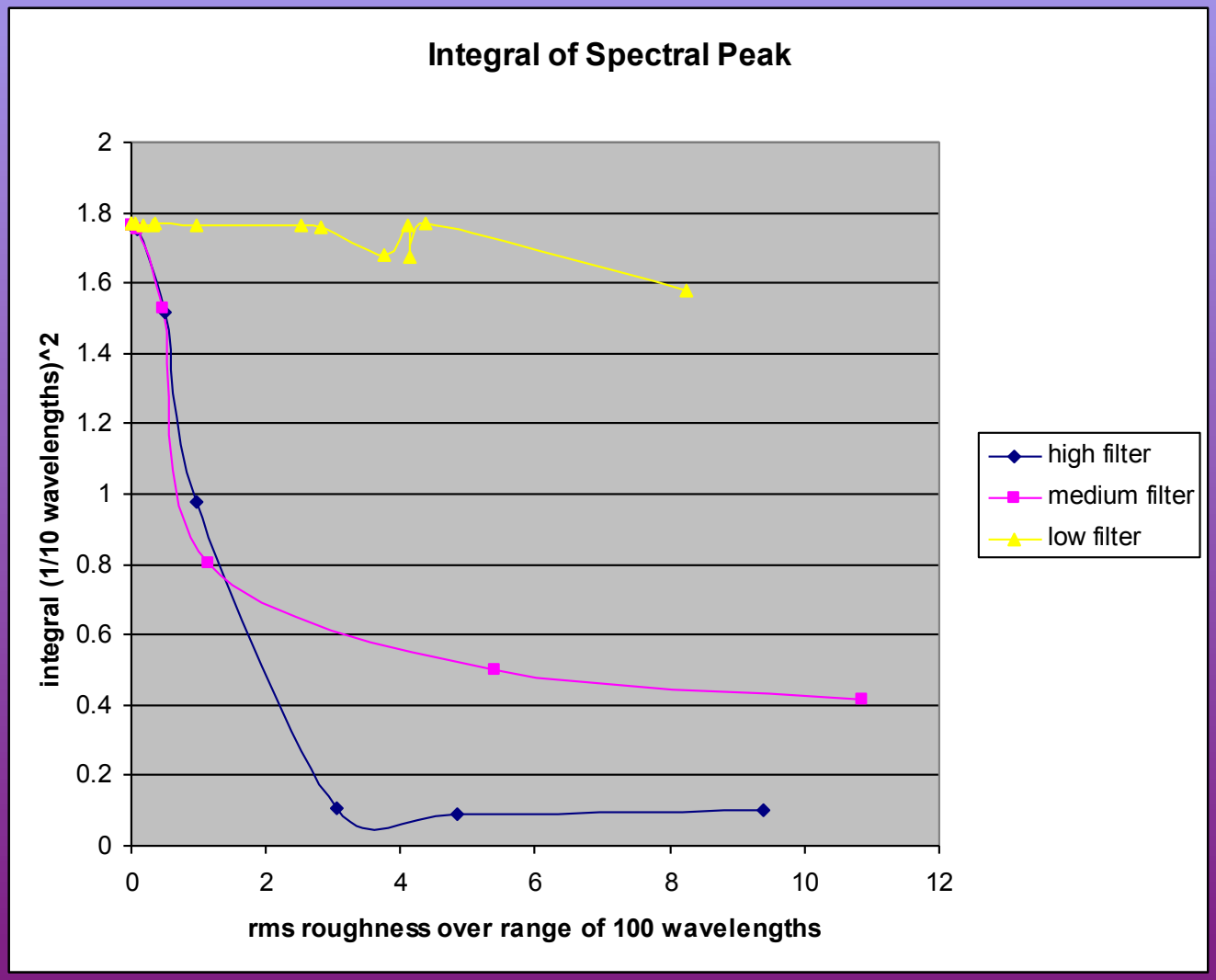
1) **Constructive/destructive interference between fields of different atoms**

2) **Roughness changes the direction of the field**

Results


Maximum Spectral Peak Height
height (1/10 wavelengths)
2.5
2
1.5
1
0.5
0
-0.5
0
2
4
6
8
10
12
rms roughness over range of 100 wavelengths
high filter
medium filter
low filter

Results


Integral of Spectral Peak
integral (1/10 wavelengths)^2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
rms roughness over range of 100 wavelengths
high filter
medium filter
low filter

Future Developments

- **Add multiple rows of scattering points**
- **Reflected radiation from scattering points affect the other points**
- **Compare to data from ALS and the reflectometer**
- **Use numerical integration to make more efficient**
- **Create a surface using a cubic spline method**

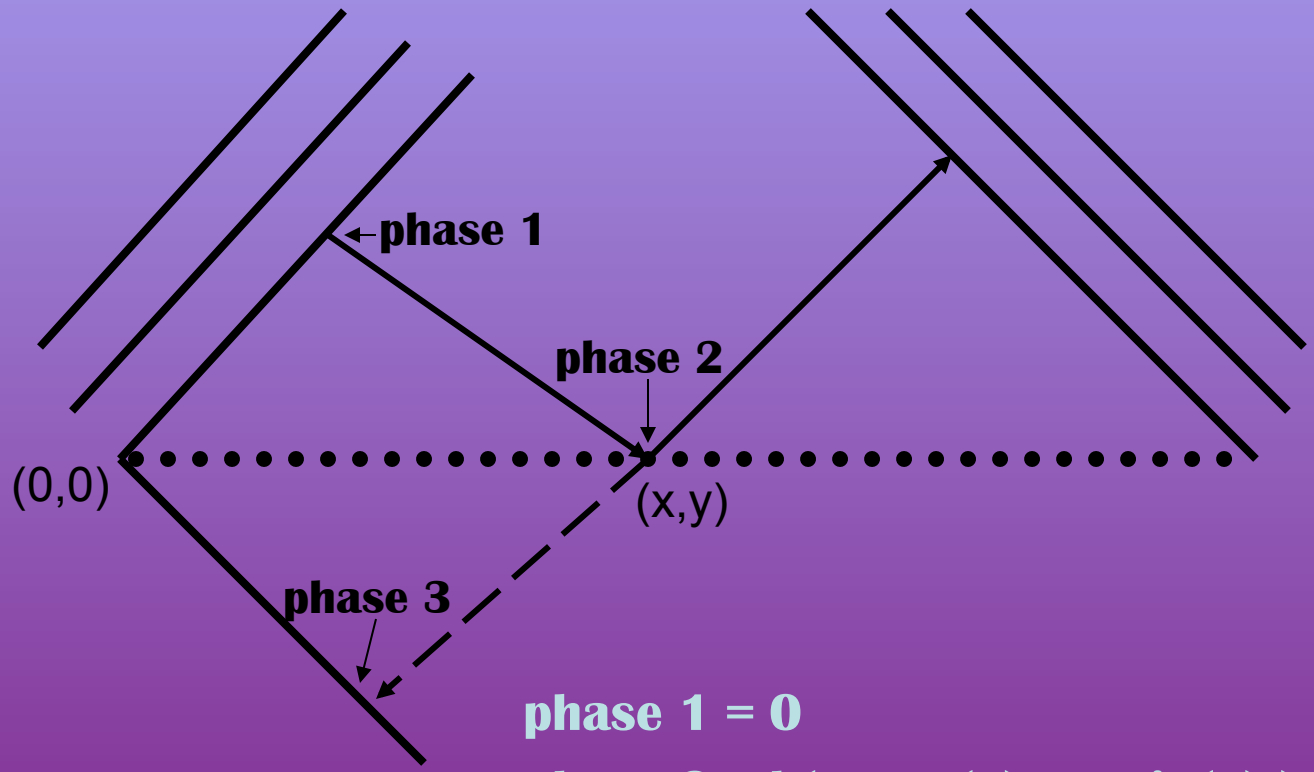
Acknowledgements

Dr. Steve Turley♪
Dr. David Allred♪
Niki Farnsworth♪
Thin Films Group♪
Rocky Mountain Space Grant Consortium♪

Thank you

The Program

Calculating Phases



phase 1 = 0

phase 2 = k(x cos(a) – y sin(a))

phase 3 = phase 2 + k(-x cos(b) + y sin(b))

The Program

Classes

- **Atom**
- **AtomModel (main class)**
- **Complex**
- **CorrelatedY**
- **EvenX**
- **OutPlaneWave**
- **PlaneWave**
- **Play**
- **RandomAroundX**
- **RandomFromLastX**
- **ResultsChart**
- **Scale**
- **SetLicense**
- **VaryY**
- **WriteArray**