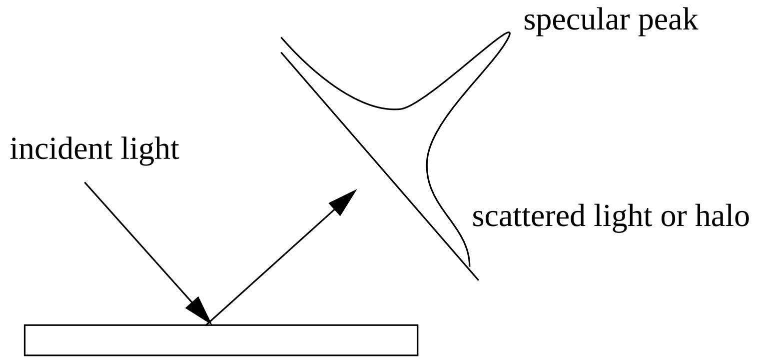
The roughness model in SHADOW

Introduction

SHADOW contains a model for analysing the surface roughness. Surface roughness is defined as irregularities in the optical surface which produces dispersion (scattering) of the incident radiation. That means the light is diffracted by the small irregularities of the surface. The model is different from the one that analyses the figure error (form) and waviness irregularities, where the geometric optics is still valid.
The usual way to analyse the roughness is by using 2-Dimensional measured mappings of the surface. Then one calculates the PSD function (Power Spectral Density) from the measured data. If one does not have a real profile then a mathematical function for the PSD can be considered. The information contained in the PSD is:
1) The roughness rms value which is the integral of the PSD function.
2) The correlation lengths (where the PSD function present peaks)

Rough optical surfaces scatters light into an halo close to the specular reflection:



The utility of the Roughness model is to know the maximum values of roughness admitted to verify the Beam line specifications and also to compare quantitatively the coupling between the roughness and slope errors effect

The jntpscalc program.

SHADOW will read a file containing the normalized PSD function. It is normalized because the effect of its integral [roughness rms value] is input independently. This permits to analyse different values of roughness rms with no need of regenerating the PSD.
The file has the following structure (written with a FORTRAN program):

```
write (41,*) npointsx
write (41,*) xstart
write (41,*) xstep
write (41,*) npointsy
write (41,*) ystart
write (41,*) ystep
```

```
do 222 j=1,npointsy
do 111 i=1,npointsx
write (41,*) psd(i,j)
111 continue
222 continue
```

Where x and y values are cm^{-1}. This file can be created by the user or calculated using the `jntpscalc` utility. This utility writes PSD functions with different options

1) Gaussian Power Spectrum: Where the PSD function is created from two independent gaussian functions (one for the x and the other for the y).

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-x_0}{\sigma_x}\right)^2}$$

$$f(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y-y_0}{\sigma_y}\right)^2}$$

and the 2-Dimensional PSD is therefore

$$PSD(x, y) = \frac{f(x) f(y)}{max(f(x) f(y))}$$

An example of this option is shown in figure 1 and the run parameters are:

```
expgd.shadow<95> jntpscalc
File to use for output to SHADOW?
jnt1.dat
 Please, input kind of Power Spectral Density you
 want to generate:
 [1] Gaussian power spectrum
 [2] PSD from a profile with normal statistics and
     Gaussian corr function
 [3] PSD from a profile with normal statistics and
     Exponential corr function
 [4] PSD along Y from a data file and gaussian
     along X
1
Number of points in y (along the mirror) and in
x (transversal): ?
100 100
input start value and end value along Y axis :
```

```
0 1000
input start value and end value along X axis :
0 1000
input sigma along Y and X directions
[frequency, cm-1] :
100
100
input center along Y and X directions :
0 0
Normalization factor is:     62831.853000000
expgd.shadow<96>
```

The second option calculates the PSD from a profile with normal statistics and Gaussian correlation function [1] :
The gaussian autocovariance function is

$$C(\tau) = \sigma^2 e^{-\left(\frac{\tau}{l}\right)^2}$$

And the corresponding one dimensional PSD function is:

$$f(x) = \frac{1}{4\pi}\sigma^2 l^2 e^{-\left(l\frac{x}{2}\right)^2}$$

and the 2-Dimensional PSD is therefore

$$PSD(x, y) = \frac{f(x)f(y)}{max(f(x)f(y))}$$

An example of this function is:

```
expgd.shadow<103> jntpscalc
File to use for output to SHADOW?
jnt2.dat
 Please, input kind of Power Spectral Density you
 want to generate:
 [1] Gaussian power spectrum
 [2] PSD from a profile with normal statistics and
     Gaussian corr function
 [3] PSD from a profile with normal statistics and
     Exponential corr function
 [4] PSD along Y from a data file and gaussian
     along X
2
```

```
Number of points in y (along the mirror) and in
x (transversal): ?
100 100
input start value and end value along Y axis :
0 1000
input start value and end value along X axis :
0 1000
for PSD in Y direction (along the mirror)
input roughness rms [Angstroms] and correlation length   [microns]:
10 50
for PSD in X direction (transversal direction)
input roughness rms [Angstroms] and correlation length   [microns]:
10 50
Normalization factor is:     1.2732395461901D+32
expgd.shadow<104>
```

The generated PSD is in figure 2.
Note: It seems to me than the normalization factor in the paper and in the program `jntpscalc` are slightly different. It does not matter because the result is normalized at the end.

The option 3 calculates the PDS from a profile with normal statistics and exponential correlation function.
The Correlation function and its one-dimensional PSD are:

$$C(\tau) = \sigma^2 e^{-\left(\frac{|\tau|}{l}\right)}$$

And the corresponding one dimensional PSD function is:

$$f(x) = \frac{1}{2\pi}\frac{\sigma^2 l^2}{\sqrt{\left(1 + (lx)^2\right)^3}}$$

and the 2-Dimensional PSD is therefore

$$PSD(x, y) = \frac{f(x)f(y)}{max(f(x)f(y))}$$

Option 4 reads the one-dimensional PSD from a file, and makes a gaussian PSD in the transversal direction.

Example of run with SHADOW

Let us demonstrate the use of surface roughness generating a point source at 8035eV with horizontal divergence of 1mrad and vertical divergence of 0.1mrad, and trace an ellipsoidal mirror focusing the source in a spot placed at 10m downstream the mirror. The distance source-mirror is 30m and the incidence angle is 88.5 deg. This system produces a punctual image when no roughness are considered and we will see how the spot size is degraded when including different values of roughness. For this purpose we need a file with the PSD function. We use the jntpscalc utility to calculate the 2-dimensional PDS function stored in files `jnt1.dat` and `jnt2.dat`.

The source description is:

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
**************  S O U R C E       D E S C R I P T I O N  **************


+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Input file specified:
end.00
FullfileSpecification:/tmp_mnt/civa/users/b/shadow/rt2.0/ROUGHNESS/end.00
 Creation Date:
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
 Random Source.
 Generated total         5000 rays.
 Source assumed BIDIMENSIONAL (flat).
 Source Spatial Characteristics: POINT
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Source Emission Characteristics
 Distribution Type: UNIFORM
 Distribution Limits. +X :   0.500000000E-03 -X:   0.500000000E-03 rad
                      +Z :   0.500000000E-04 -Z:   0.500000000E-04 rad
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
 Source Photon Energy Distribution: SINGLE LINE
 Photon Energy:   8035.0     eV, or   1.5431     Angs.
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
***************                E N D                ***************
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

and the system description is:

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
********************   MIRROR  DESCRIPTION   ********************
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++


+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Input file specified:end.01
FullfileSpecification:/tmp_mnt/civa/users/b/shadow/rt2.0/ROUGHNESS/end.01
 Creation Date :
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

 Surface figure was defined as:        ELLIPTICAL
Cylindrical figure                      NO
Roughness on from
jnt1.dat
RMS in Y (angstroms)                      10.0000000000000
RMS in X (angstroms)                      10.0000000000000
Element type                            REFLECTOR
Reflectivity                            OFF
Mirror dimensions                       UNLIMITED
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
Central Axis parameters :
Source Plane Distance                          3000.0000000000
Image  Plane                                  1000.00000000000
Incidence Angle                                88.500000000001
Reflection/Diffraction Angle                   88.500000000001

Mirror parameters                          COMPUTED
Same configuration as Central Axis         YES
Objective focus at                             3000.0000000000
Image focus at                                1000.00000000000
Incidence angle                                88.500000000001
Parameters used follow:
   Semi-major axis      2000.0000000000
   Semi-minor axis      45.339804456340
   Semi-focal-length    1999.4860094864
   Eccentricity        0.99974300474320
Source of this O.E. moved                  NO
Mirror at pole position ( no mov. )        YES
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
***************                E N D                 ***************
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

For the case with no roughness one obtains a point spot. With 10 A roughness rms in both dimensions and roughness files `jnt1.dat` and `jnt2.dat` the results are in fig 3 and fig 4 respectively.

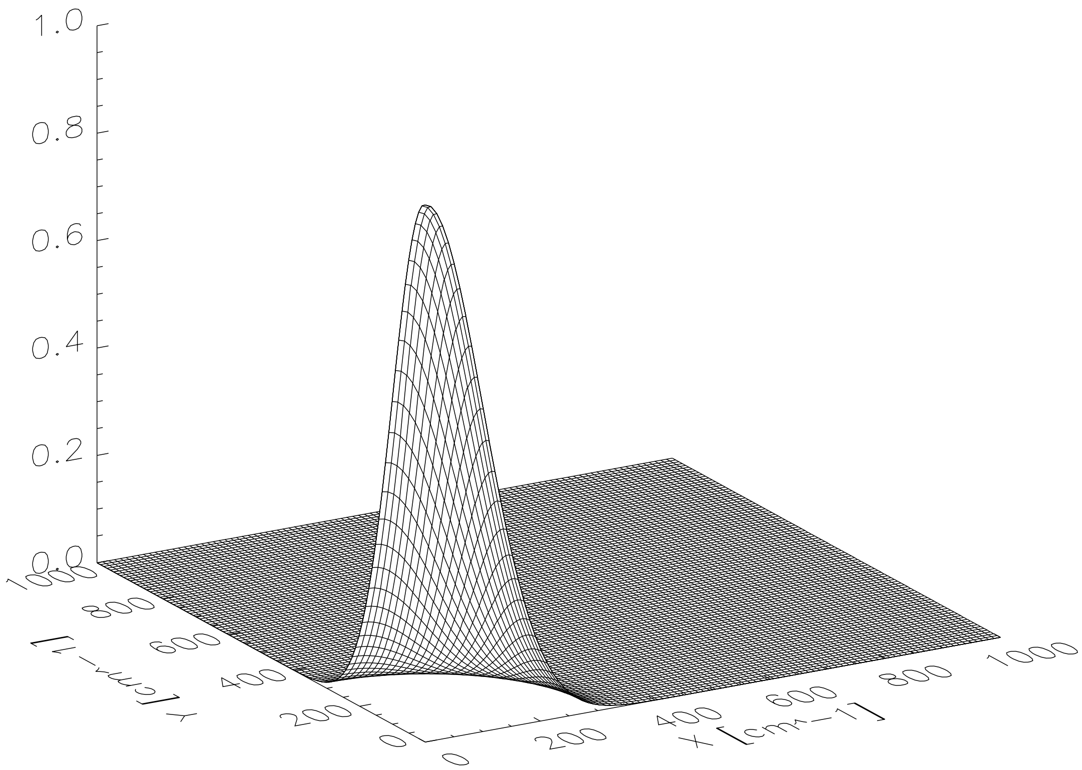


Fig 1. Gaussian PSD function

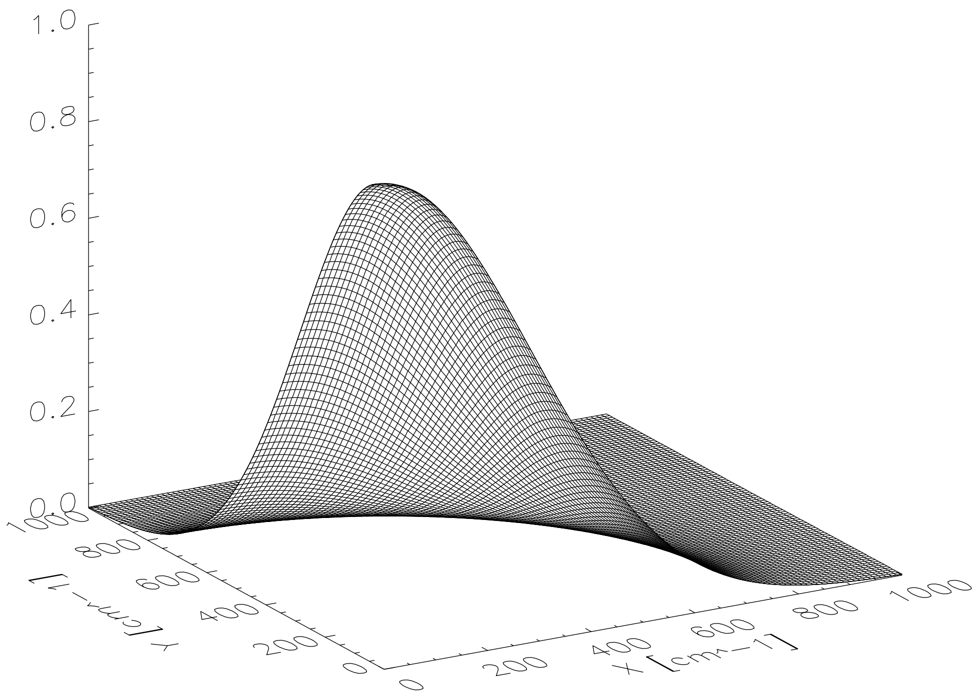


Fig 2. Normalized PSD function from a profile with normal statistics and Gaussian correlated function (τ=50μm).

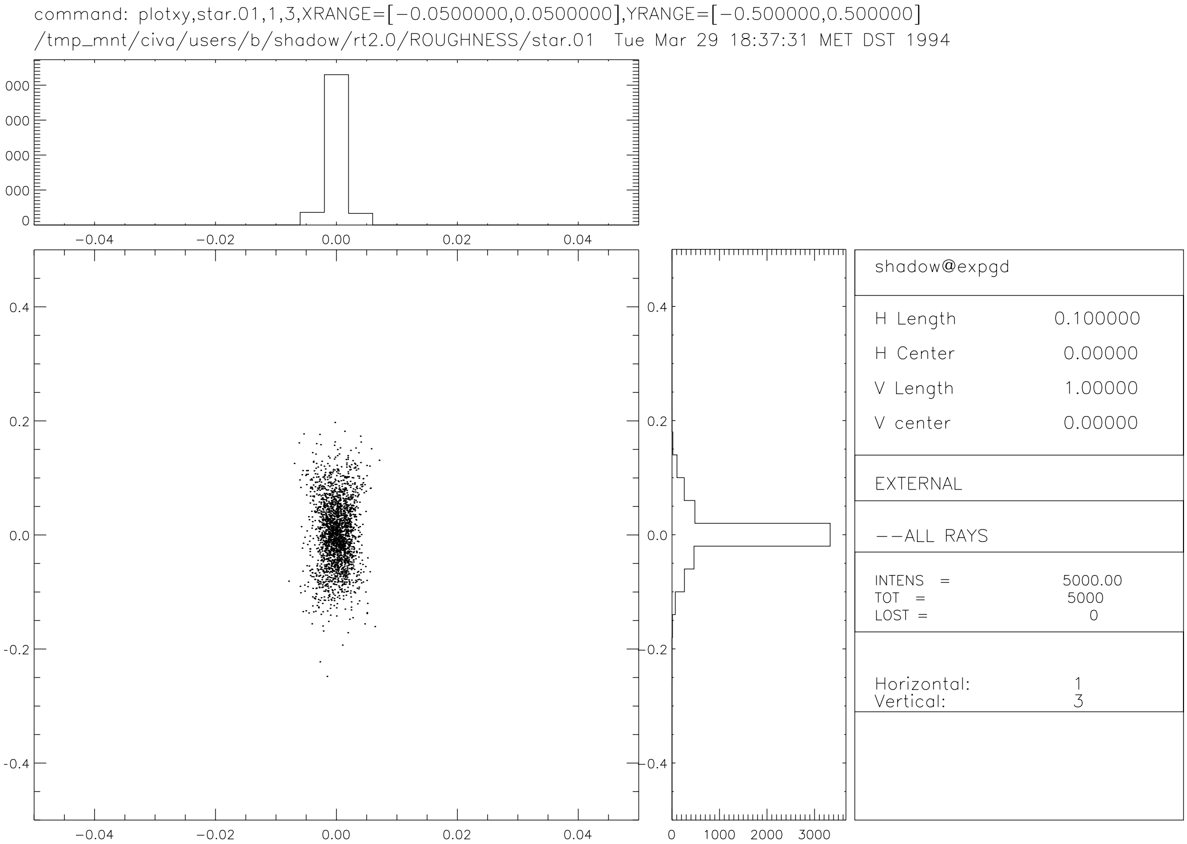


Fig 3 . Effect of the roughness. File with PSD function is in `jnt1.dat`

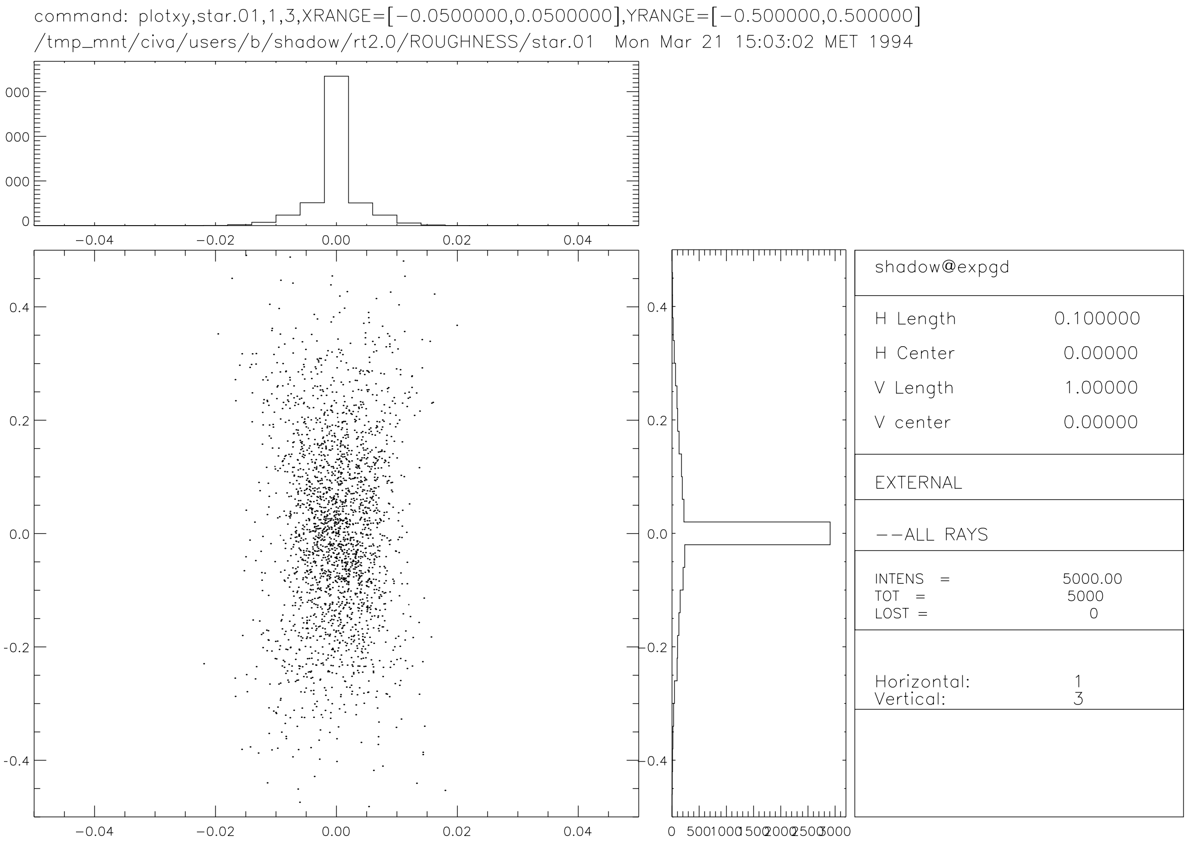


Fig 4. Roughness effect. From file `jnt2.dat`

References

[1] E.L. Church, H.A. Jenkinson and J.M. Zavada. "Relationships between surface scattering and microtopographic features", Optical Engineering 18 No. 2 (1979) 125-136