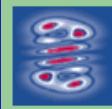


X-ray server: an online resource for simulations of X-ray diffraction and scattering

Sergey Stepanov

Argonne National Laboratory,
GM/CA CAT at Advanced Photon Source

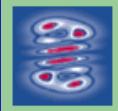


What is X-ray Server?

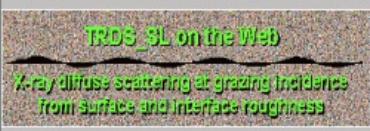
X-ray Server is a public project operational at the APS since 1997 with the goals to explore novel network technologies for providing wide scientific community with access to personal research results, establishing scientific collaborations, and refining scientific software.

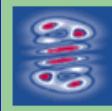
The Server provides Web-based access to a number of programs developed by the author in the field of X-ray diffraction and scattering. The software code operates directly on the Server available for use without downloading. Currently seven programs are accessible that have been used close to 90,000 times.

<http://sergey.gmca.aps.anl.gov>



Software available through X-ray Server

X - R A Y S E R V E R	
<p>This site has been online since 1997 and has served 89409 x-ray jobs</p>	
 Xoh on the Web Xoh Search	<p>Xoh on the Web interpolates dielectric susceptibilities x_0 and x_h for some crystals and other materials in wide range of x-ray wavelengths with the option to compare the data from different databases [12].</p> <p>Xoh-search is based on Xoh and it provides tool to search for Bragg planes under various conditions.</p> <p>42040 jobs</p>
 GID_SL on the Web Dynamical x-ray diffraction from strained crystals, multilayers and superlattices at usual and grazing incidence angles	<p>GID_SL on the Web calculates x-ray diffraction curves of strained crystals and multilayers for any Bragg-case diffraction with scans around arbitrary axis. It can be used for usual symmetric and asymmetric diffraction, for extremely asymmetric diffraction, as well as for grazing incidence and other non-coplanar cases [16], [19], [20], [21], [31].</p> <p>22129 jobs</p>
 TER_SL on the Web X-ray specular reflection from multilayers with rough interfaces at grazing incidence	<p>TER_SL on the Web calculates x-ray specular reflection from multilayers with interface roughness and transition layers [31], [20].</p> <p>9361 jobs</p>
 MAG_SL on the Web X-ray resonant specular reflection from magnetic multilayers	<p>MAG_SL on the Web calculates x-ray resonant specular reflection from magnetic multilayers with interface roughness and transition layers [33], [36]. NEW, added 07/2003</p> <p>8140 jobs</p>
 TRDS_SL on the Web X-ray diffuse scattering at grazing incidence from surface and interface roughness	<p>TRDS_SL on the Web calculates x-ray diffuse scattering from interface roughness. It implements several different models of roughness and can calculate such effects as skew roughness transfer, dependence of interface-interface roughness correlations on lateral size of roughness and x-ray scattering from atomic steps [23], [24], [26], [29], [32].</p> <p>7178 jobs</p>
 BRL on the Web X-ray multiple Bragg/Laue diffraction	<p>BRL on the Web calculates multiple Bragg diffraction of x-rays by perfect crystals. Can simulate up to 12-wave dynamical Bragg diffraction of x-rays from a plate-shaped crystal including the cases of x-ray waves grazing along the plate surface and Bragg angles being close to 90° [18], [17], [11]. NEW, added 07/2003</p> <p>561 jobs</p>



How it works

Web browser
on remote
computer



HTML form
HTML results



Windows computer
on my desk. Seamlessly
serves about 40 x-ray
jobs per day 24*7



CGI
interface
HTML
results



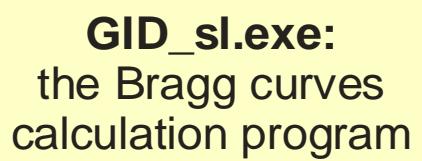
Data file
Zip file



Input
file
Data
file



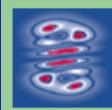
Data file
PNG
image



LEGEND:

needs to be developed
research product (no extra work)
freeware (no extra work)

For more details see poster session!



Background algorithm

X0h calculates material susceptibilities χ_0 and χ_h for x-ray wavelength range by interpolating data tabulated in the International Tables for X-ray Crystallography and several other tables.

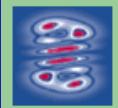
The highlight of **X0h** is the way it interpolates the dispersion corrections df' and df'' [1]. The dispersion corrections are calculated with the formulae given by Don Cromer [Acta Crystallogr. vol.18 (1965) p.17-23]:

$$df' = \sum_{k=1}^{N_s} g_k P(X_k, N_k)$$
$$df'' = 0.5\pi \sum_{k=1}^{N_s} g_k (N_k - 1) / X_k^{N_k - 1}$$

First, X0h applies the above equations to known tabulated dispersion corrections and evaluates g_k . Then, it uses calculated g_k to find the dispersion corrections of interest.

Once the χ_0 and χ_h are found, **X0h** can fulfill a lot of useful service tasks like evaluating the HWFM of Bragg peaks, searching for Bragg reflections that satisfy certain conditions, and etc.

[1] O.M.Lugovskaya & S.A.Stepanov, (1991) Sov. Phys. Crystallogr. **36**, 478-471.



X_{0h} on the Web !!!

Web input form

X-rays:

Wavelength (Å):

Energy (keV):

Characteristic line: Cu-Kα1

Target:

Crystal: Silicon

Other material:

Chemical formula: and density (g/cm³):

Reflection:

Miller indices: 1 1

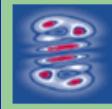
Database Options for dispersion corrections df1, df2:

Use X_{0h} data (5-25 keV or 0.5-2.5 Å) -- recommended for Bragg diffraction.

Use Henke data (0.01-30 keV or 0.4-1200 Å) -- recommended for soft x-rays.

Use Brennan-Cowan data (0.03-700 keV or 0.02-400 Å)

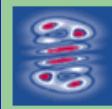
Compare results for all of the above sources.



X_{oh} on the Web !!!

Example web results

Structure :	Silicon
Symmetry :	Cubic
Density (gm/cm ³) :	2.3293
Unit cell constants (Å) :	5.4309 , 5.4309 , 5.4309
Unit cell angles (degr.) :	90.000 , 90.000 , 90.000
Poisson Ratio :	0.2800
Composition: Element -- N_sites (Sites occupation)	Si -- 8 (1.000)
X-ray line :	Cu-Kα1
Wavelength (Å) :	1.54056
Energy (keV) :	8.04778
Closest absorption edge (keV) :	1.84 (for element Si) 
Database for df ₁ , df ₂ :	*** XDh (International Tables), 5-25 keV ***
x_{r0}, x_{i0} ($n = I + x_{r0}/2 + i * x_{i0}/2$) :	-0.15127E-04, 0.34955E-06
delta, eta ($n = I - \text{delta} - i * \text{eta}$) :	0.75634E-05, -0.17477E-06
? Absorption factor (1/cm) and length (um) :	142.56, 70.144
? Extinction length at TER (Å) :	63.033
? Critical angle for TER (degr., mrad) :	0.22287, 3.8898 GET THE CURVE !
Reflection :	(1 1 1)
Bragg angle (degr.) :	14.221
Interplanar spacing (Å) :	3.1355
sin(QB), cos(QB) :	0.24566, 0.96936
tan(QB), cotan(QB) :	0.25343, 3.9459
sin(2*QB), cos(2*QB) :	0.47627, 0.87930
Polarization :	Sigma
$ x_{rh} , x_{ih} $:	0.79801E-05, 0.24314E-06
Phase difference ($x_{rh} - x_{ih}$) :	1.0000 * pi
Relative intensity (x_h / x_0) :	52.765 %
? Symmetric Laue-case extinction length (um) :	18.705
? Symmetric Bragg-case extinction length (um) :	1.5089
? Double-crystal curve FWHM (arcsec., urad) :	9.7797, 47.413
? Darwin curve FWHM (arcsec., urad) :	6.9153, 33.526 GET THE CURVE !
Polarization :	Pi
$ x_{rh} , x_{ih} $:	0.70169E-05, 0.21274E-06
Phase difference ($x_{rh} - x_{ih}$) :	1.0000 * pi
Relative intensity (x_h / x_0) :	46.396 %
? Symmetric Laue-case extinction length (um) :	21.273
? Symmetric Bragg-case extinction length (um) :	1.7160
? Double-crystal curve FWHM (arcsec., urad) :	8.5992, 41.690
? Darwin curve FWHM (arcsec., urad) :	6.0806, 29.479 GET THE CURVE !



X_{oh} Search

Web input form and results

X-rays:

- Wavelength (A):
- Energy (keV):
- Characteristic line: Cu-Kα1

Crystal:
Select code

Bragg planes range:
From: To:

Bragg angle range:
From: To:

Intensity control:
Minimum |x_h/x₀| (%):

Database option for dispersion corrections df1, df2:

- Use X_{oh} data (5-25 keV or 0.5-2.5 Å) -- recommended for Bragg diffraction.
- Use Henke data (0.01-30 keV or 0.4-1200 Å) -- recommended for soft x-rays.
- Use Brennan-Cowan data (0.03-700 keV or 0.02-400 Å)

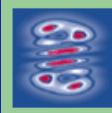
Find only those Bragg planes which make certain angles to the surface:

Surface plane indices:

- Planes make angles from Theta1 to Theta2
- Planes make angles from Theta1 to (Bragg_Angle - Theta2)
- Planes make angles from (Bragg_Angle - Theta1) to (Bragg_Angle - Theta2)

Theta1: , Theta2:

SEARCH CONDITIONS :		
Crystal:	Silicon	
Symmetry group:	Cubic	
Density (gm/cm ³):	2.3293	
Unit cell constants (Å):	5.4309 , 5.4309 , 5.4309	
Unit cell angles (degr.):	90.000 , 90.000 , 90.000	
X-ray wavelength (Angstrom):	1.540562	
X-ray energy (keV):	8.047777	
X-ray characteristic line:	Cu-Kα1	
Bragg planes range:	(1 0 0) -- (1 1 1)	
Bragg angles range:	0.0000 -- 30.0000	
Minimum intensity (x _h /x ₀):	0.0000%	
Surface:	(1 0 0)	
Planes angles to surface:	From Theta1 to Theta2	
Theta1, Theta2:	0.0000 -- 180.0000	
SEARCH RESULTS :		
Planes found: 4. Planes being displayed: 4		
hkl	Angle to surface	Bragg angle
(1 0 0)	0.0000	8.1540
(1 0 1)	45.0000	11.5711
(1 1 0)	45.0000	11.5711
(1 1 1)	54.7356	14.2211

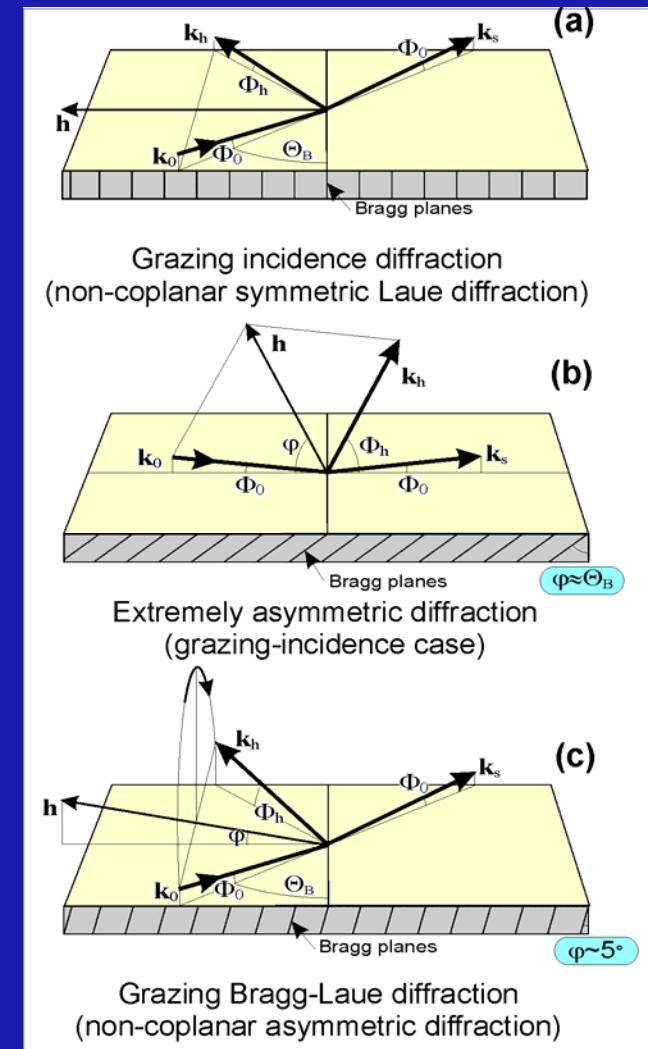


Background algorithm

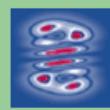
GID_sl (Grazing Incidence Diffraction from Superlattices) was originally developed for GID (Fig.1a) from multilayers, but then extended to arbitrary Bragg case including coplanar (Fig.1b) and non coplanar asymmetric diffraction (Fig.1c).

The program can calculate Bragg diffraction from imperfect crystals with given profiles of normal lattice strains $da(z)/a$, dielectric susceptibilities $\chi_0(z)$, $\chi_h(z)$, and interface roughness height $\sigma(z)$.

The advantage of **GID_sl** over most of other Bragg diffraction simulation software is that it takes into account specular reflection and refraction of X-rays at crystal surface and interfaces in multilayers. **GID_sl** implements a "discrete" algorithm, i.e. the crystal is subdivided onto "perfect" sublayers and the reflection from the whole stack is calculated with the help of (2x2) recursive matrix algorithm.



S.A.Stepanov, E.A.Kondrashkina, R.Koehler, D.V.Novikov, G.Materlik, and S.M.Durbin,
Phys. Rev. B, v.57, No 8, p. 4829-4841, (1998).

**Top layer profile (optional):**

```
period=
t= sigma= da/a= code= x= code2= x2= code3= x3= code4= x0= xh= xhdf= w0= wh=
end period
period=20
t=100 code=Gals sigma=2
t=70 code=Alls sigma=2 da/a=a
end period
```

Web input form

X-rays: Wavelength(A) / Energy(keV) = 1.540562 Line= Cu-Ka1 ? Polarization= Sigma

Crystal: GaAs ? X0h data (0.5-2.5A) Sigma=0. A W0=1. Wh=1.

Bragg Reflection: 4 0 0 Substrate da/a=0.

Geometry specified by: [5]. Surface orientation & condition of symmetric Bragg case ?

-- Geometry parameter ([1,7]=incidence angle, [2,8]=exit angle, [6]=Bragg planes angle, [9]=g0/gh): [] []

-- Surface plane ([1-5]): 1 0 0 Miscut direction: 0 1 1 Miscut angle: 0. degr.

Scan axis: [k0 x h] ? Indices, if other scan axis: [] [] [] Invert scan axis

Scan limits: from -2000. to +2000. sec. Scan points=401 Plot argument= incidence angle

watch progress Submit Query (single click, please!)

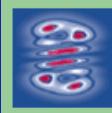
Available codes:**[2] Crystals:**

AlAs
AlP
AlSb
AlYO3
BaTiO3
Beril
Beryllium

[3] Non-crystals:

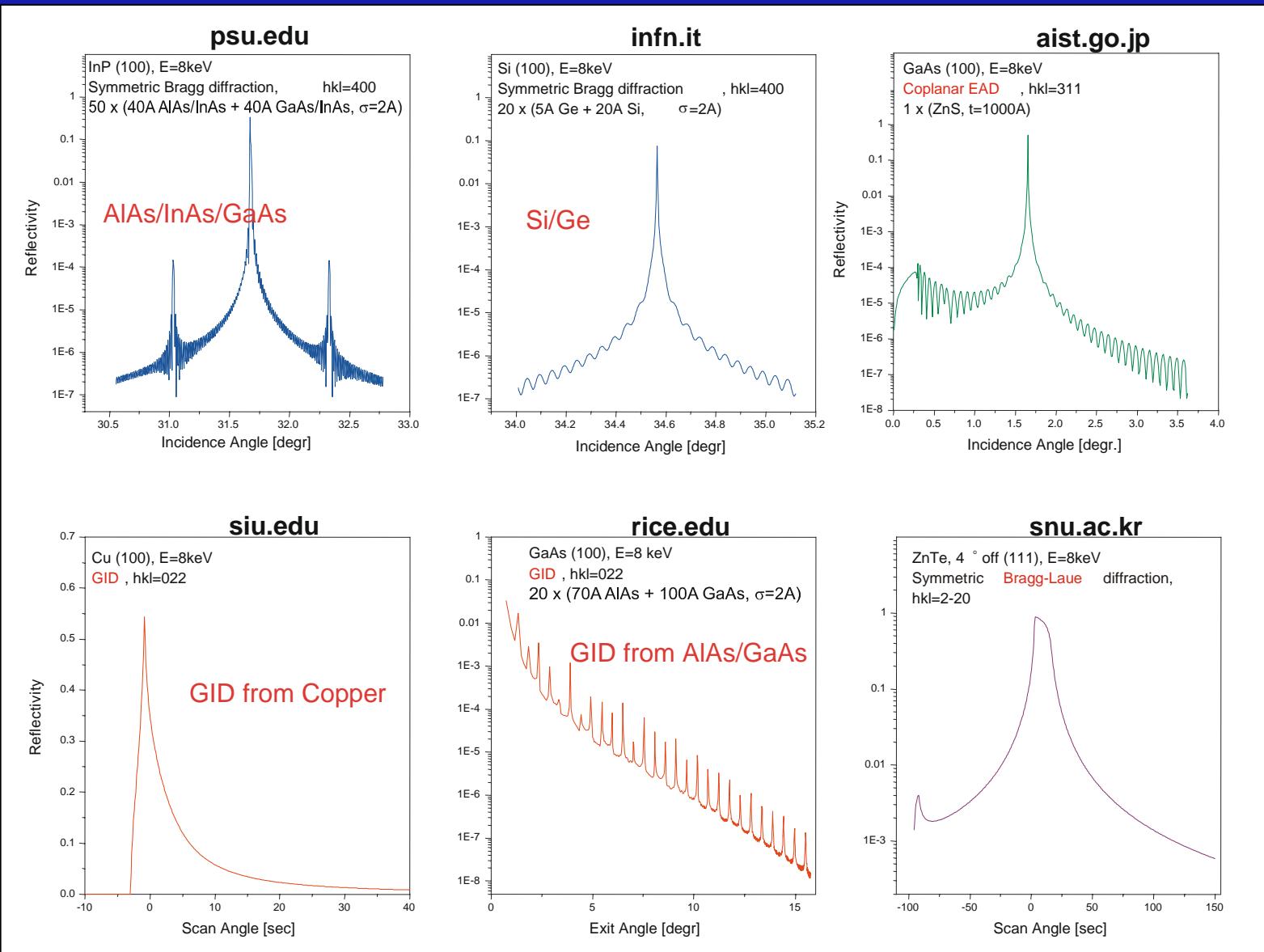
Al2O3
B4C
BeO
BN
Cr2O3
CsI
Fluorite

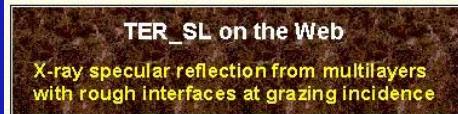
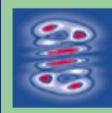
I? Elements:



GID_SL on the Web
Dynamical x-ray diffraction from strained crystals, multilayers and superlattices at usual and grazing incidence angles

Example web results

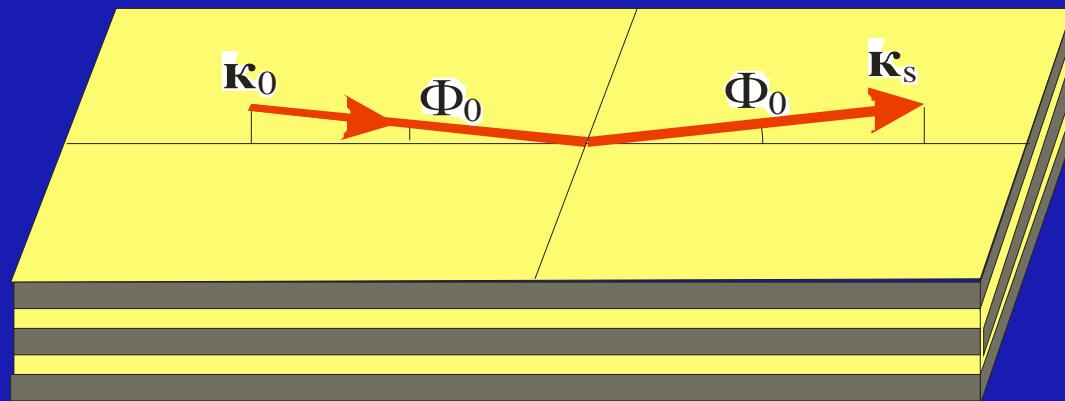




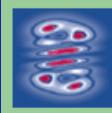
Background model

TER_sl (Total External Reflection) software simulates X-ray specular reflection from multilayers with the account for interface roughness or transition layers.

The advantage of **TER_sl** over the well known Parratt recursive technique is a faster convergence of recursions because **TER_sl** expresses the reflection from a stack of N layers through the reflectivity of (N-1) layers, while the Parratt technique expresses the reflectivity of N-th layer via that of the underlying (N-1)-th layer.



S.A.Stepanov, E.A.Kondrashkina, R.Koehler, D.V.Novikov, G.Materlik, and S.M.Durbin,
Phys. Rev. B, v.57, No 8, p. 4829-4841, (1998).



TER_SL on the Web

X-ray specular reflection from multilayers
with rough interfaces at grazing incidence

Web form

X-rays: Wavelength(A) / Energy(keV) = 1.540562 Line=Cu-Ka1 Polarization= Sigma

Substrate: Database code: GaAs X0h data (5-25keV; 0.5-2.5A)
 Chemical formula: rho= g/cm³
 Susceptibility x0 = () / format: x0=(Re(x0), Im(x0)); note: x0=2*delta /
x0 correction: w0 = 1. / this is used as: x0 = w0 * x0 /
Roughness: sigma = 4. Angstrom OR Transition layer tr = 0. Angstrom

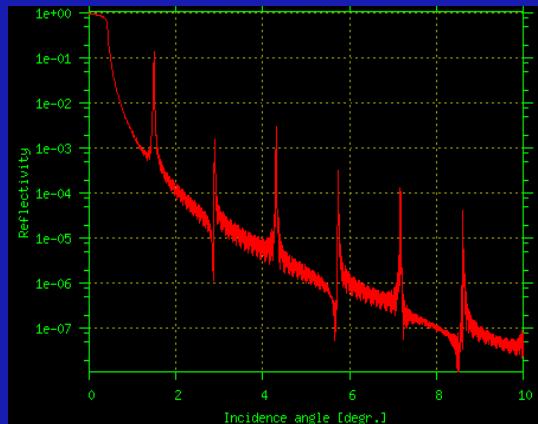
Incidence angle limits: from 0. to 3. degr.

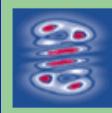
watch progress (single click, please!)

Top layer profile (optional):
period=
t= sigma= tr= code= rho= x= code2= x2= code3= x3= code4= x0= w0=
end period
t=20 w0=0.5 sigma=5 !surface oxide, organic contamination or dust
period=20
t=100 code=Gals sigma=4
t=70 code=Alas sigma=4
end period

Available codes:
(use Copy/Paste)

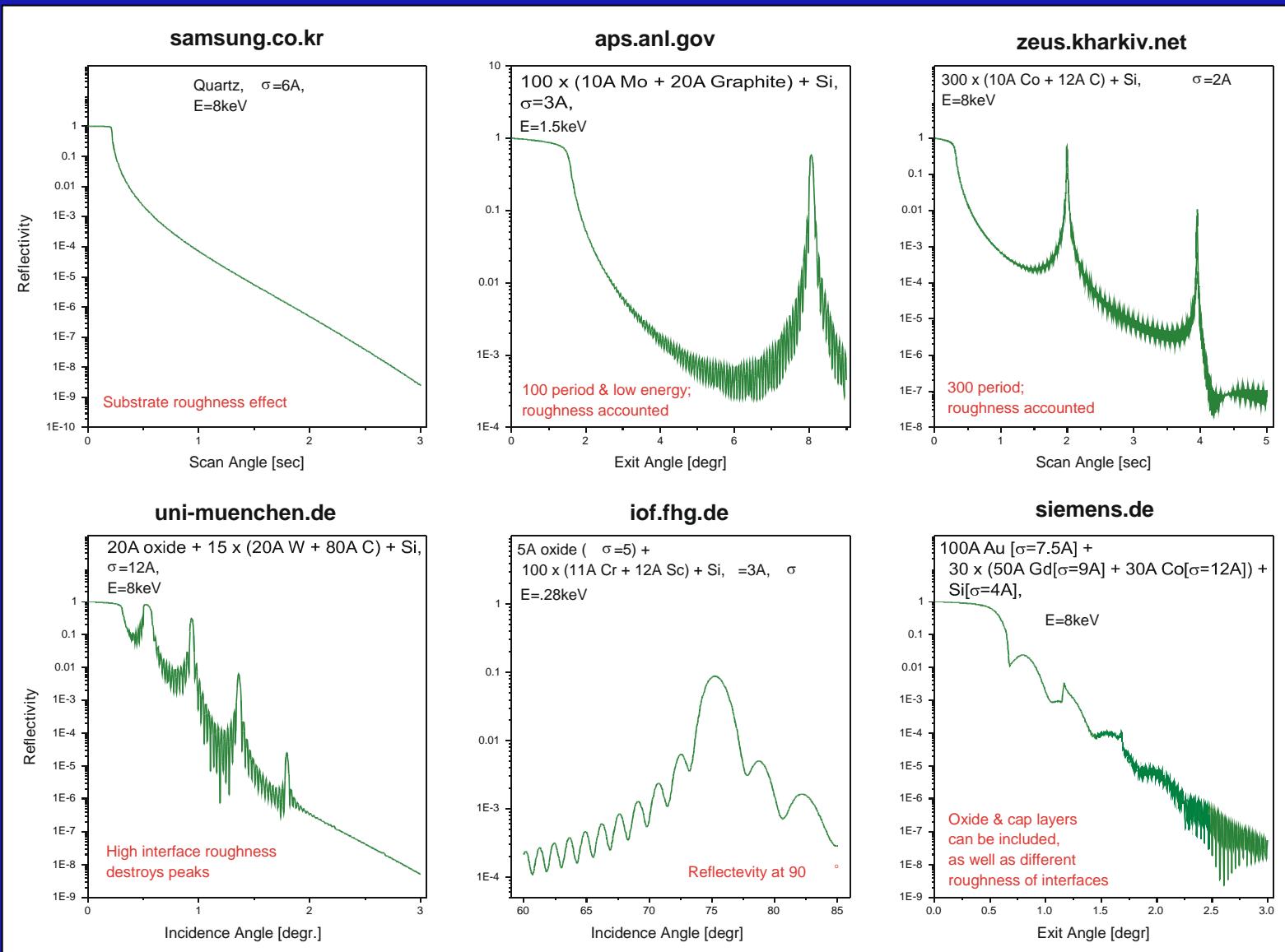
- Ac
- Ag
- Al
- Al₂O₃
- AlAs
- AlP
- AlSb
- Al₂Y₃
- Am
- Ar
- As
- At
- Au
- B
- B₄C
- Ba
- BaTiO₃
- Be
- BeO
- Beril
- Beryllium





TER_SL on the Web
X-ray specular reflection from multilayers
with rough interfaces at grazing incidence

Example web results



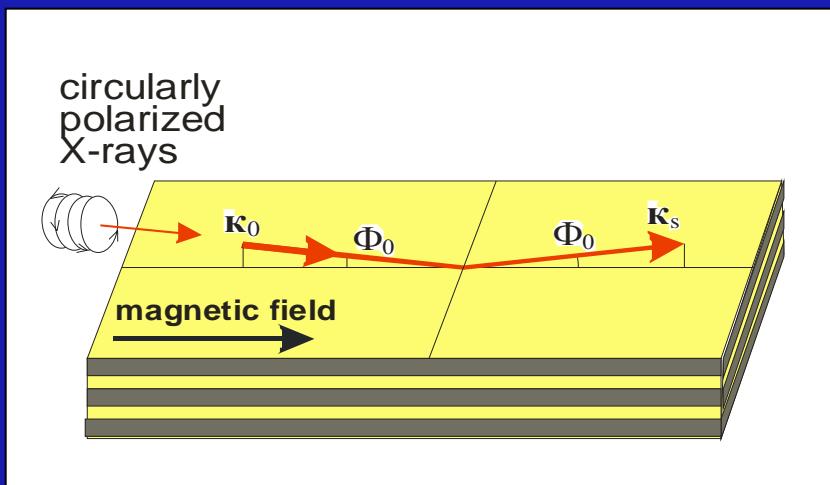


MAG_SL on the Web

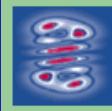
X-ray resonant specular reflection
from magnetic multilayers

Background algorithm

The **MAG_sl** program solves the problem of resonant X-ray reflectivity from magnetic multilayers. The major application of X-ray resonant magnetic scattering is to probe thin magnetic films and magnetic multilayers. This is a hot topic related to studying magnetic heads for computer hard drives. However, since in this case the media susceptibility is a tensor, the conventional Parratt technique for calculating X-ray specular reflection is not applicable. The problem is solved in **MAG_sl** applying a recursive algorithm for (2x2) scattering matrices similar to that of **GID_sl**.



S.Stepanov and S.Sinha, Phys. Rev. B, **61** (2000) 15302-15311.



MAG_SL on the Web

X-ray resonant specular reflection
from magnetic multilayers

Web form

X-rays: Wavelength(Å) / Energy(keV) = 7.243 Line= [] ?
Polarization: 4. Circular - [] angle to Sigma-plane for Option-3 []

Substrate: Database code: Silicon [] ? X0h data (5-25keV; 0.5-2.5Å) []
 Chemical formula: [] rho= [] g/cm³
 Susceptibility x0 = ([]) / format: x0=(Re(x0), Im(x0)); note: x0=2*delta /
x0 correction: w0 = [1.] / this is used as: x0 = w0 * x0 /
Roughness: sigma = [0.] Angstrom OR Transition layer tr = [0.] Angstrom
Magnetic atoms share (0--1) / density (1/cm³): [0.]
Magnetic orientation X=[0] Y=[0] Z=[0]
Magnetic amplitudes F10=[0., 0.] F11=[0., 0.] F1T=[0., 0.]

Scan (incidence angle or qz): from [0.] to [4.] degr. Scan points= [4001]

Magnetic model: generic (may have numeric problems for hard x-rays) / hard x-rays (E>6keV)

watch progress (single click, please!)

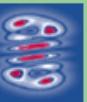
Top layer profile (optional):
period=
t= sigma= tr= code= rho= x= code2= x2= code3= x3= code4= x0= w0=
mshare= mdensity= mvector= F10= F11= F1T=
end period
period=15
code=Gd t=50 F11=(-0.22,9.35) F1T=(0.37,9.65) mshare=1 mvector=(1 0 0)
code=Fe t=35
end period

(same "Submit" action as above; single click, please!)

Available codes:
(use Copy/Paste)

- Ac
- Ag
- Al
- Al2O3
- AlAs
- AlP
- AlSb
- AlYO3
- Am
- Ar
- As
- At
- Au
- B
- B4C

[More details](#)



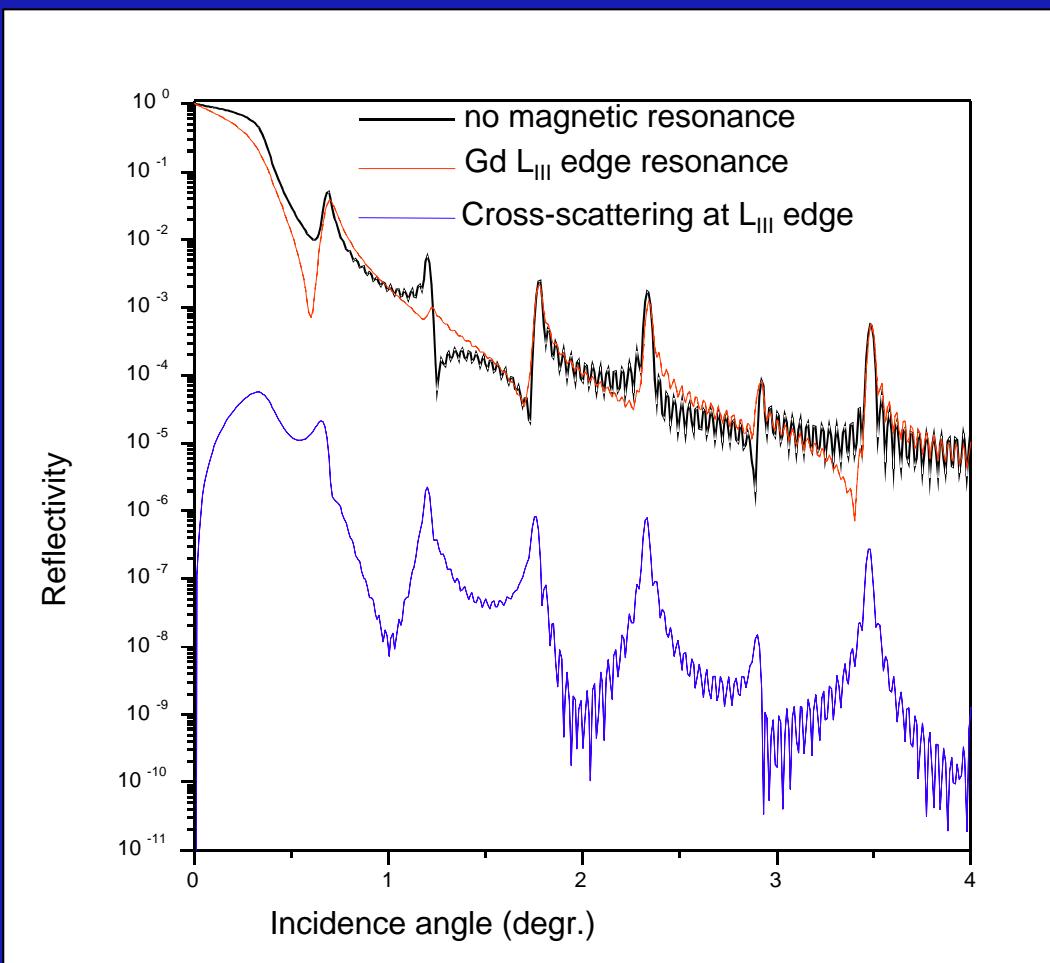
MAG_SL on the Web

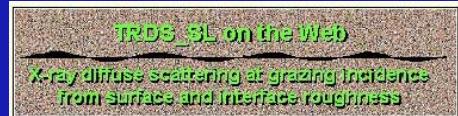
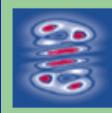
X-ray resonant specular reflection
from magnetic multilayers

Example web results

SPIE Annual Meeting 2004

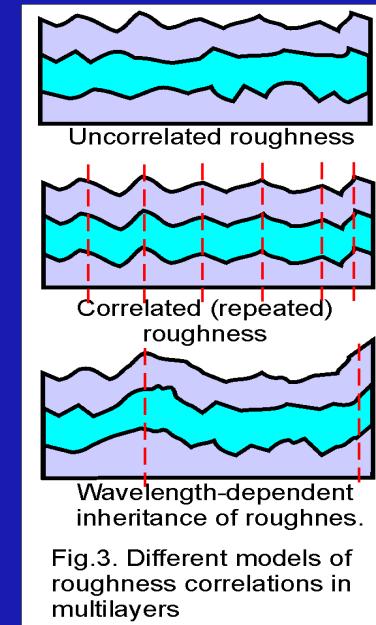
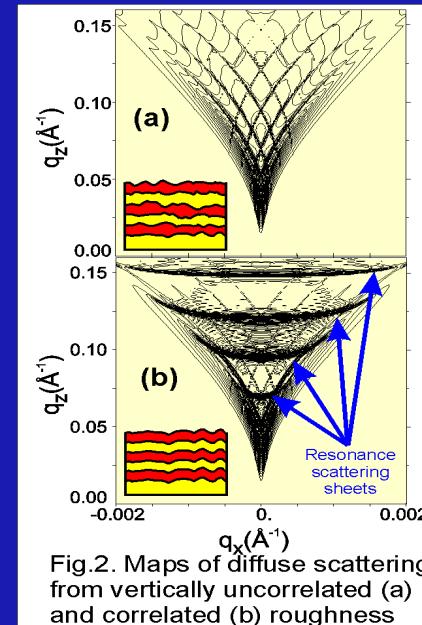
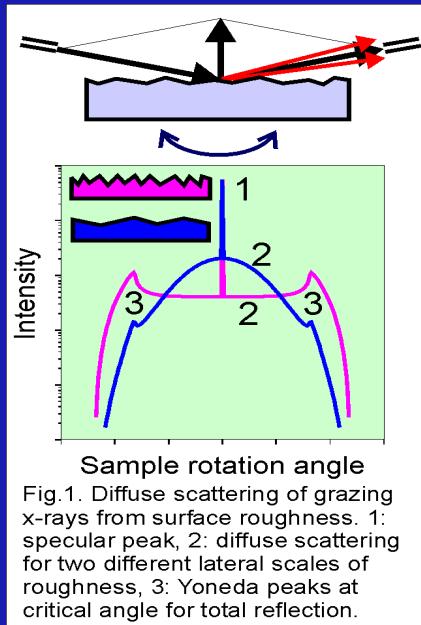
X-Ray Server

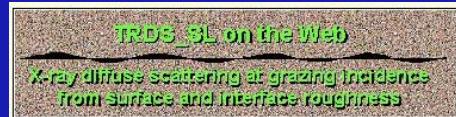
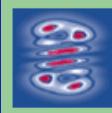




Background algorithm - I

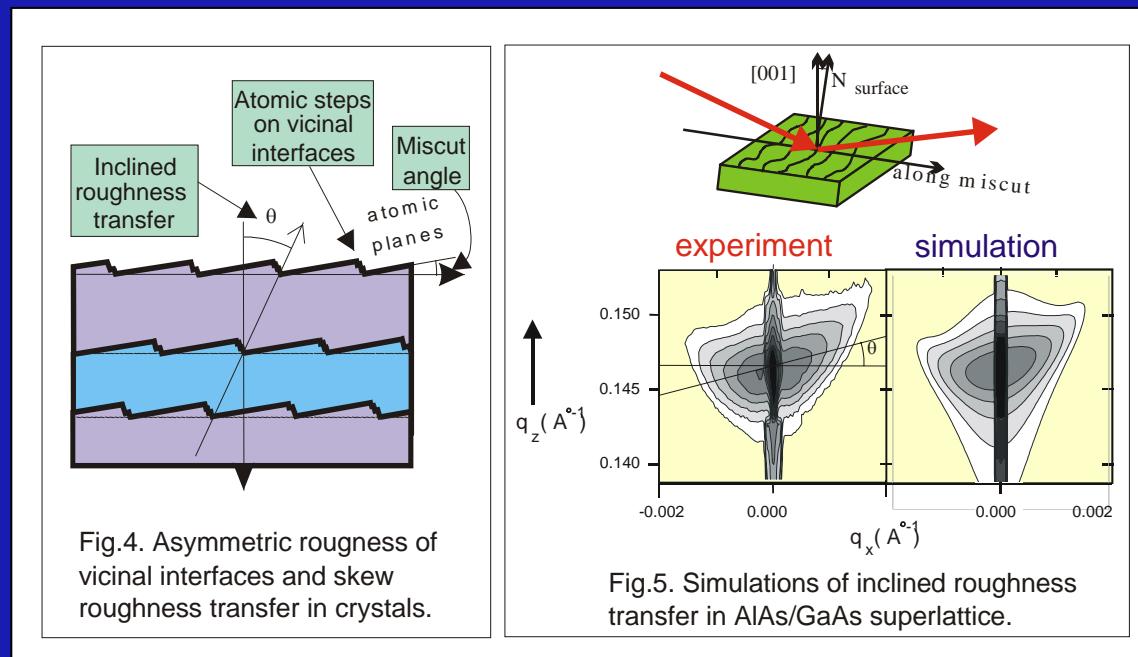
TRDS_sI (Total Reflection Diffuse Scattering from Superlattices) was developed for the simulations of X-ray diffuse scattering from interface roughness in multilayers (Fig.1). This program implement a number of different models for interface roughness and for correlations between roughness at different interfaces in multilayers (Fig.2). Notable is the implementation of the model allowing to study wavelength-dependent inheritance of roughness in layer-by-layer grown multilayers (Fig.3).





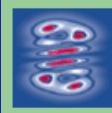
Background algorithm - II

Another notable models implemented in **TRDS_sI** are the X-ray scattering from atomic steps on vicinal interfaces and the scattering due to inclined roughness transfer in crystalline multilayers (Fig.4). Both of those effects provide asymmetry of x-ray diffuse scattering (Fig.5), but each of different kind.



E.A.Kondrashkina, S.A.Stepanov, R.Opitz, M.Schmidbauer, R.Koehler, R.Hey,
M.Wassermeier, and D.V.Novikov,

Phys. Rev. B, v.56, No 16, p. 10469-10482, (1997).



TRDS_BL on the Web

X-ray diffuse scattering at grazing incidence
from surface and interface roughness

Web form

X-rays: Wavelength(Å) / Energy(keV) = 1.540562 Line= Cu-Kα1 Polarization= Sigma

Substrate: Database code: GaAs X0h data (5-25keV; 0.5-2.5Å)
 Chemical formula: rho= g/cm³
 Susceptibility x0 = () / format: x0=(Re(x0), Im(x0)); note: x0=2*delta /
x0 correction: w0 = 1. / this is used as: x0 = w0 * x0 /
Roughness: sigma = 3. Angstrom / this is rms roughness height /

Type of scan: Q-scans at fixed 2Q Units for Q,2Q: degr. Units for qx,qz: 1/Å
Scan limits: from 0. to 2. points=201
Offset limits: from 2. to 2. points=1
Compute at specular rod: scattering reflection

Accelerators: Use K instead of exp(K)-1 Use semi-Born approximation

Roughness: lateral correlation length= 1000. A vertical correlation length= A jaggedness= 1.
angle of skew transfer= 0. degr.

Models:

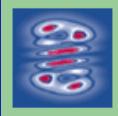
<input checked="" type="radio"/> Uncorrelated roughness
<input checked="" type="radio"/> Completely correlated roughness
<input type="radio"/> Ming's model
<input type="radio"/> Lagally's model lateral size of vertically correlated roughness= A
<input type="radio"/> Holy's model
<input type="radio"/> Spiller's model (*very slow!*)
Data for all Pukite's models:
<input type="radio"/> Classic Pukite's model
<input type="radio"/> Smoothed Pukite's model effective rms height of steps= A
<input type="radio"/> Pershan's model terraces size spread= A

watch progress Submit Query (single click, please!)

Top layer profile (optional):
period=
t= sigma= tr= code= rho= x= code2= x2= code3= x3= code4= x0= w0=
end period

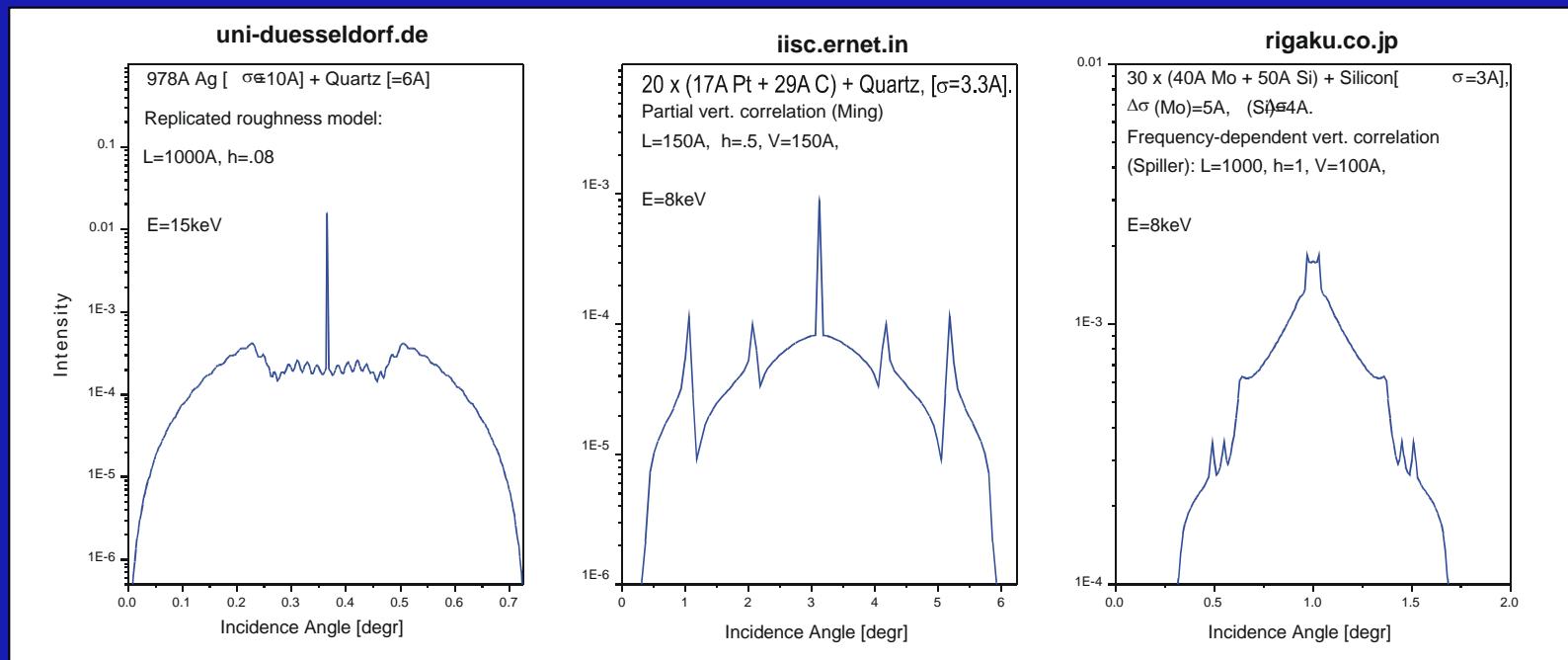
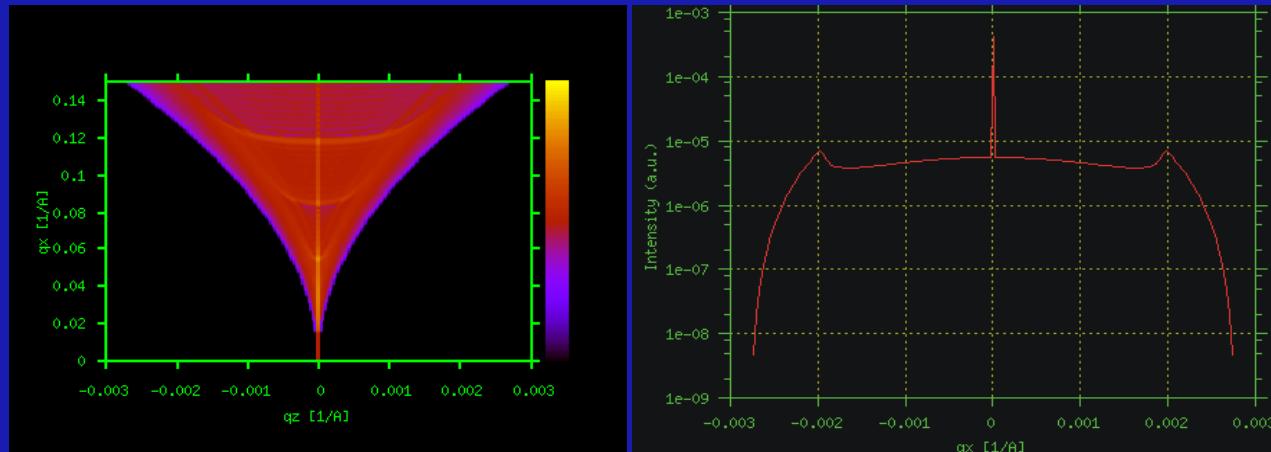
Available codes:
(use Copy/Paste)

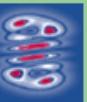
Ac
Ag
A1
Al2O3
...



TRDS_BL on the Web
X-ray diffuse scattering at grazing incidence
from surface and interface roughness

Example web results



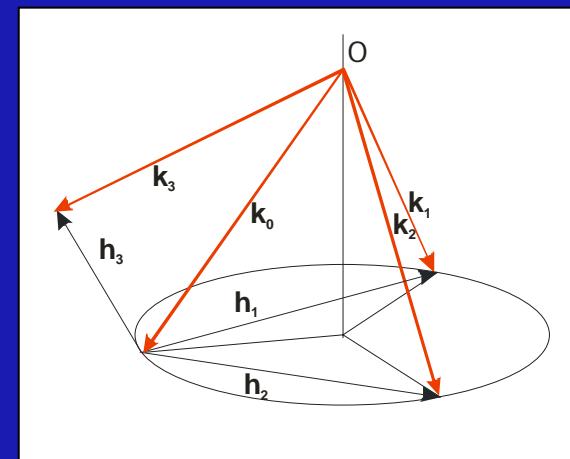


Background algorithm

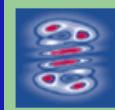
BRL (Bragg/Laue) calculates multiple Bragg diffraction patterns with the algorithm based on the extended dynamical diffraction theory.

Typically the calculations of multiple Bragg diffraction are reduced to the eigenvalue problem for a $2N \times 2N$ scattering matrix. However, when the diffraction geometry involves grazing X-ray waves, the calculations are reduced to the eigenvalue problem for $4N \times 4N$ scattering matrix [Colella, Acta Cryst. **A30** (1974) 413].

BRL implements an algorithm where the calculations are reduced to a *generalized* eigenvalue problem for $2(N+N_s) \times 2(N+N_s)$ scattering matrix where N_s is the number of grazing waves. Thus, if there are no grazing waves, the matrix size is $2N \times 2N$ and if all of the waves are grazing it becomes $4N \times 4N$. In some cases the calculations are reduced dramatically.



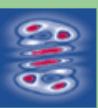
S.Stepanov and A.Ulyanenkov, Acta Cryst. **A50** (1994) 579-585.



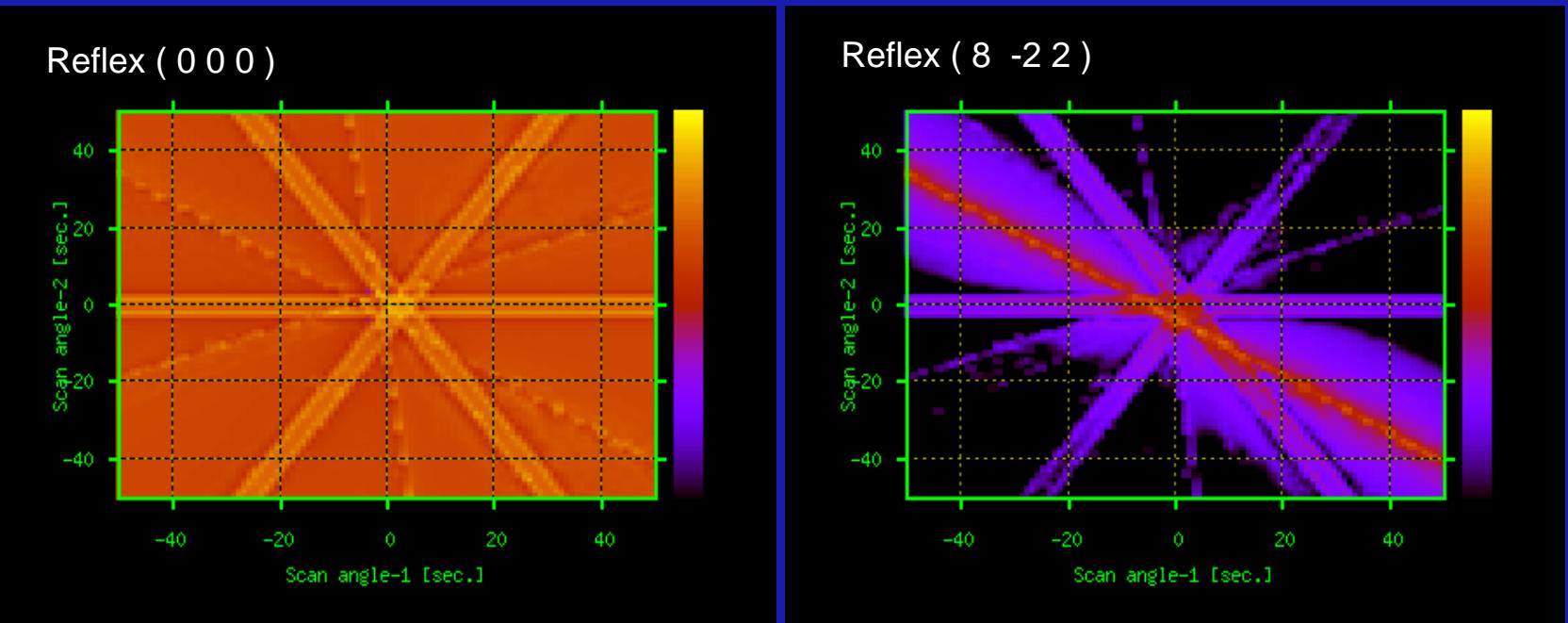
Web form

Target:Crystal: Silicon Surface: Base plane: Miscut direction: Miscut angle: degr. **Reflections:**Reflex-1: Reflex-2: Index search range: Min. Intensity filter:
($|xh/x0| * 100\% > \dots$)**X-rays:** Wavelength (Å): Energy (keV): Characteristic line: Cu-Ka1 Fixed by coplanar case Fixed by Reflex-3: **Database Options for dispersion corrections df1, df2:**

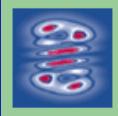
- Use X0h data (5-25 keV or 0.5-2.5 Å) -- *recommended*
- Use Henke data (0.01-30 keV or 0.4-1200 Å)
- Use Brennan-Cowan data (0.03-700 keV or 0.02-400 Å)



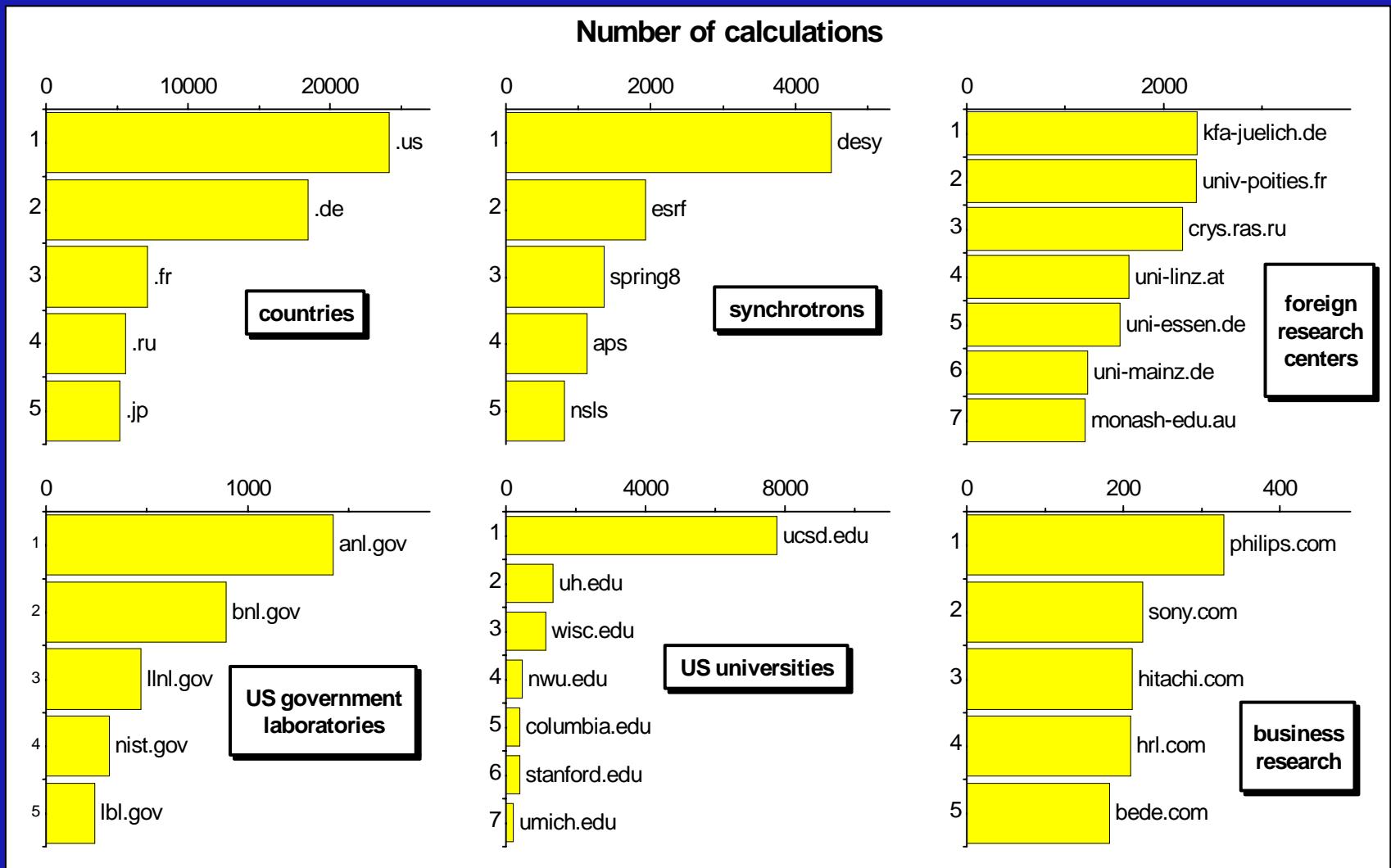
monash.edu.au

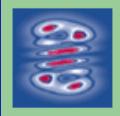


Some maps produced by 10-wave case calculations
(Silicon, $\lambda = 0.6968004107\text{\AA}$)

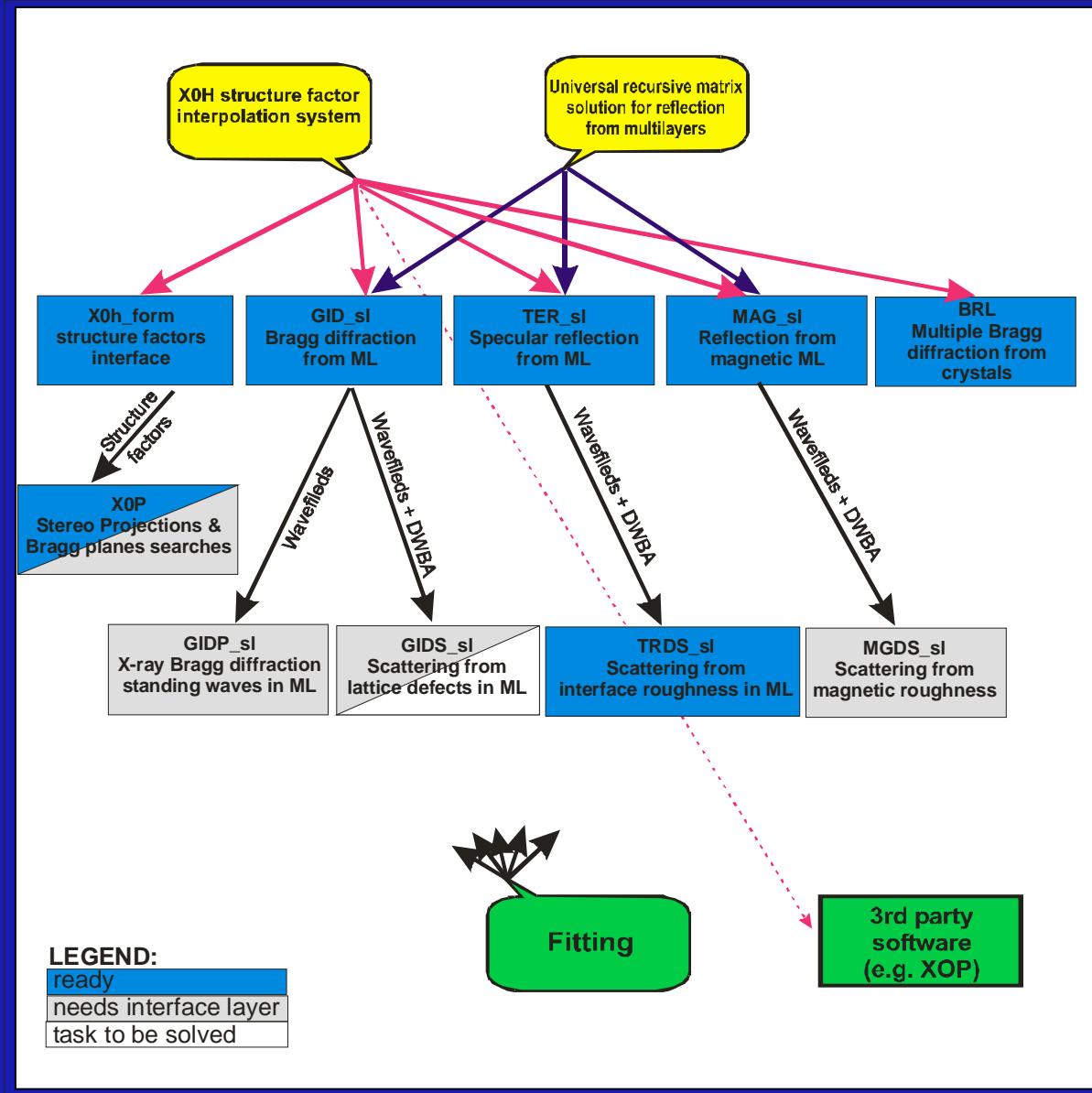


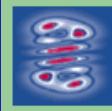
Some X-ray Server statistics





Future Server plans

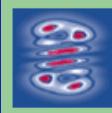




Conclusions

We have given 7-years test to a new technology of sharing research results. It was proven to be:

- Complimentary to a scientific publication
- Reaching wide audience with small extra effort
- Great for refining scientific software
- Helping to establish new collaborations
- Very useful for scientific community



Acknowledgements

Co-authors of algorithm presented through the X-ray Server:

S.Durbin, T.Jach, B.Jenichen, V.Kaganer, R.Koehler, E.Kondrashkina, O.Lugovslaya, G.Materlik, D.Novikov, U.Pietsch, S.Sinha, A.Souvorov, A.Ulyanenkov.

X-ray Server users contributed by their feedback:

B.Barnes, A.Van der Lee, G.Bertschinger, D.Black, C.Blome, W.Cai, G.Ceriola, K. Chandrasekaran, H.Chapman, Y.Danon, A.Declemy, C.Dufour, R.Forrest, M.Dias Franco, M.Grundmann, E.Gullikson, L.Hudson, E.Ikonen, C.-C.Kao, J.Langer, B.Lings, J.Santiso, R. Medicherla, A. Fontcuberta-i-Morral, P.Muduli, P.Nilsson, C.Noyan, R.Osgood, F. Pfeiffer, E.Roa, X.Huang, D. Satapathy, D. Schroff, M. Servidori, X.Su, S.Warren, M.Weimer, M.Zhong, and many others!

X-ray Server hosts:

Management of BIO and GM/CA Collaborative Access Teams at the Advanced Photon Source for hosting X-ray Server on their computers. The GM/CA and BIO CATs are the research centers sponsored by the National Institutes of Health.