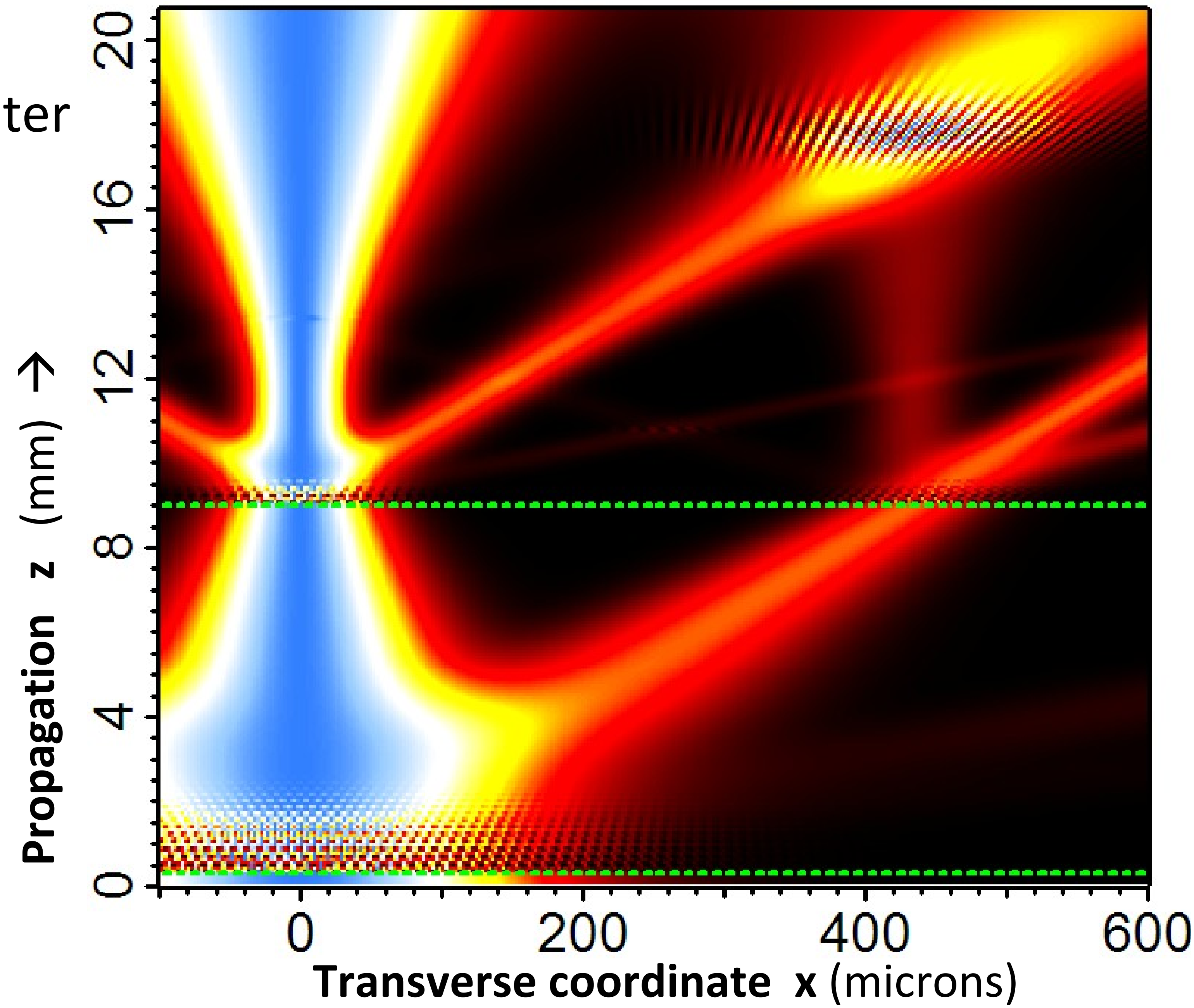
Grating Interferometer Simulation



McMorran B. and Cronin, A.D., "Model for partial coherence and wavefront curvature in grating interferometers," Phys. Rev. A. **78**, 013601 (2008)

Outline

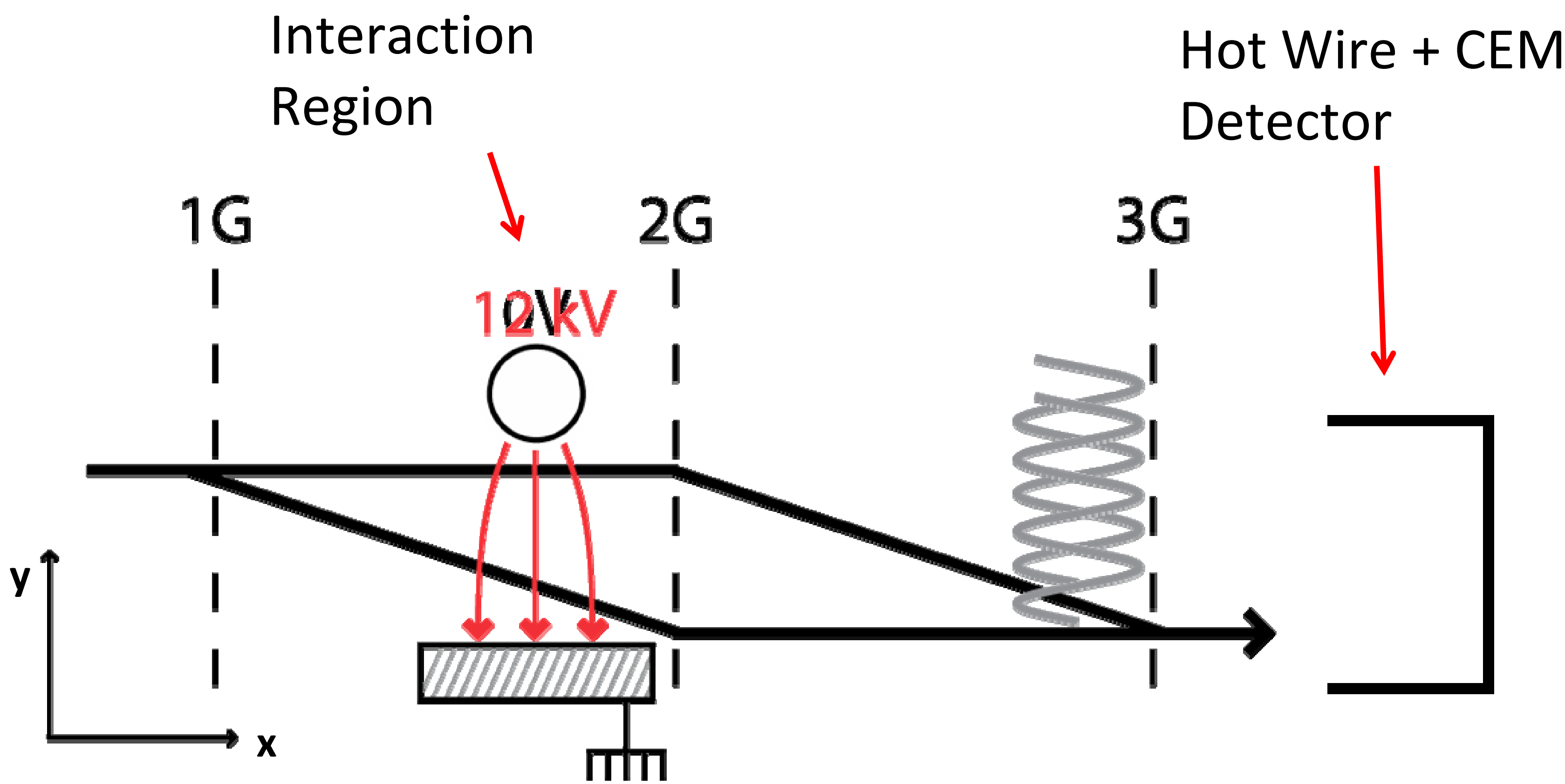
1. **New polarizability measurements**

2. **Atom Interferometry C3 measurements**
   - **tests of potential power law**
   - **limits on non-Newtonian gravity**

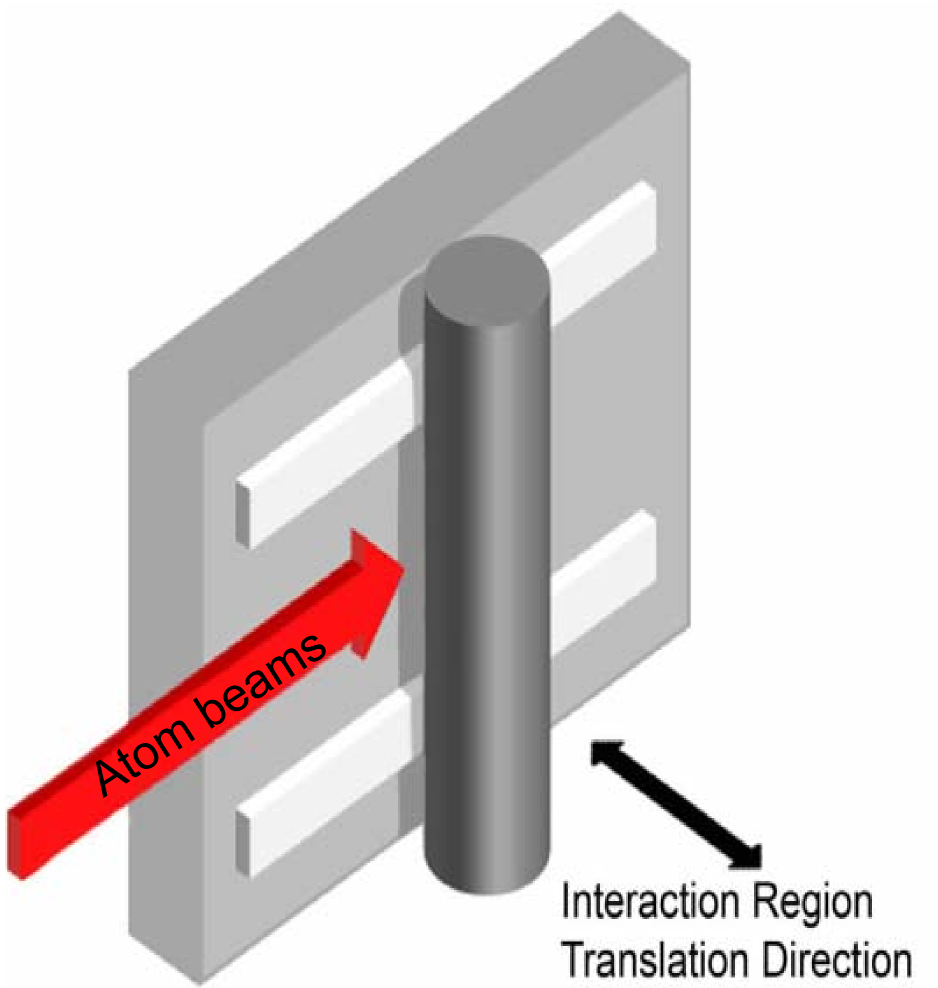
3. **More precise diffraction experiments**
   - **Magic open fraction**
   - **Effect of AuPd**
   - **Ratios of C3 for Rb, K, Na**

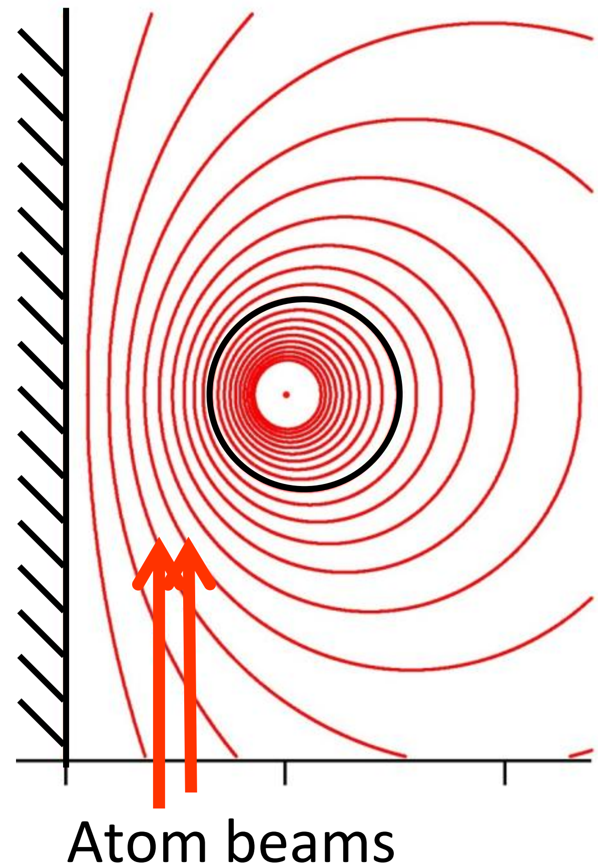
4. **Laser modified vdW interactions**

Polarizability experiment

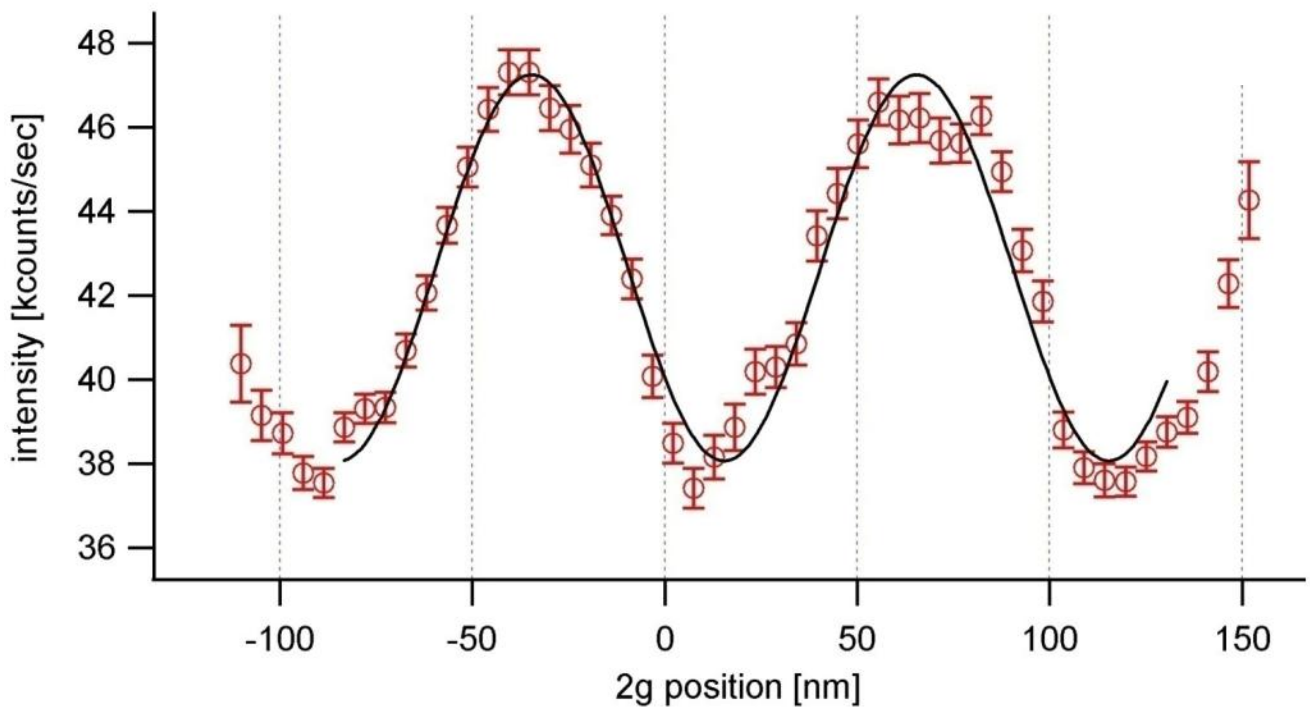


Interaction Region



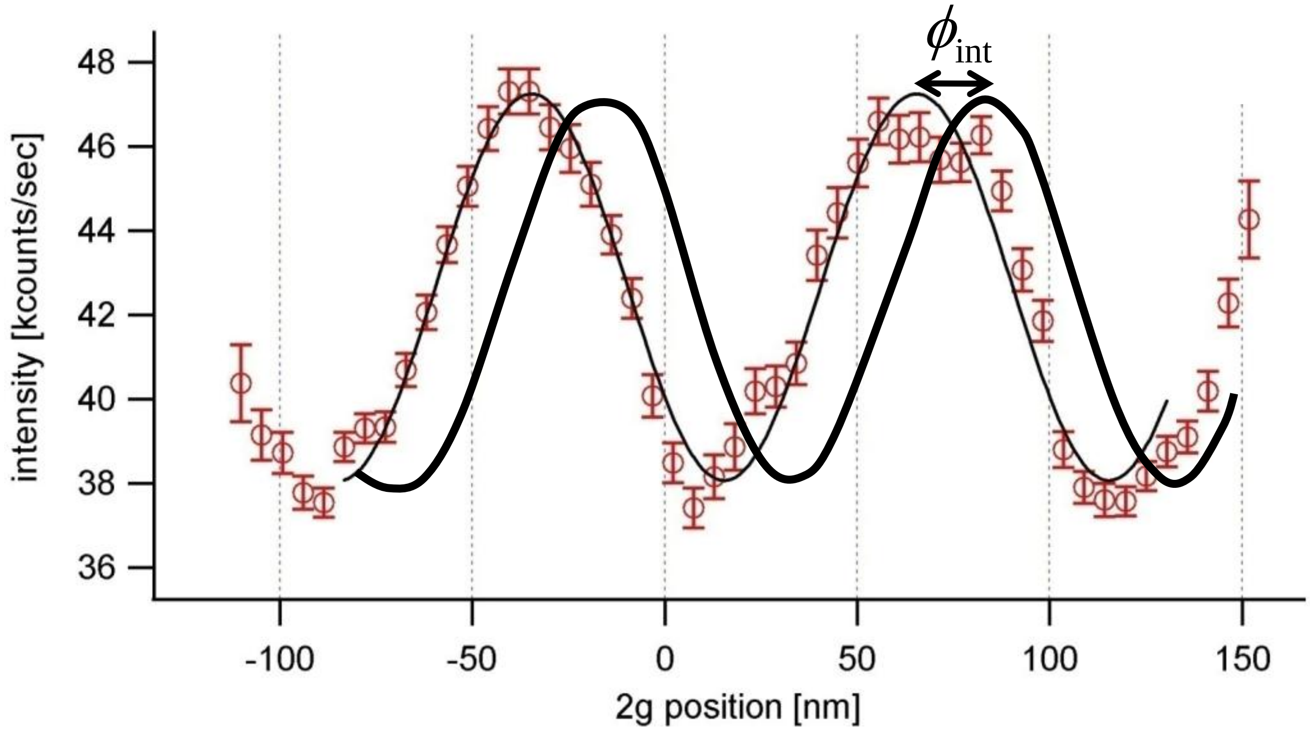


Interference Fringe Data

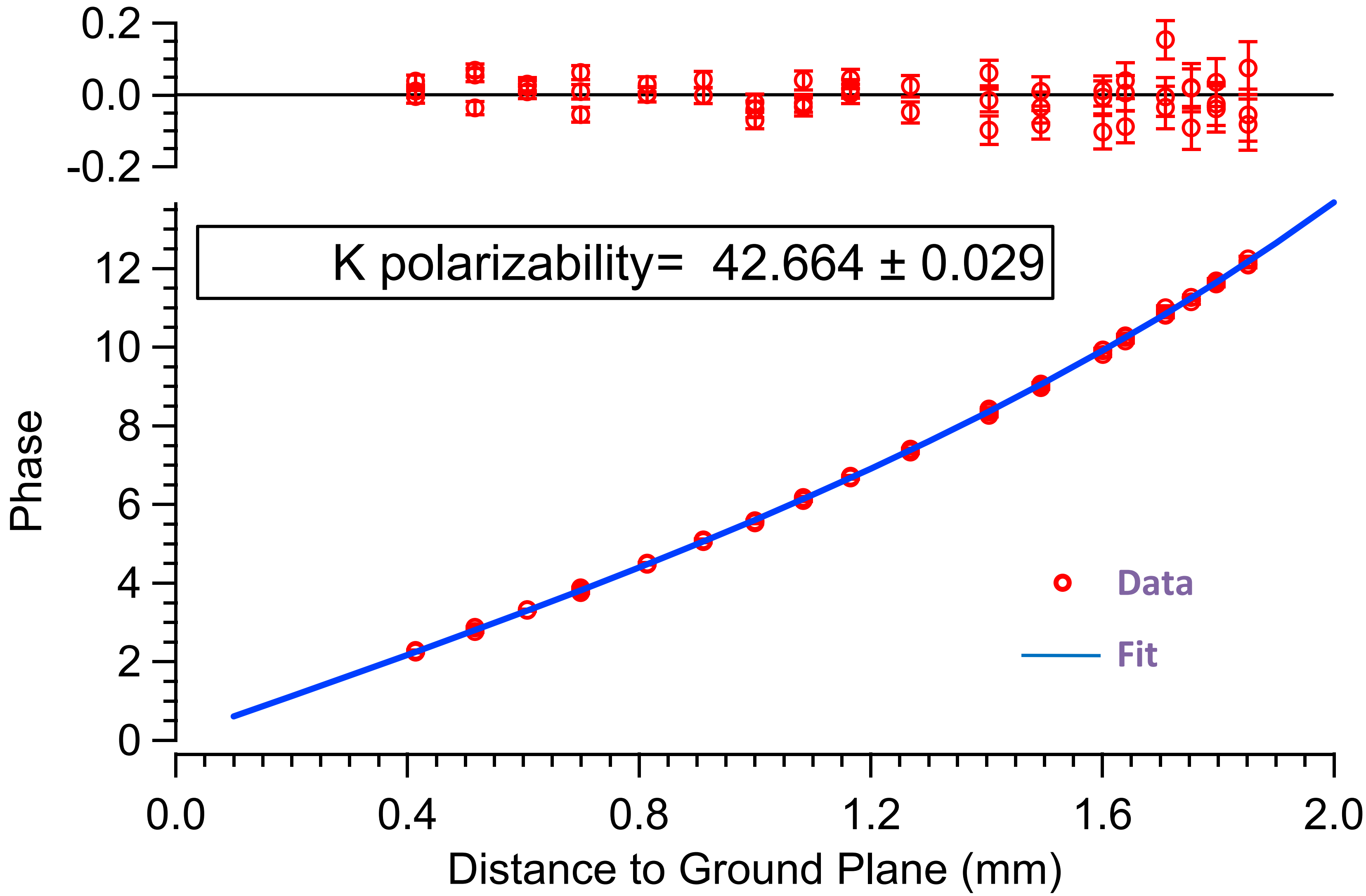


- **We record atom flux vs grating position**

Interference Fringe Data

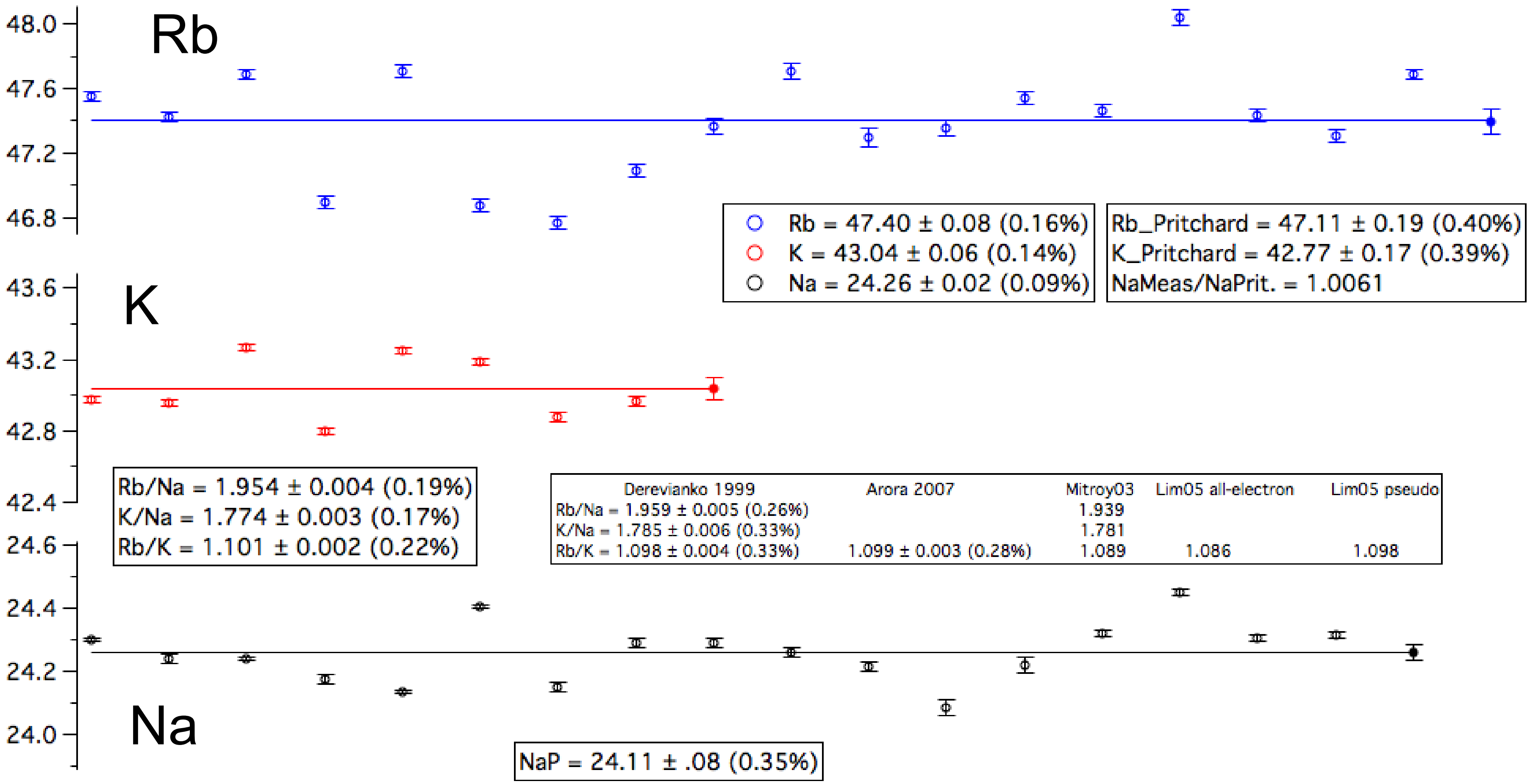


- **We record atom flux vs grating position**
- **Polarizability relates to this phase shift**



0.2
0.0
-0.2
K polarizability= 42.664 ± 0.029
12
10
8
6
4
2
0
Phase
Data
Fit
0.0
0.4
0.8
1.2
1.6
2.0
Distance to Ground Plane (mm)

Preliminary Polarizability Experiment Results



Preliminary Results from Polarizability Measurements

α_{Na} = 24.26 (0.09% stat) (1% syst)

α_{K} = 43.04 (0.14% stat) (1% syst)

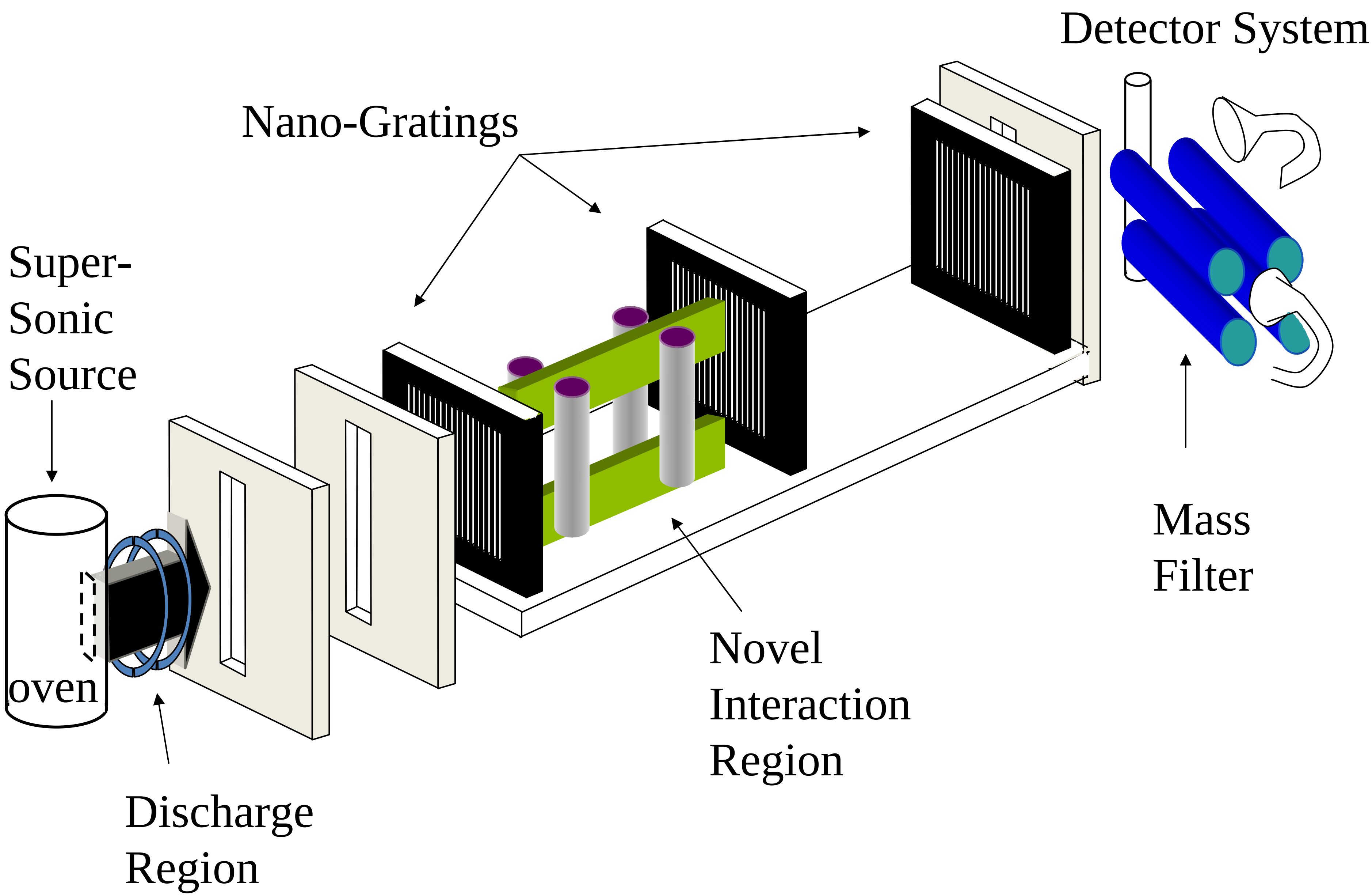
α_{Rb} = 47.40 (0.16% stat) (1% syst)

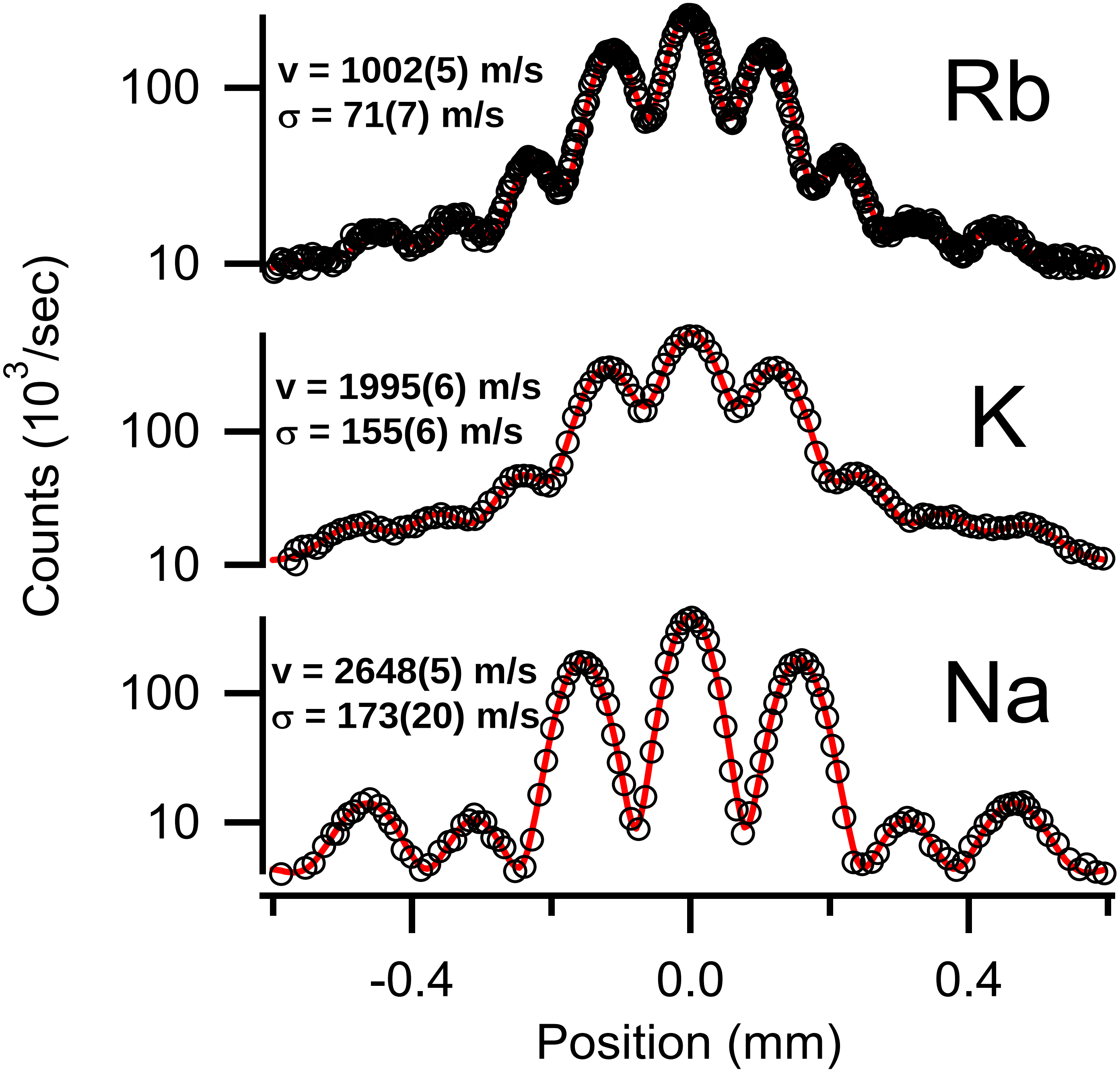
U. Arizona (2009) Experiment: $$\frac{\alpha_K}{\alpha_{Na}} = 1.774 \pm 0.003$$

Derevianko (1999) Calculation: $$\frac{\alpha_K}{\alpha_{Na}} = 1.785 \pm 0.006$$

Experiment ratio precision: 0.26% Theory: 0.33%. Disagreement: 0.6%

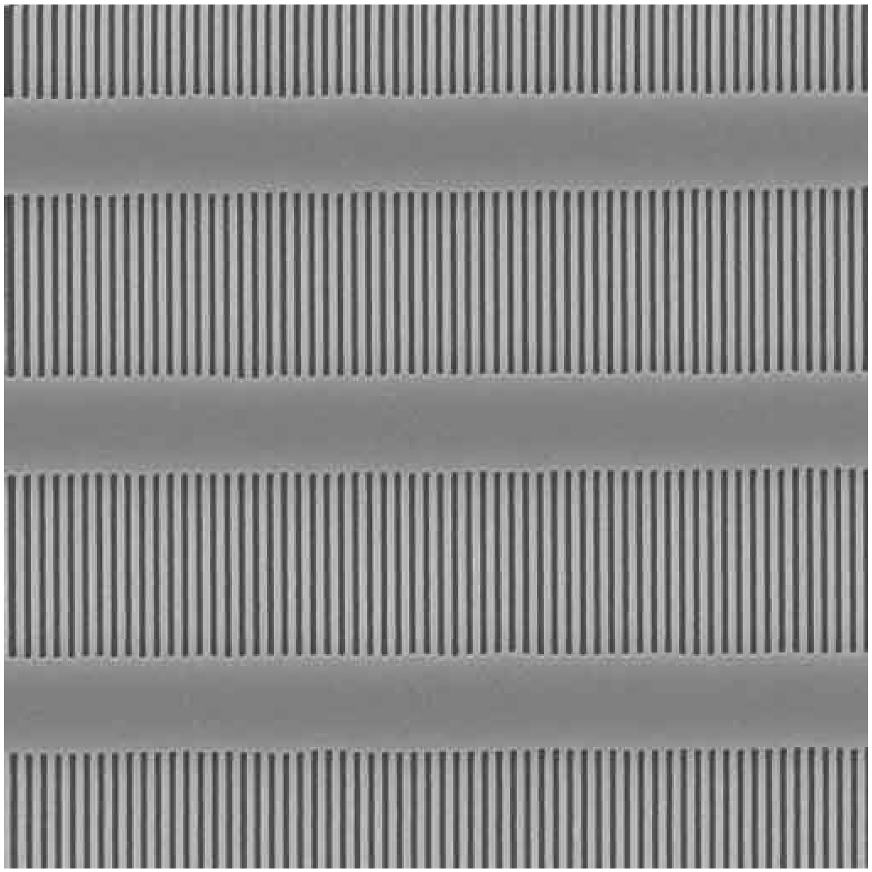
Plan for α_{Sr^*}

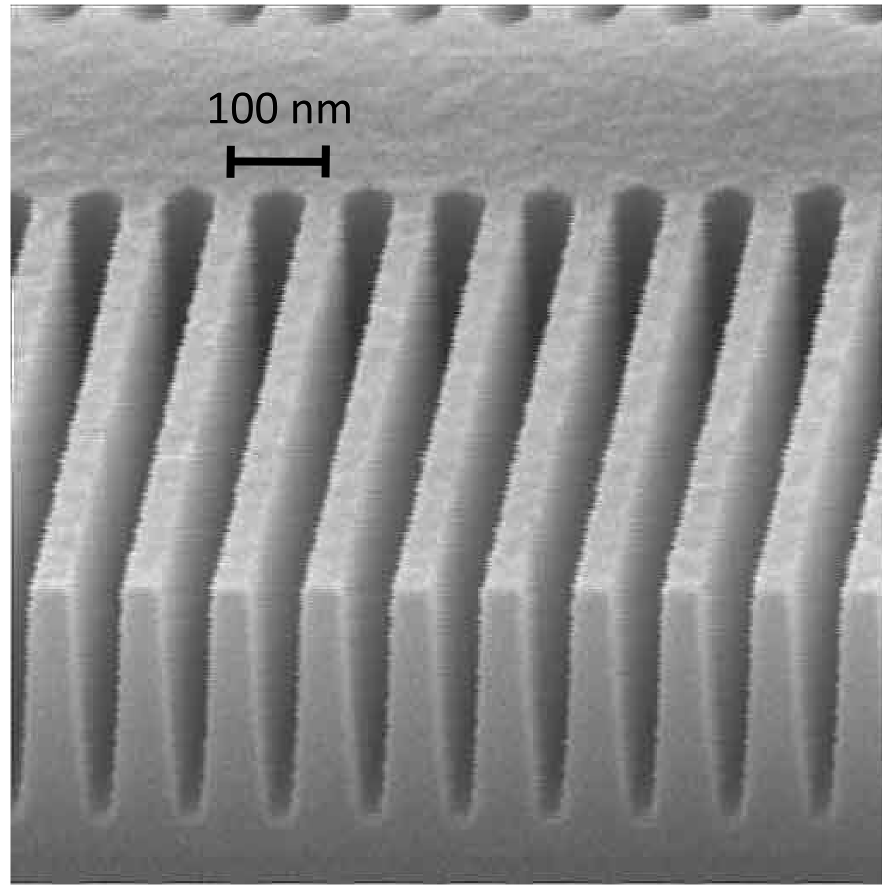


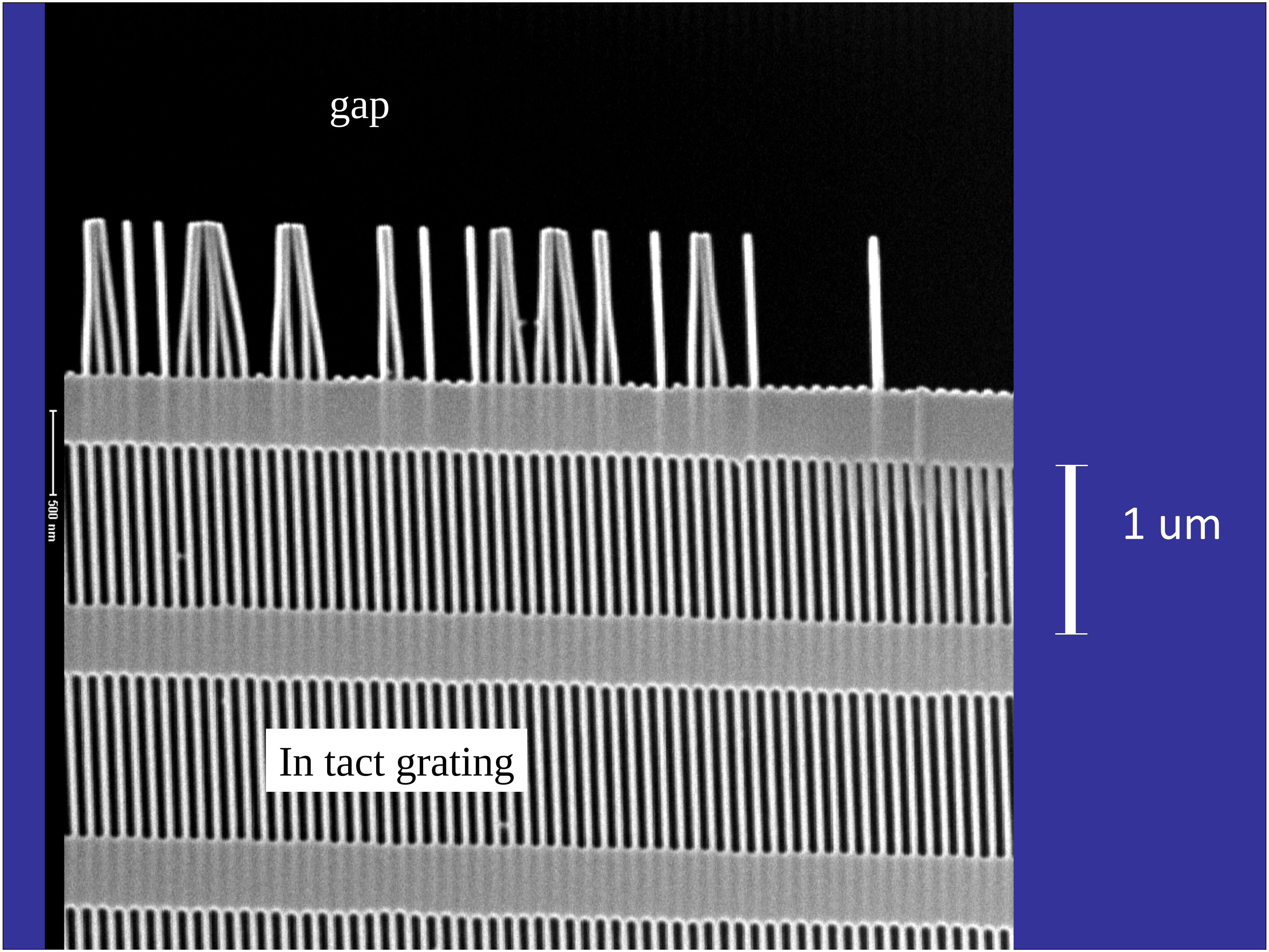


v = 1002(5) m/s
σ = 71(7) m/s
Rb
v = 1995(6) m/s
σ = 155(6) m/s
K
v = 2648(5) m/s
σ = 173(20) m/s
Na
100
10
Counts (10^3/sec)
-0.4
0.0
0.4
Position (mm)

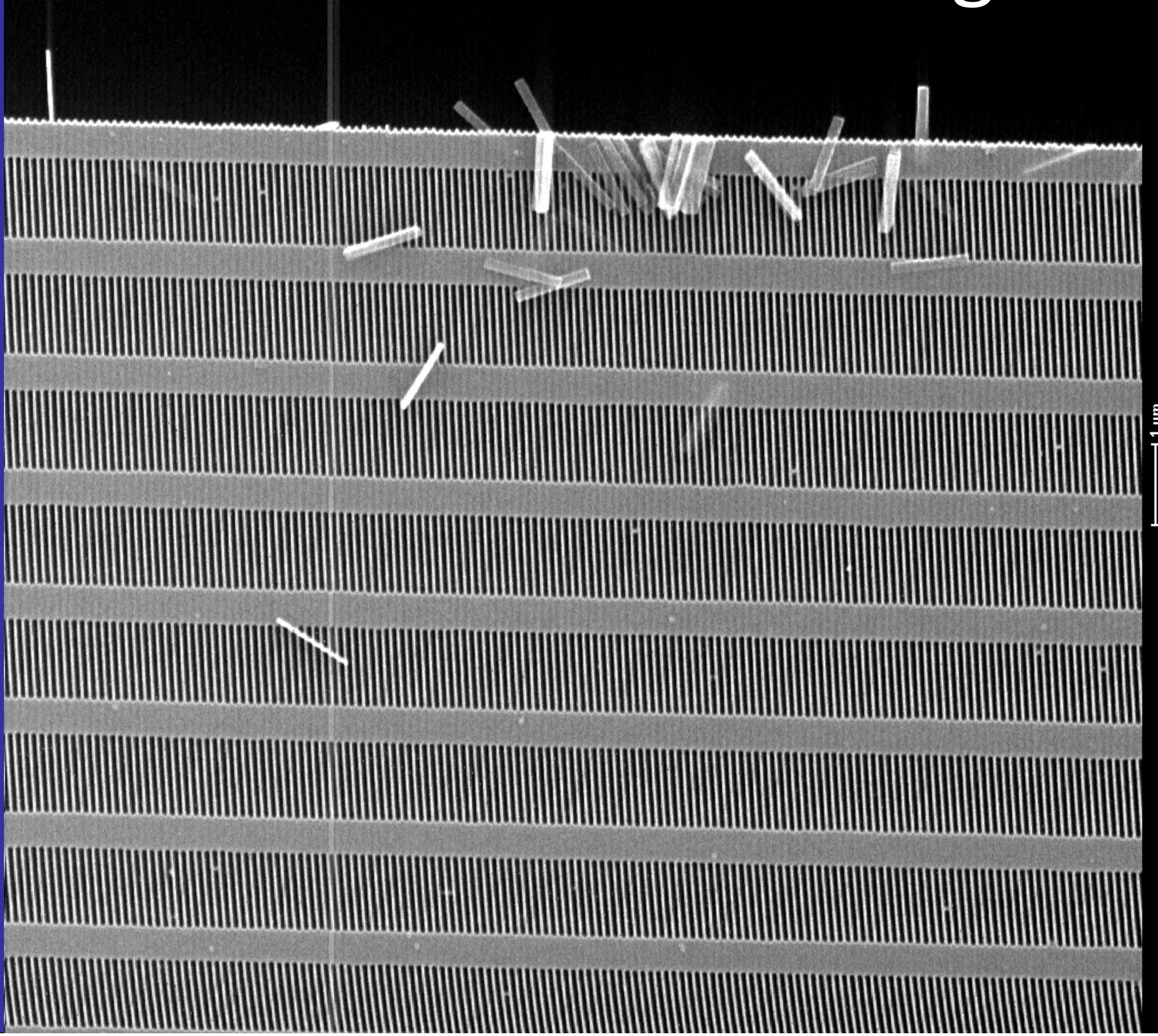
Nano-Grating beam splitters






gap
500 nm
In tact grating
1 um

Nano-Structure Grating



1 um

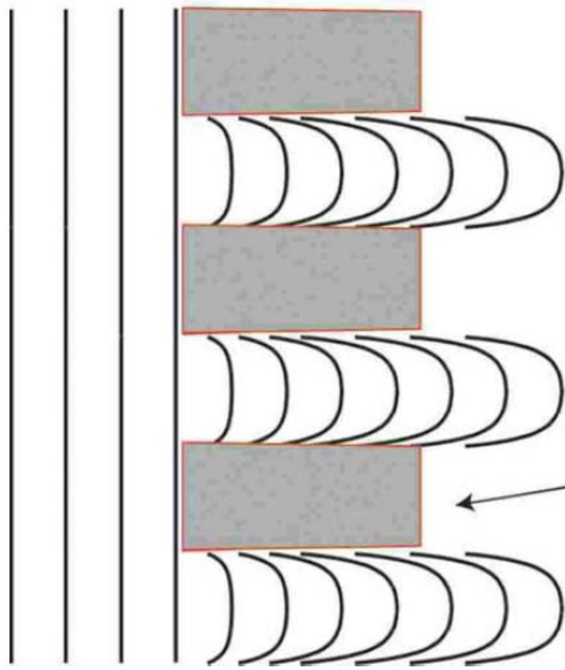


FIG. 63. (Color online) Distorted de Broglie waves. van der Waals interactions with mechanical grating bars cause near-field phase shifts. This view is exaggerated: in beam experiments there are typically 10^4 wave fronts in the 100-nm thickness of a nanograting slot (Grisenti *et al.*, 1999; Perreault *et al.*, 2005).

Cronin, A.D., Schmiedmayer J., and Pritchard D.E., “Optics and Interferometry with atoms and molecules.” Rev. Mod. Phys **81**, 1051 (2009)

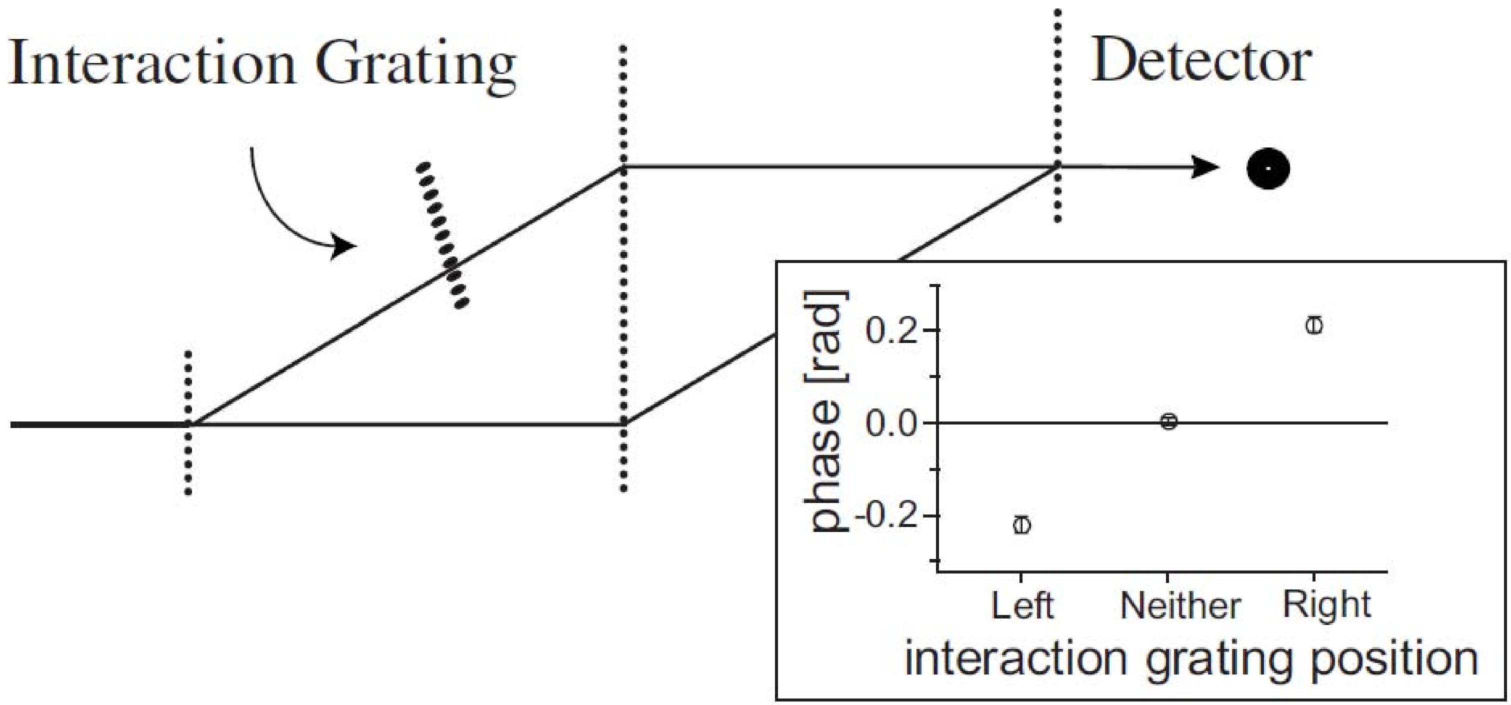


FIG. 68. An "interaction grating" was inserted and removed from each path of an interferometer to measure the phase shift Φ_0 due to van der Waals interactions (Perreault and Cronin, 2005).

Cronin, A.D., Schmiedmayer J., and Pritchard D.E., "Optics and Interferometry with atoms and molecules." Rev. Mod. Phys **81**, 1051 (2009)

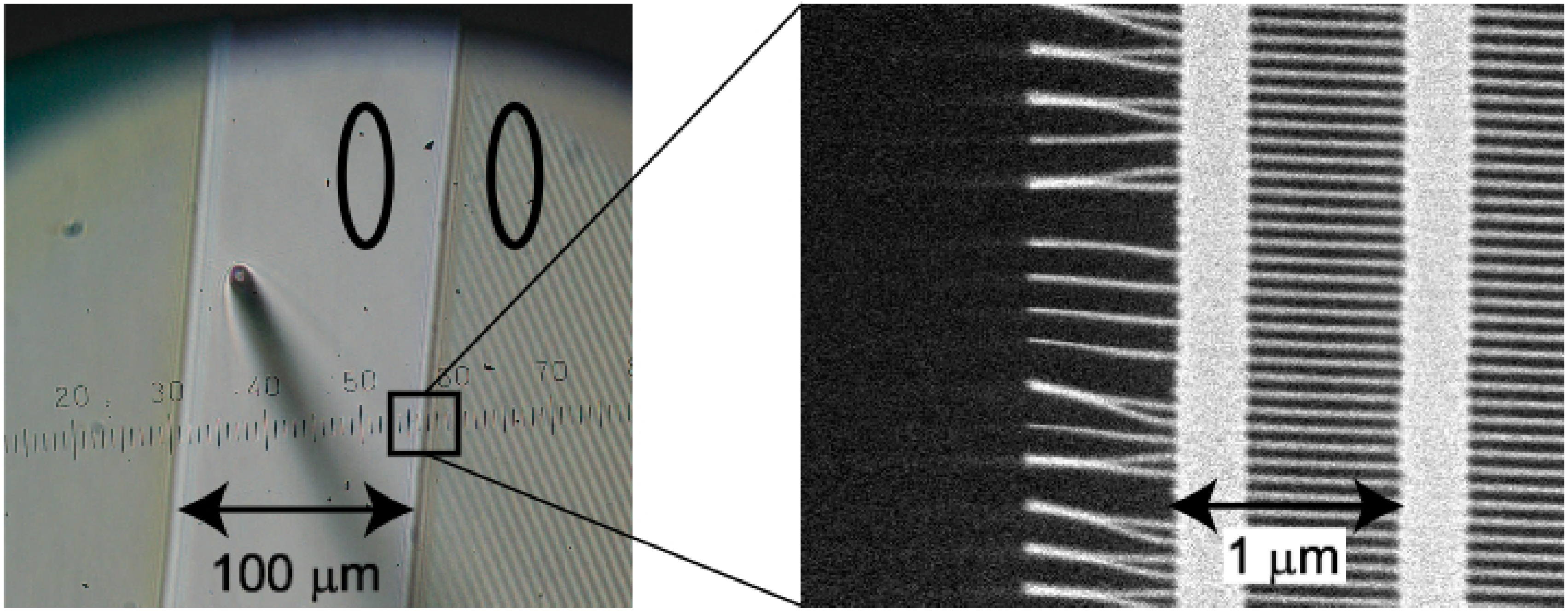
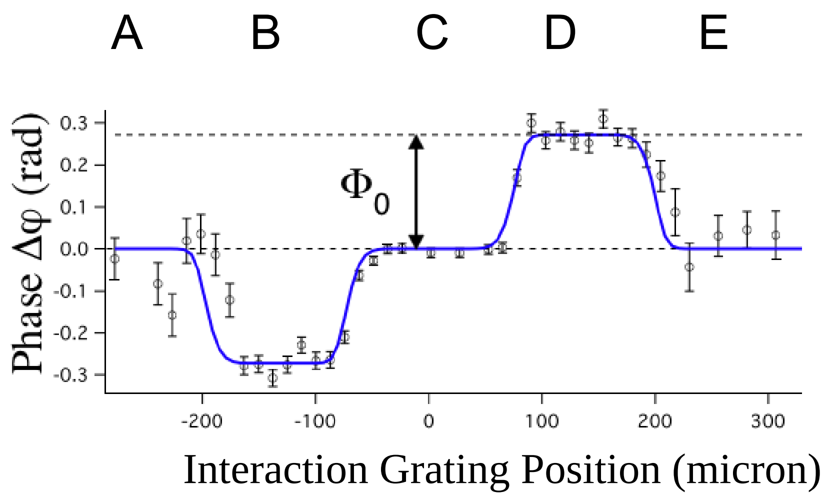
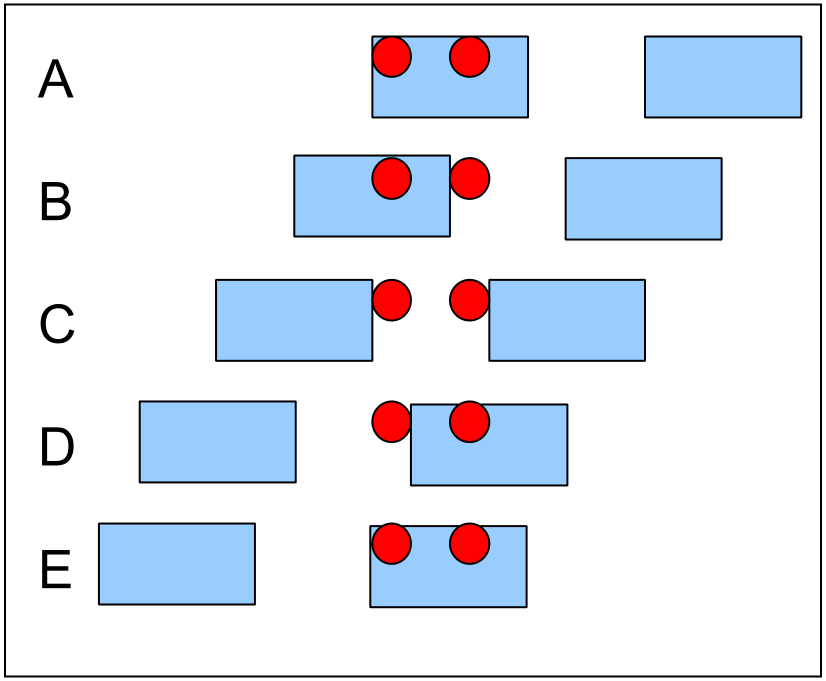


Figure 5.4: Preparation of interaction grating. The left image shows an optical micriscope image with the glass capillary tube in the perforation. The ellipses represent the test and reference arms (not to scale) of the interferometer going into the page. The scanning electron microscope image on the right shows a further magnified view of the transition from intact grating to gap.

From John Perreault PhD Thesis (2005) www.atomwave.org

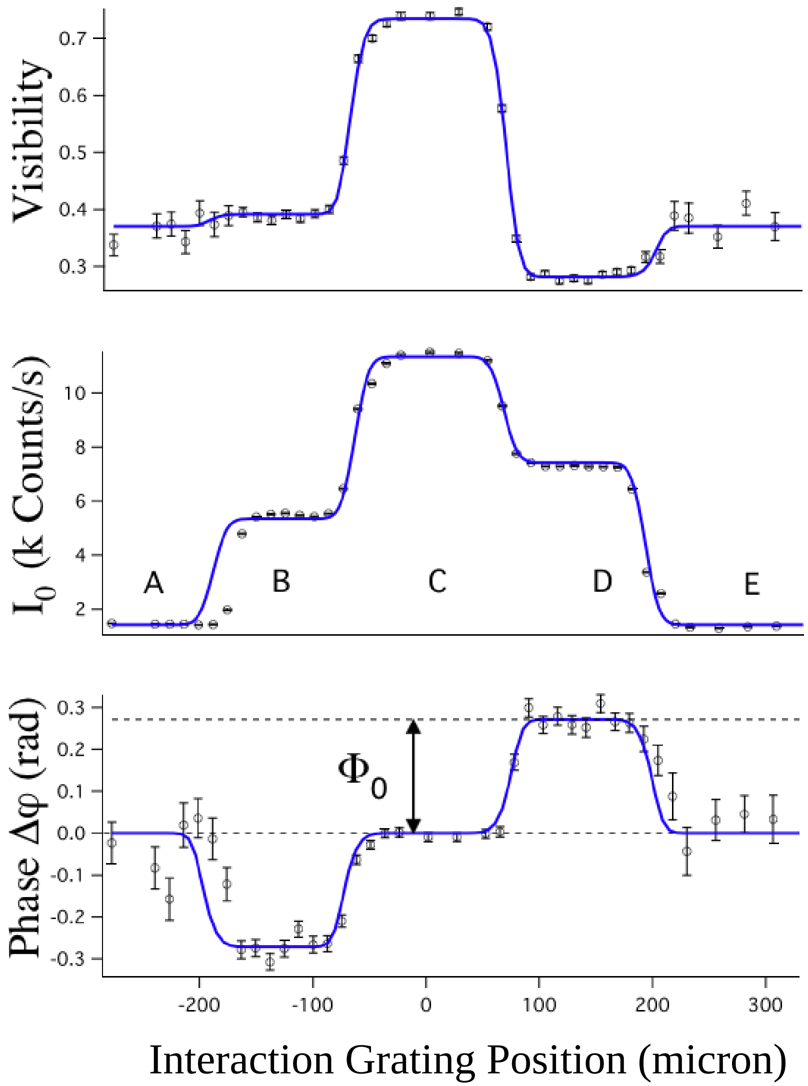
Phase vs Interaction Grating Position

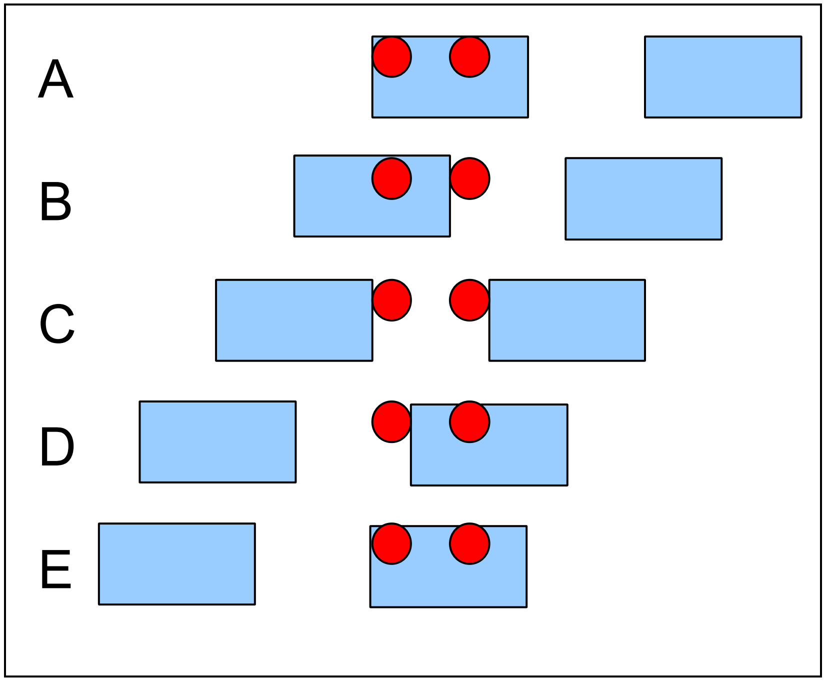




Lepoutre, S., Haikel J., Trenec G., Bruchner M., Vigue J., Lonij V., and Cronin A.D., “Dispersive atom interferometry phase shifts due to atom-surface interactions,” submitted to Europhysics Letters, (2009)

Visibility, Intensity, and Phase





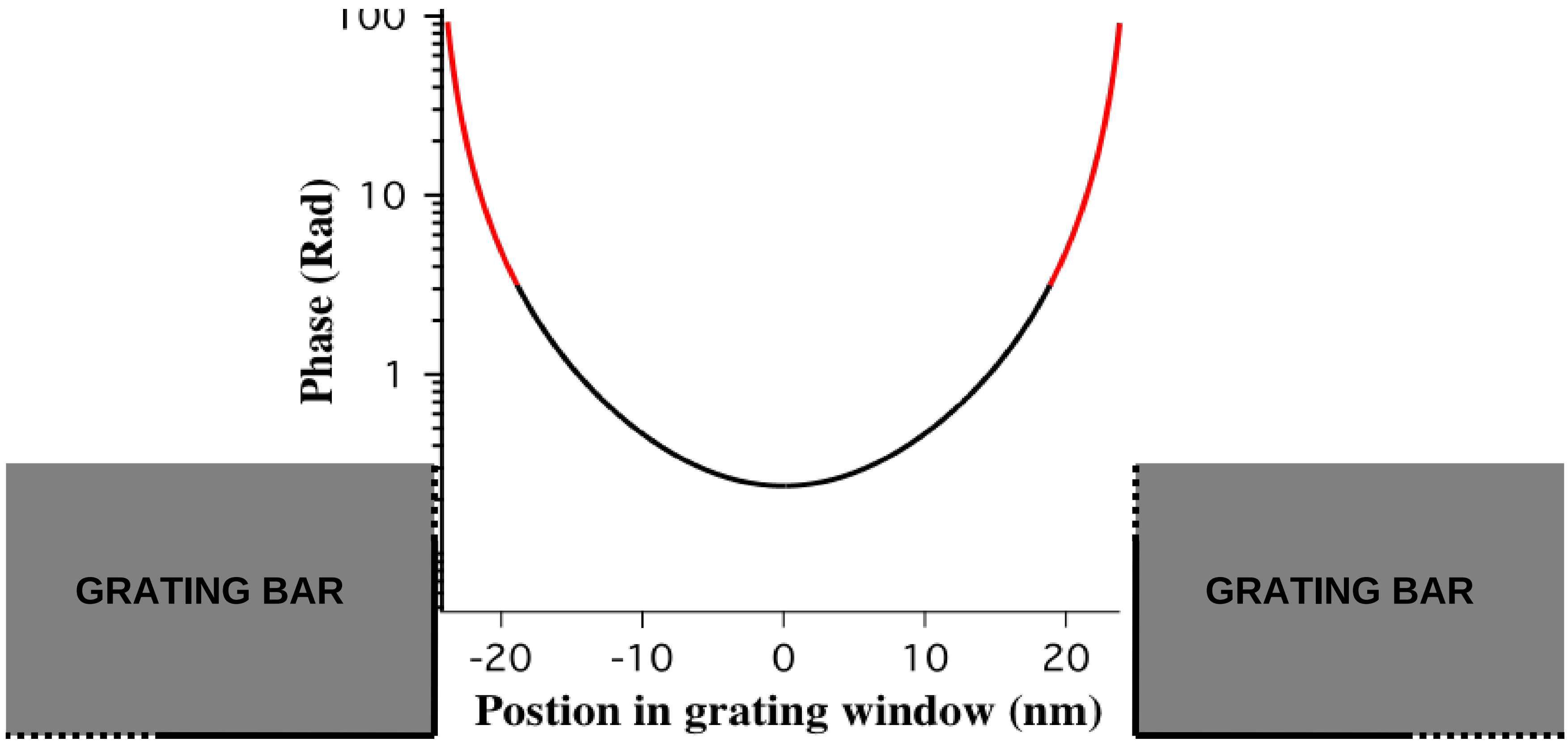
Acquired phase

near field

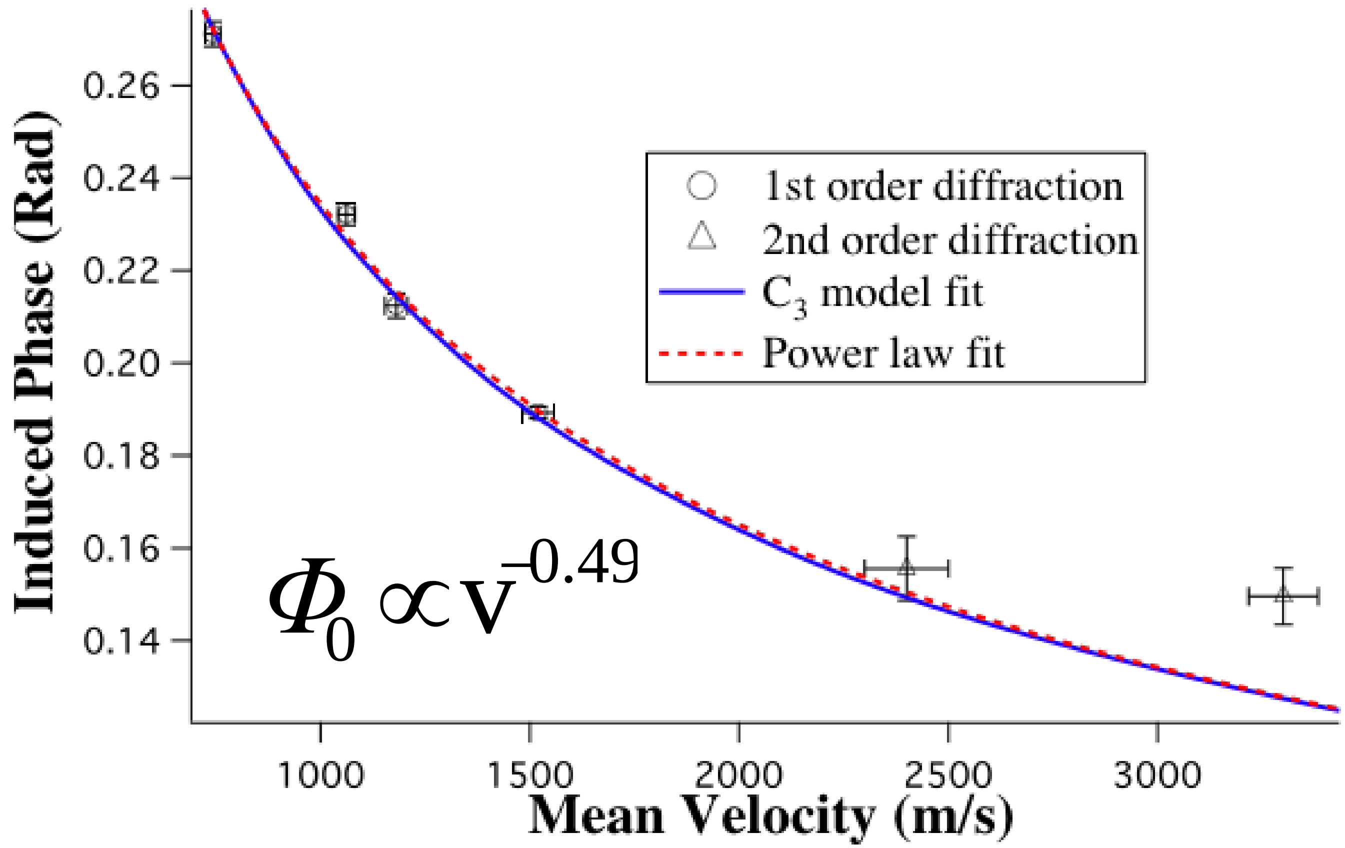
$$\phi(x) \propto \frac{C_3}{\hbar}\left[x_1^{-3} + x_2^{-3}\right]\frac{L}{v}$$

far field

$$\Phi_0 = \arctan\left(\frac{\int_{-w/2}^{w/2}\sin[\phi(x)]dx}{\int_{-w/2}^{w/2}\cos[\phi(x)]dx}\right)$$

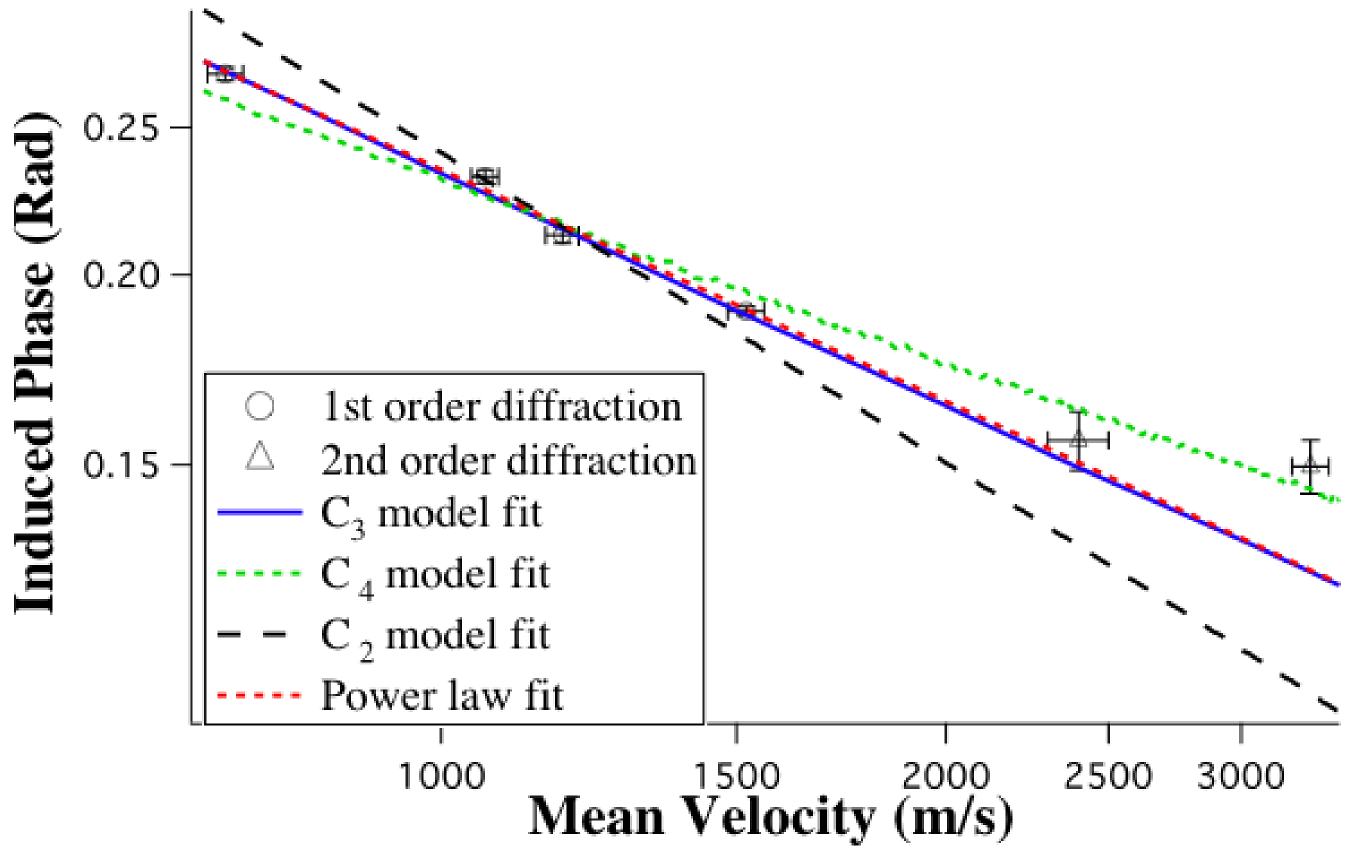


Velocity Dependence



Lepoutre, S., Haikel J., Trenec G., Bruchner M., Vigue J., Lonij V., and Cronin A.D., "Dispersive atom interferometry phase shifts due to atom-surface interactions," submitted to Europhysics Letters, (2009)

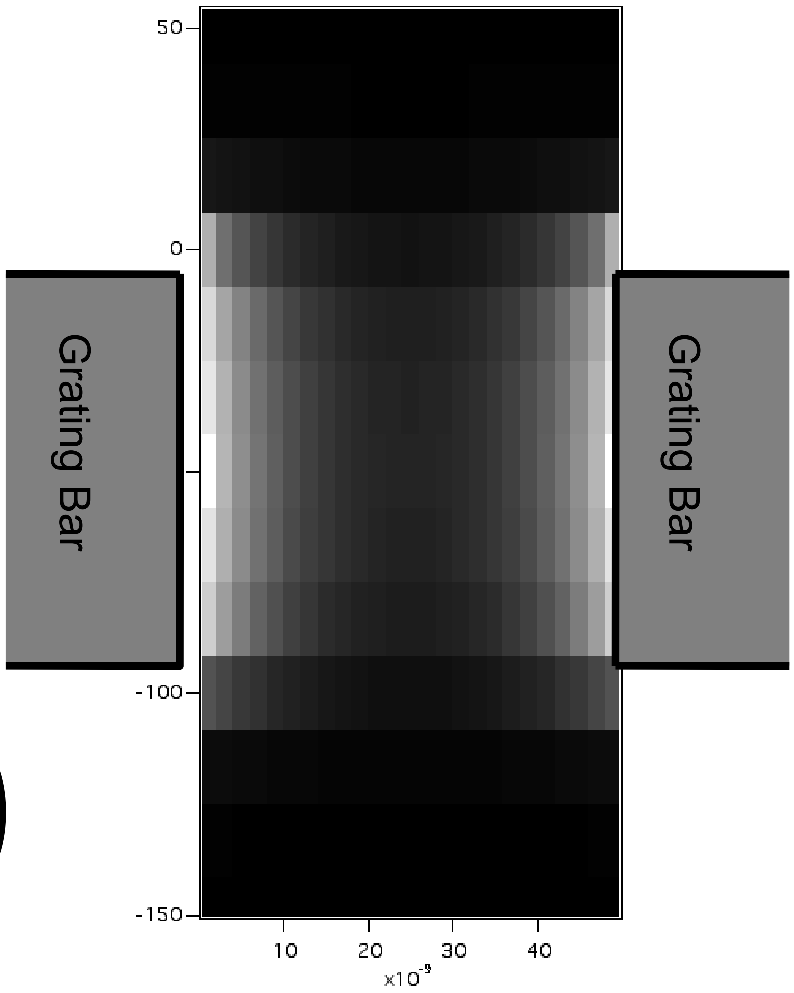
Testing the Potential Power Law



$$U = -\frac{C_p}{r^p} \qquad p = 2.9 \pm .2$$

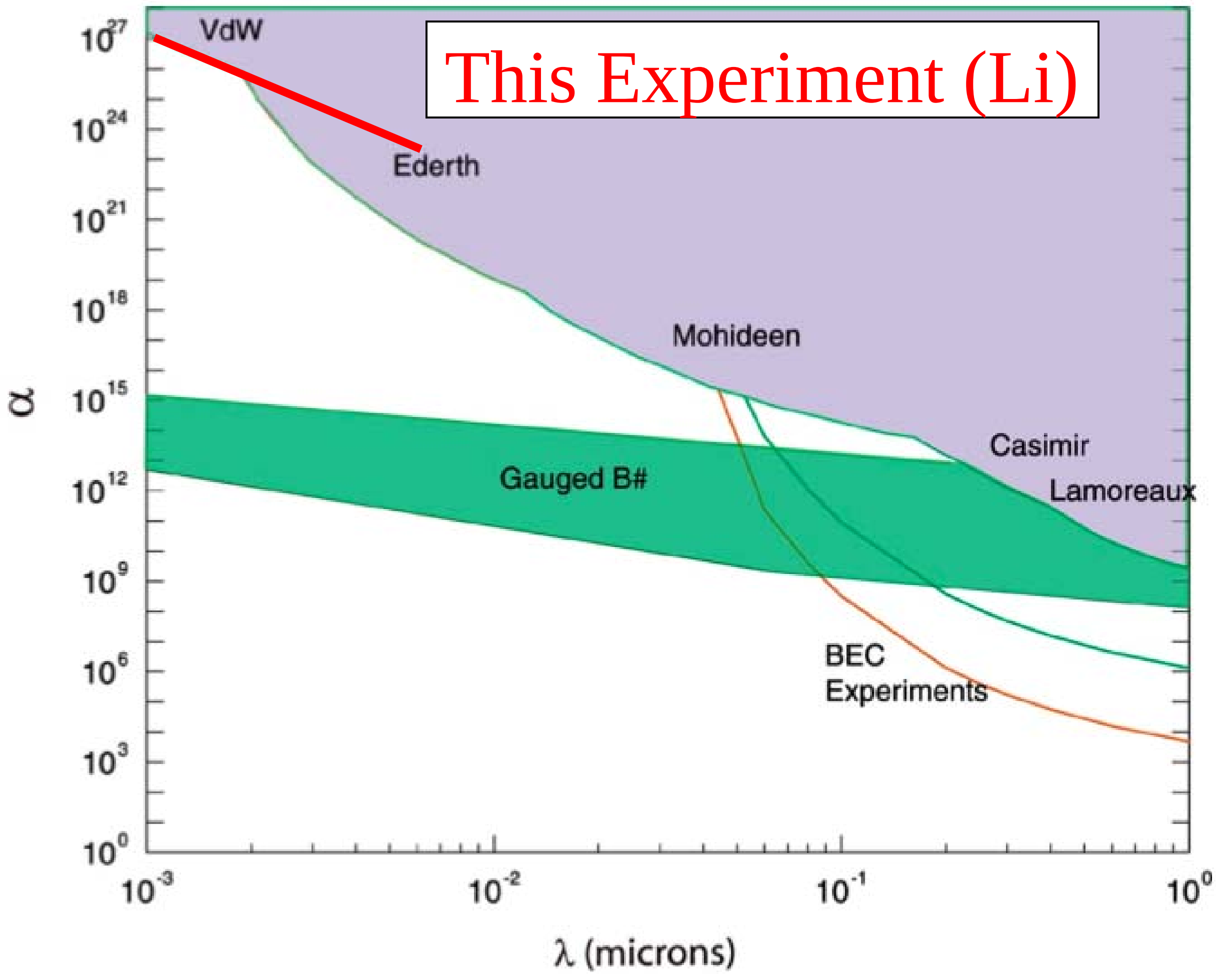
Non-Newtonian Gravity

Potential inside the grating due to modified gravitational interaction on a log scale



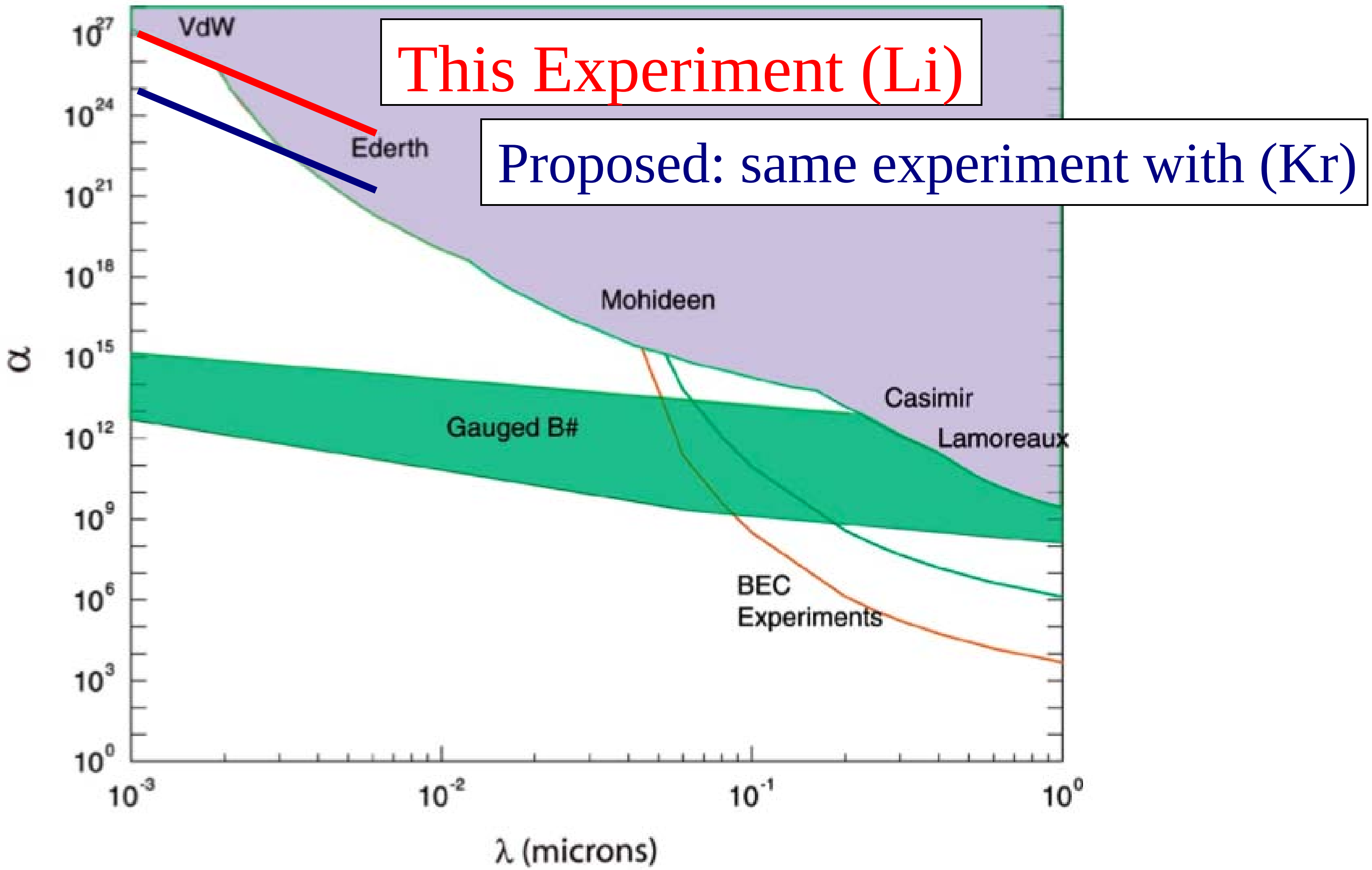
$$U_g = G\frac{m_1 m_2}{r}\left(1+\alpha e^{-r/\lambda}\right)$$

Non-Newtonian Gravity



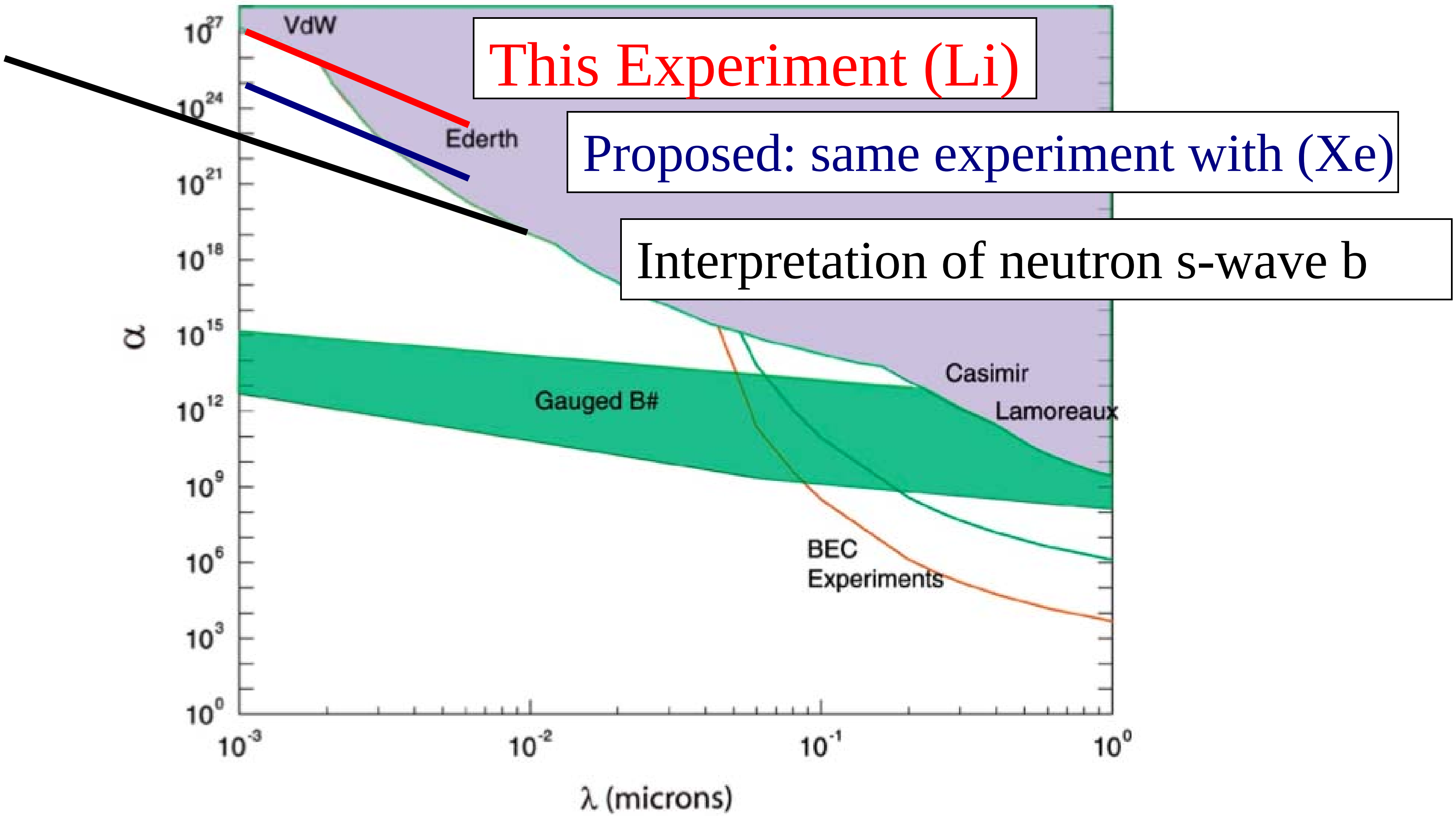
“Probing submicron forces by interferometry of Bose-Einstein condensed atoms”
Savas Dimopolous and Andrew Geraci PRD 68, 124021 (2003)

Non-Newtonian Gravity



"Probing submicron forces by interferometry of Bose-Einstein condensed atoms"
Savas Dimopolous and Andrew Geraci PRD 68, 124021 (2003)

Non-Newtonian Gravity



"Probing submicron forces by interferometry of Bose-Einstein condensed atoms"
Savas Dimopolous and Andrew Geraci PRD 68, 124021 (2003)

S-wave scattering length

nN Gravity

$$\Phi = N\lambda_{dB}bL = \frac{UL}{\hbar v}$$

$$\frac{N\hbar bL}{m_n v} = \frac{2\pi G m_n (N m_n A)\alpha\lambda^2 L}{\hbar v}$$

$$\alpha\lambda^2 < 10^7 m^2$$

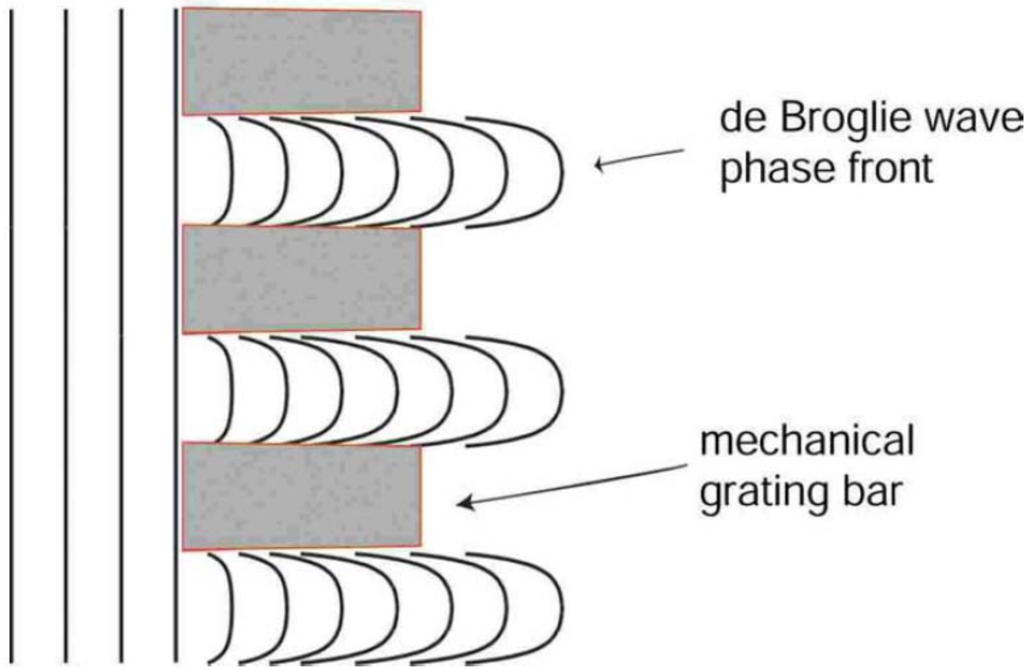


FIG. 63. (Color online) Distorted de Broglie waves. van der Waals interactions with mechanical grating bars cause near-field phase shifts. This view is exaggerated: in beam experiments there are typically 10^4 wave fronts in the 100-nm thickness of a nanograting slot (Grisenti *et al.*, 1999; Perreault *et al.*, 2005).

Cronin, A.D., Schmiedmayer J., and Pritchard D.E., "Optics and Interferometry with atoms and molecules." Rev. Mod. Phys **81**, 1051 (2009)

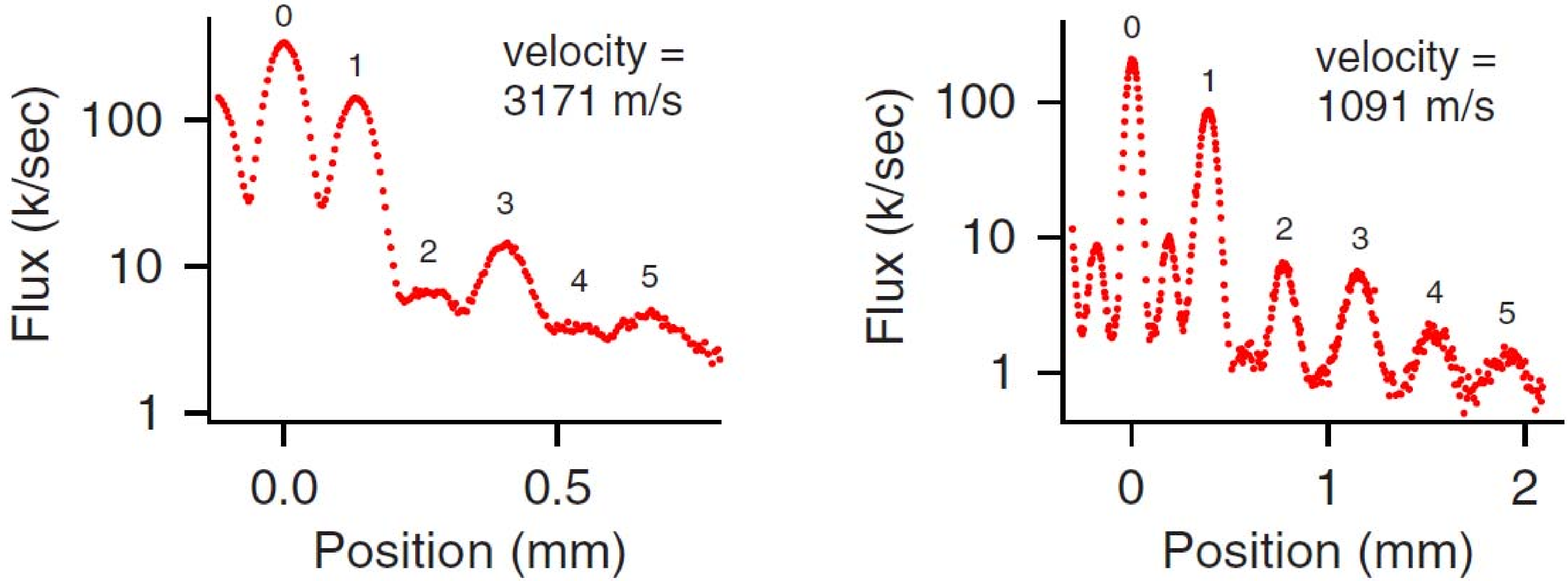
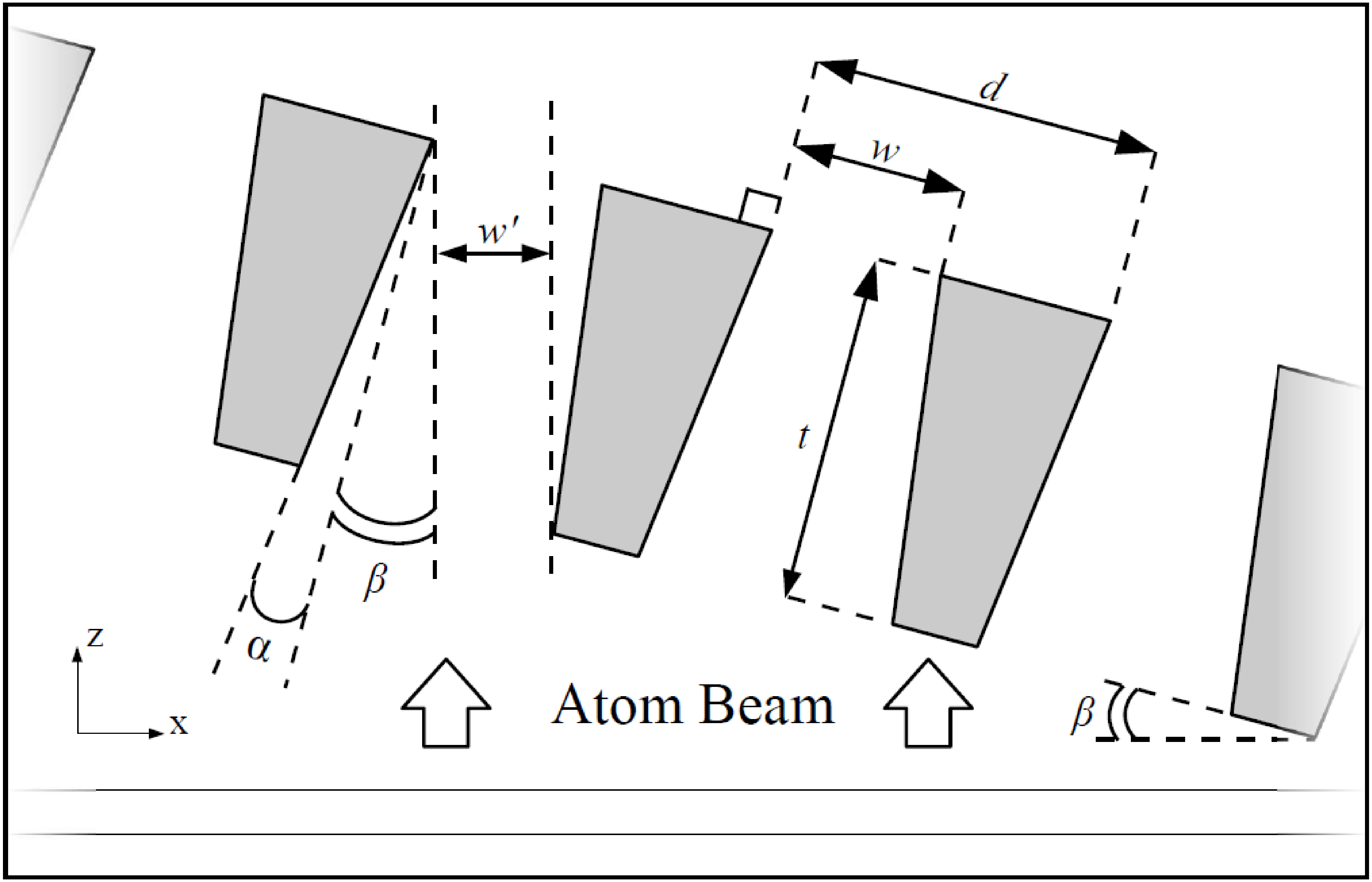


FIG. 65. (Color online) Diffraction intensities used to measure the strength of C_3 for Na-silicon nitride (Perreault *et al.*, 2005). Data for two different velocities show how the second- and third-order change their relative intensity (as predicted in Fig. 64). Diffraction of Na_2 molecules is also visible.

Cronin, A.D., Schmiedmayer J., and Pritchard D.E., "Optics and Interferometry with atoms and molecules." Rev. Mod. Phys **81**, 1051 (2009)


d
w
w'
t
β
α
β
z
x
Atom Beam

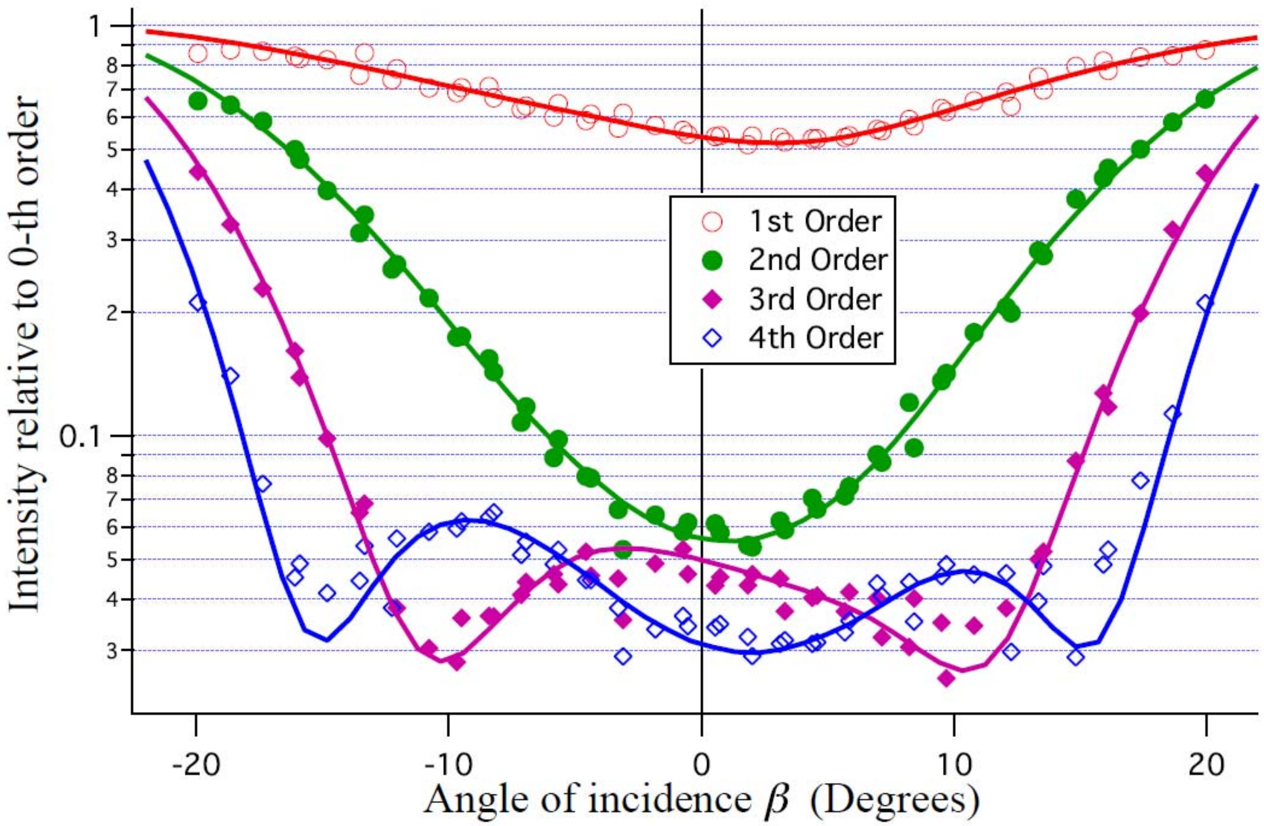


FIG. 6: The intensity of orders 1, 2, 3, and 4 relative to the 0-th order as a function of the grating rotation β (see Fig. 1). Each set of points at one angle represents one diffraction scan like the one shown in Fig. 2. A least squares fit to these data allows us to determine α and t. Although w and C_3 are left as free parameters in this fit, they are not well constrained. The data represented here are for a grating determined to have $\alpha = 5 \pm 1$ degrees and $t = 110 \pm 10$ nm.

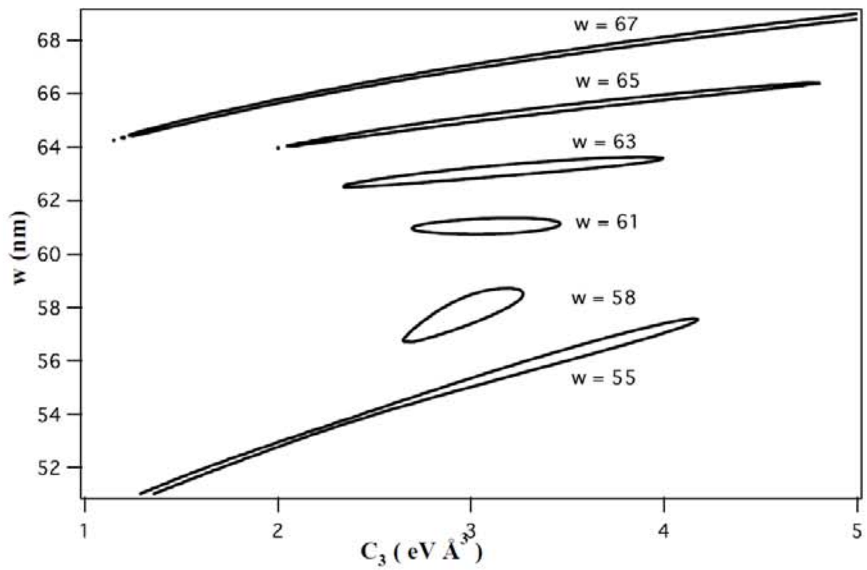


FIG. 4: The figure shows contours of $\chi^2 = \chi^2_{min} + 1$ in the C_3-w plane corresponding to the $1 - \sigma$ uncertainty of the parameters. Contours are shown for simulated data sets with $C_3 = 3$ eV$\mathring{A}^3$, d =100 nm, and different values of w. The contours describe extended valleys at most open-fractions but narrow to a well defined minimum for one particular magic open-fraction.

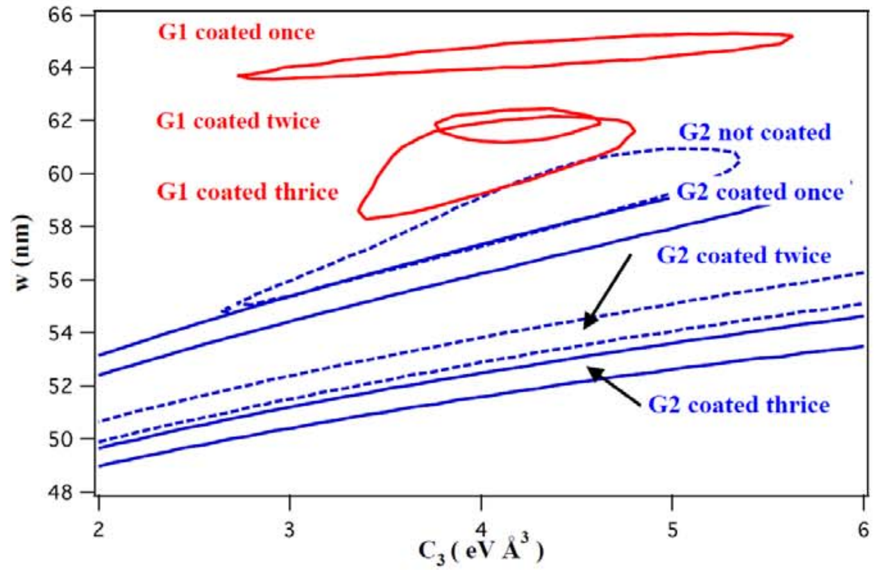


FIG. 5: Contours of $\chi^2 = \chi^2_{min} + 1$ in C_3-w space for two grat ings (labeled G1 and G2) after repeated coating with Au/Pd The small contour for "G1 coated twice" shows the impact o the magic open-fraction.

Lonij, V., W. Holmgren, and A. Cronin,
"Magic ratio of window width to grating period for Van der Waals potential measurements using material gratings," submitted to Phys. Rev. A (2009)

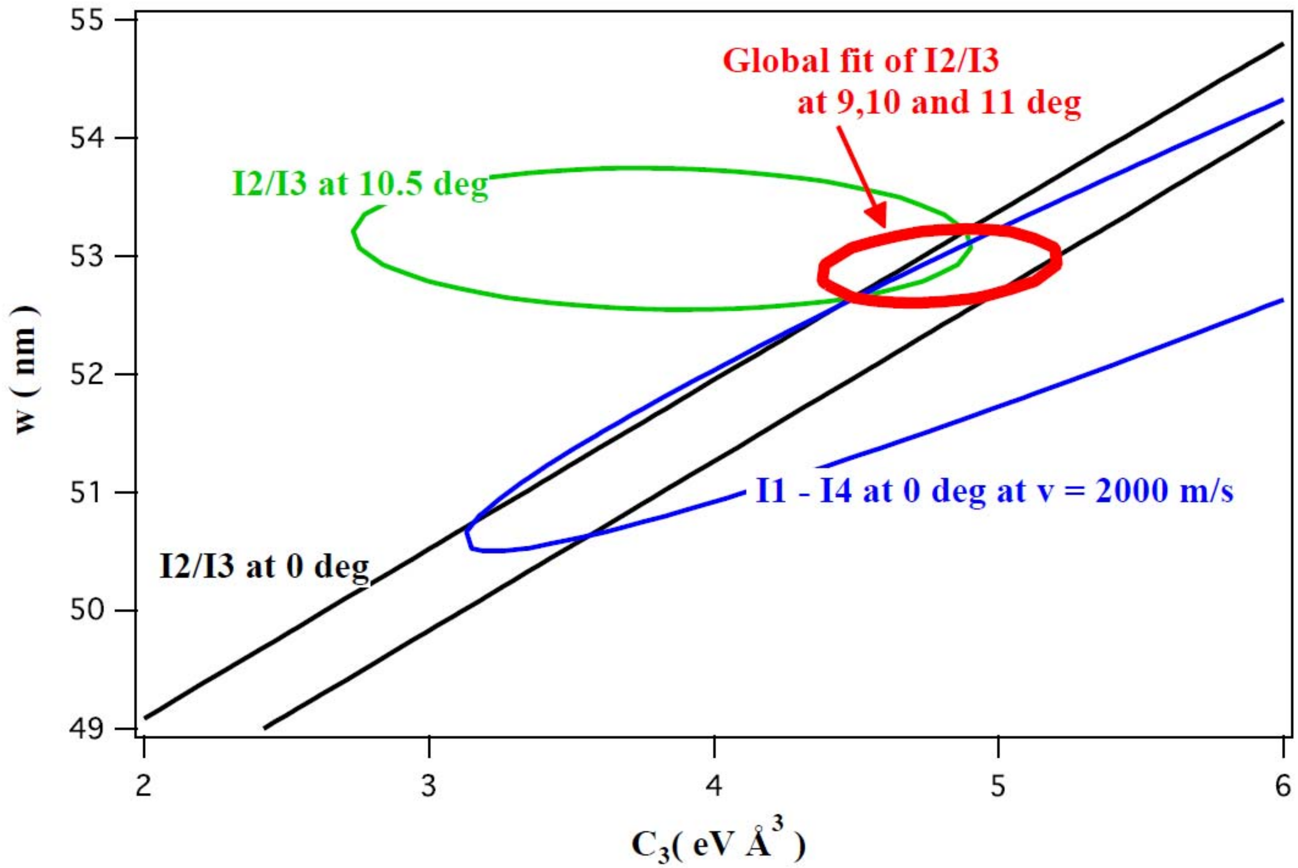


FIG. 8: Contours of $\chi^2 = \chi^2_{min} + 1$ in C_3-w space for different angles. The blue ellipse corresponds to a fit of data like Fig. 2 at 2000 m/s at normal incidence. The black and green ellipses correspond to data similar to Fig. 7 at a single angle $\beta = 0$ and $\beta = 10.5$ degrees respectively. The red ellipse corresponds to the fit of the three angles shown in Fig. 7.

TABLE I: Experimental results and theoretical predictions

Experiment	$C_3 (eV \mathring{A}^3)$	
This work:		
Na and SiN_x fit parameter	3.26	$\pm$ 0.16 [a]
Na and Au/Pd fit parameter G1	4.30	$\pm$ 0.5
Na and Au/Pd fit parameter IG	4.80	$\pm$ 0.5
Na and SiN_x with PWI correction	3.42	$\pm$ 0.19 [a]
Na and Au/Pd with PWI correction G1	4.51	$\pm$ 0.5
Na and Au/Pd with PWI correction IG	5.04	$\pm$ 0.5
Previous work:		
Na and SiN_x [3]	2.70	$\pm$ 0.8
Theory		
Na and perfect conductor	7.6	[13]
Na and SiN_x using single oscillator $\alpha_{\rm pol}(i\omega)$ and tabulated $\epsilon(i\omega)$	3.3	[12], eqn. (5)
Na and SiN_x using tabulated $\alpha_{\rm pol}(i\omega)$ and $\epsilon(i\omega)$	3.48	[12, 15], eqn. (5)
Na and Bulk Au	5.11	[16]
Na and 1 nm Au at $r = 10$ nm	4.3	[17]
Na and 2 nm Au at $r = 10$ nm	4.5	[17]
Na and 3 nm Au at $r = 10$ nm	4.6	[17]

[a] The source of the reported error is discussed in appendix B.

TABLE I: Experimental results and theoretical predictions

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This work:		
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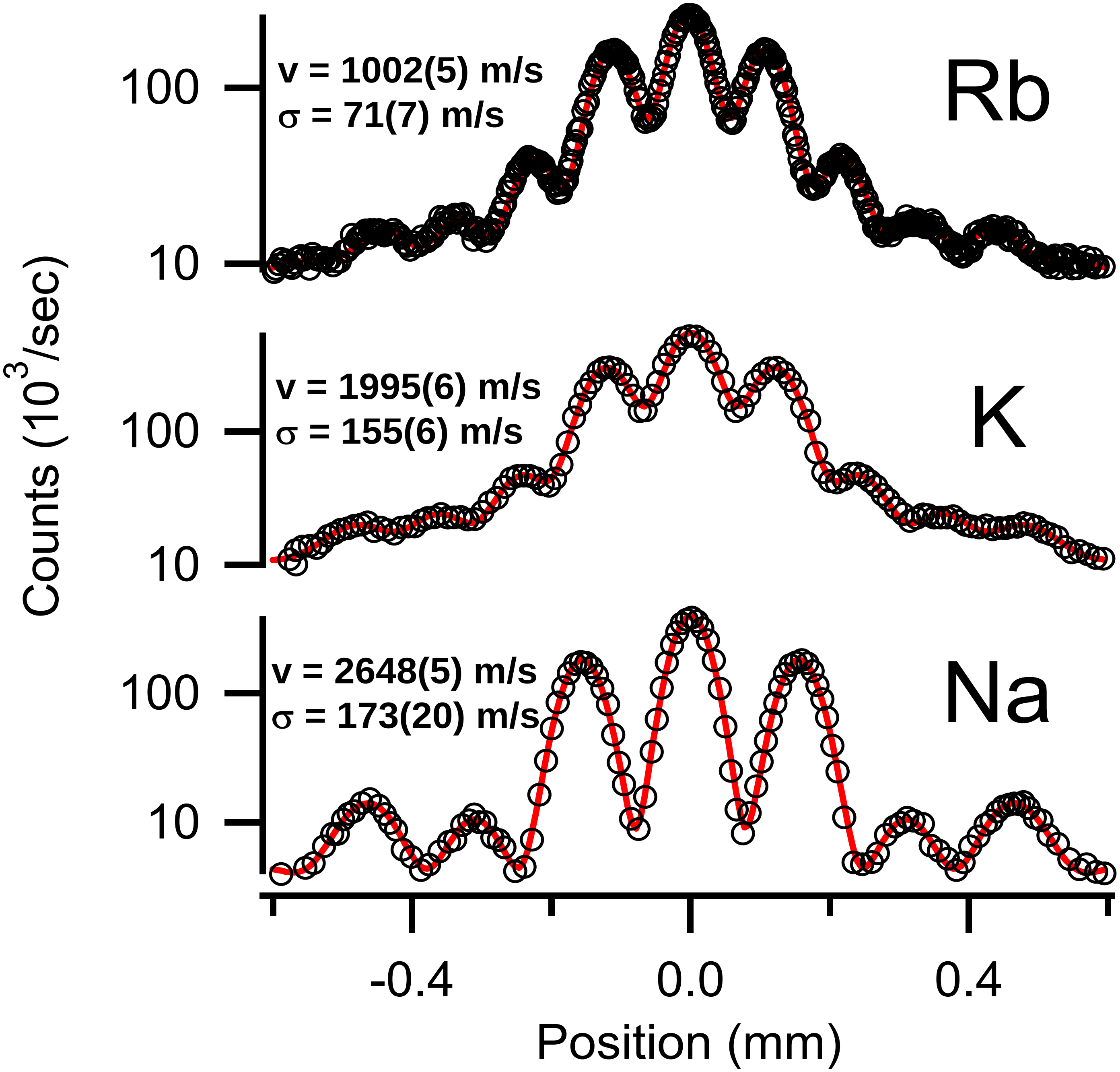
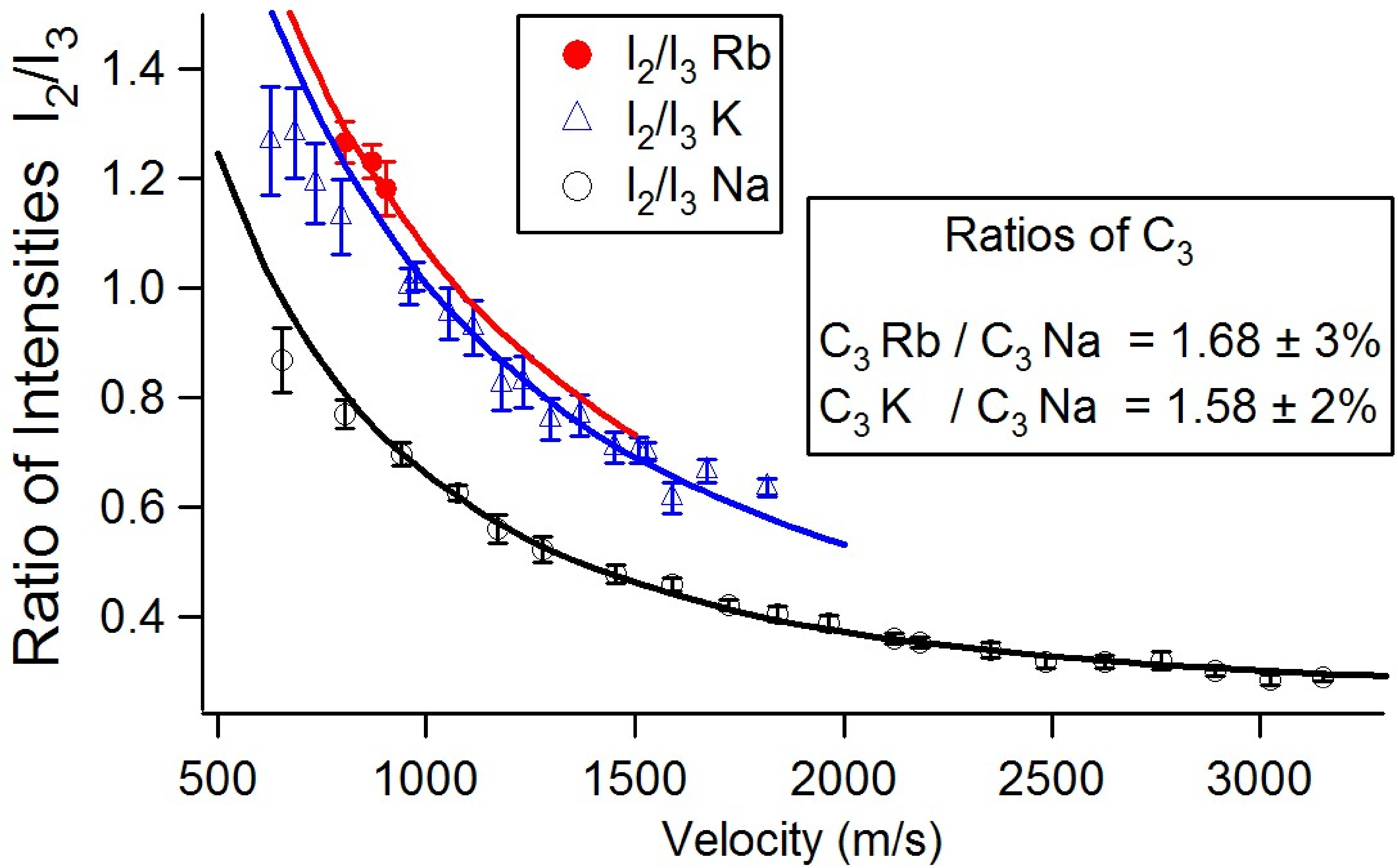
Na and 2 nm Au at $r = 10$ nm	4.5	[17]
Na and 3 nm Au at $r = 10$ nm	4.6	[17]

[12] H. R. Philipp, Journal of the Electrochemical Society **120**, 295 (1973).

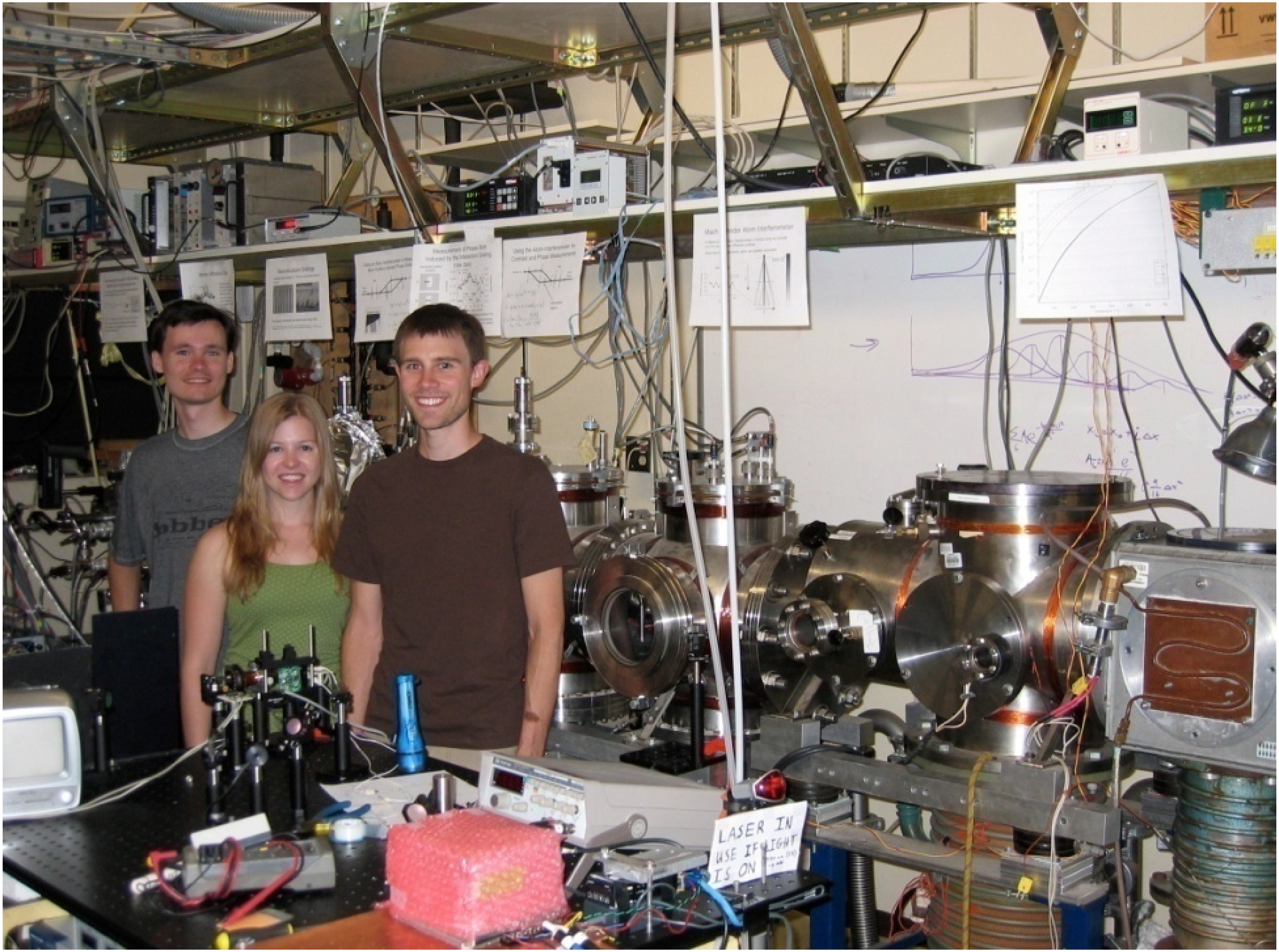
[15] A. Derevianko, S. G. Porsev, and J. F. Babb, arXiv:0902.3929v1 (2009).



Counts (10^3/sec)
100
10
v = 1002(5) m/s
σ = 71(7) m/s
Rb
100
10
v = 1995(6) m/s
σ = 155(6) m/s
K
100
10
v = 2648(5) m/s
σ = 173(20) m/s
Na
-0.4
0.0
0.4
Position (mm)


Ratio of Intensities I_2/I_3
1.4
1.2
1.0
0.8
0.6
0.4
500
1000
1500
2000
2500
3000
Velocity (m/s)
I_2/I_3 Rb
I_2/I_3 K
I_2/I_3 Na
Ratios of C_3
C_3 Rb / C_3 Na = 1.68 ± 3%
C_3 K / C_3 Na = 1.58 ± 2%

C_3	Li – SiNx:	3.25	± 0.20	(6 %)
C_3	Na – SiNx:	3.42	± 0.19	(5 %)
C_3	Na – AuPd:	5.04	± 0.50	(10 %)
C_3	K – SiNx:	5.40	± 0.39	(8 %)
C_3	Rb – SiNx:	5.74	± 0.40	(8 %)


LASER IN
USE IF LIGHT
IS ON

Outline

1. **New polarizability measurements**

2. **Atom Interferometry C3 measurements**
   tests of potential power law
   limits on non-Newtonian gravity

3. **More precise diffraction experiments**
   Magic open fraction
   Effect of AuPd
   Ratios of C3 for Rb, K, Na

4. **Laser modified vdW interactions**

PHYSICAL REVIEW A **77**, 043406 (2008)

Modifying atom-surface interactions with optical fields

John D. Perreault
JILA, University of Colorado, Boulder, Colorado 80309-0440, USA

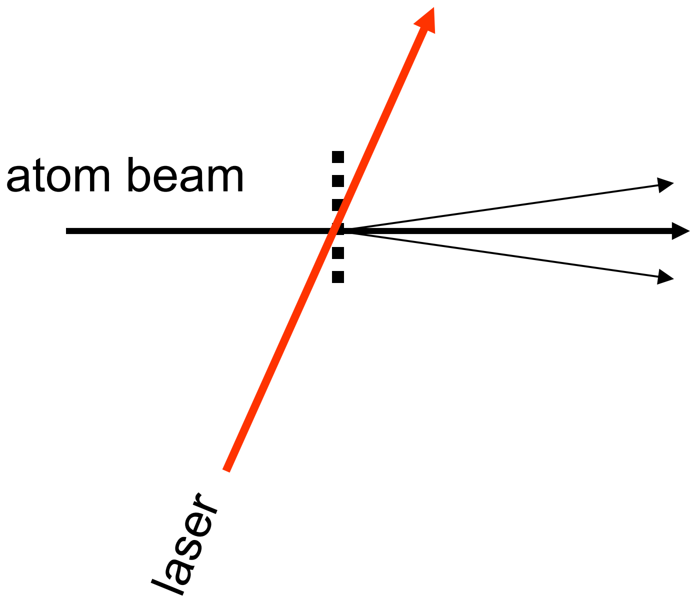
M. Bhattacharya, Vincent P. A. Lonij, and Alexander D. Cronin
Department of Physics, University of Arizona, Tucson, Arizona 85721, USA

- Intensity of 5 W/cm^2 will double the vdW attractive force with Δ = 100 Γ.

- Light polarization will change the enhancement by a factor of 2

- Enhancement depends on laser detuning squared $(\omega - \omega_0)^2$

- Dielectric and conducting surfaces have the same laser-induced enhancement factor.



PHYSICAL REVIEW A **77**, 043406 (2008)

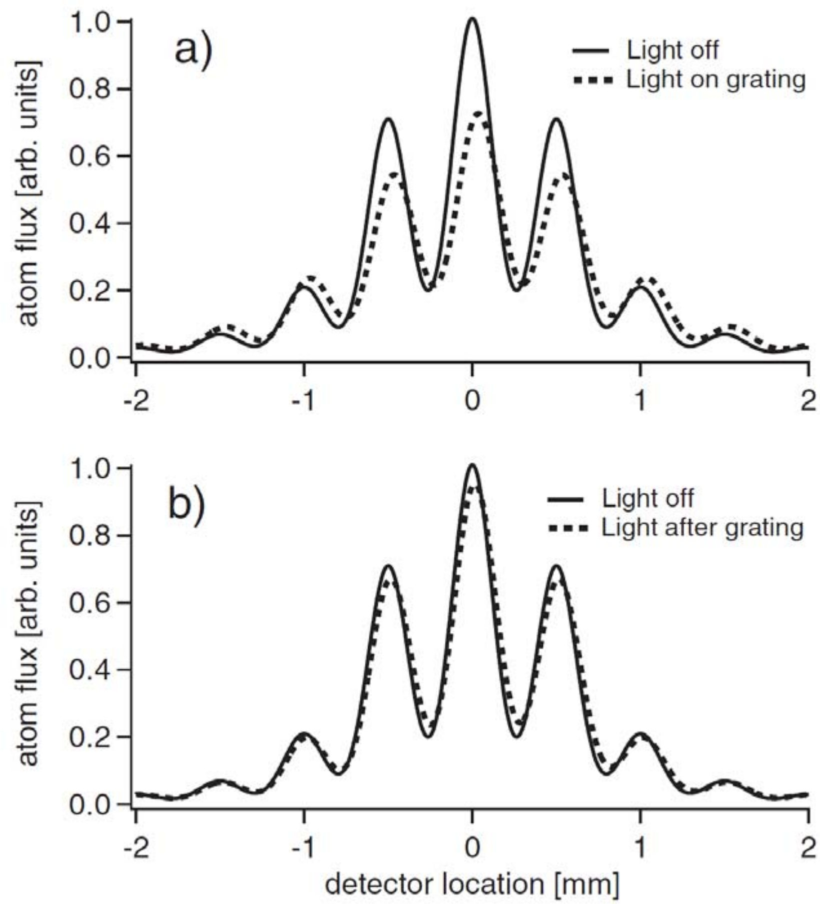


FIG. 3. Simulated laser-modified atom diffraction patterns. Light is predicted to change the diffraction patterns because of modified atom-surface interactions and also photon scattering. Plot (a) shows the effect of a laser beam, with intensity $I=5\ \mathrm{W/cm^2}$ and detuning $\Delta=100$ MHz, illuminating the atoms inside a nanograting. Plot (b) shows the effect of the same laser illuminating atoms after passing through a nanograting. In each simulation atoms exposed to the laser have an equal probability of spontaneously scattering 1 or 0 photons.

Thank You

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