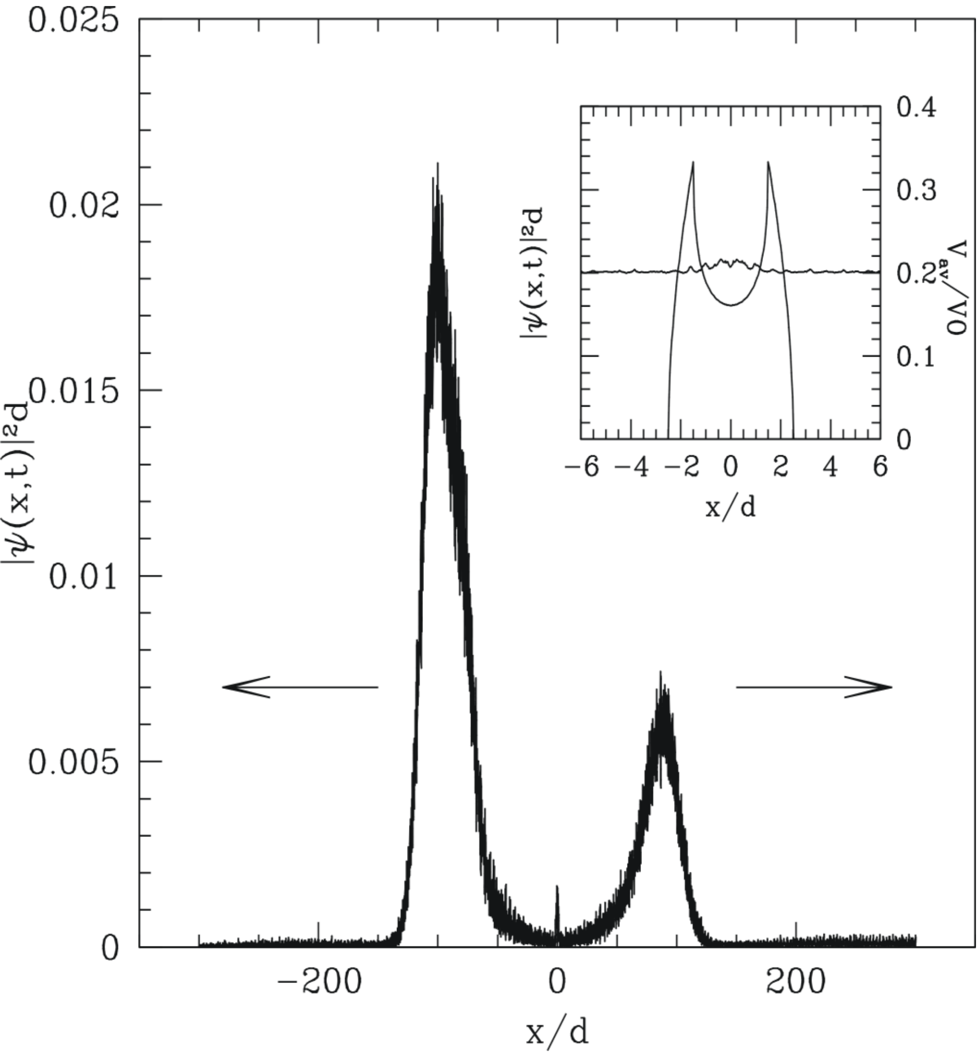
Analyze one effect at a time

- **Start with the case of noninteracting atoms at high frequency driving**
- **Proceed by tuning the frequency from very low to high**
- **Go back to high frequencies but switching on the nonlinear interactions**

The Physical Mechanism



❖An atomic beam with $E_k = 0.2V_0$ near resonance and spread ΔE impinges on a light barrier of width d and height V_0 oscillating as

$$V(x,t) = V(x - l\ \cos(2\pi\nu\ t))$$

$$V(x) = V_0[\theta(x - d/2) - \theta(x + d/2)]$$

$$\nu = 10\ KHz \text{ and } l = 2d$$

❖A large portion of matter wave is transmitted well below barrier and a fraction still dwells inside the barrier

❖Why (strictly true for $\nu \to \infty$): the time-averaged potential $V_{av} = 1/T\int V(x,t)dt$ allows for metastable states with energy E_0 and width Γ_0 possibly resonant with the incoming beam.

The Model

- The problem can be considered as <u>one-dimensional</u>, since in the experiment the atomic beam travels along a <u>waveguide</u>. If the transverse confinement energy is much larger than all other energies, the wavefunction in the transverse direction is frozen

- One-dimensional Gross-Pitaevskii equation, that is a nonlinear Schroedinger equation for the condensate wavefunction $\psi(x,t)$ along the direction of motion x

$$i\hbar \frac{\partial \Psi(x,t)}{\partial t} = \left[-\frac{\hbar^2 \nabla^2}{2m} + V(x,t) + g \left| \Psi(x,t) \right|^2 \right] \Psi(x,t)$$

moving under the action of the barrier V(x,t) oscillating at frequency ν (or the static averaged potential $V_{av}(x)$)

❑ **Atomic interactions** **enter the nonlinear term, with g modelled from the 3D value** $g^{3D} = \frac{4\pi\hbar^2 aN}{m}$ **to maintain the same level of average interactions**

$$E_I = \frac{\int g \left|\Psi(x,t)\right|^4 dx}{\int \left|\Psi(x,t)\right|^2 dx} = \frac{\int g^{3D} \left|\Psi^{3D}(\vec{r},t)\right|^4 d\vec{r}}{\int \left|\Psi^{3D}(\vec{r},t)\right|^2 d\vec{r}}$$

For a gaussian wavepacket of oscillator length $a_\perp$ **and frozen in transverse direction the condition is satisfied by**

$$g = \frac{g^{3D}}{\pi a_\perp^2}$$

Requirements and System Parameters

- Requirements to observe a clean effect:
  - ✓ $l > d$ to have double-barrier structure in V_{av}
  - ✓ V_0 and l to have ony one quasi-bound state in V_{av}
  - ✓ $\Delta E = \Gamma_0$ (thus need to use a BEC)
  - ✓ ν ? inverse tunnelling time to have high transparency

- **System parameters are here tailored for sodium atoms from a transfer-matrix calculation and can be rescaled for other species**

d	V_0/h	E_0/h	Γ_0/h
$827nm$	$4.2KHz$	$0.90KHz$	$0.06KHz$

- **For the noninteracting atomic beam we have taken**

$$\Delta E/h = 0.21KHz$$

- **Reasonable set of parameters for the interacting atomic beam**

$$\Delta E^{*}/h ;\ 0.016\,KHz = 0.0039\,V_0 \qquad g ;\ 2g_0 \equiv 2\frac{h^2}{2md} \qquad a_{\perp} ;\ 1\,\mu m \qquad N=100$$

- **Atomic velocities:** 2 **to** 18 **mm/s** ***i. e.*** $0.1 < E_k < V_0 < 1$