lecture 4.11.2010

we had in the last week:

- preparation of atomic beams II: thermodynamics
- cooling in the supersonic jet expansion

today:

- pulsed atomic beams and simulations
- selected examples with supersonic beams
- atom beam diffraction

Ideal Pulsed Beam Source

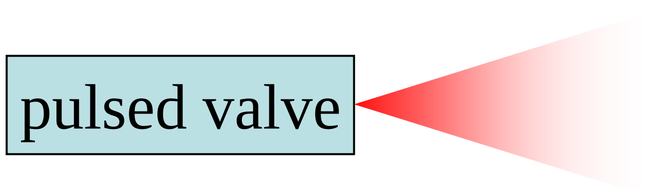
Pump out time $\tau = \dfrac{V}{S}$

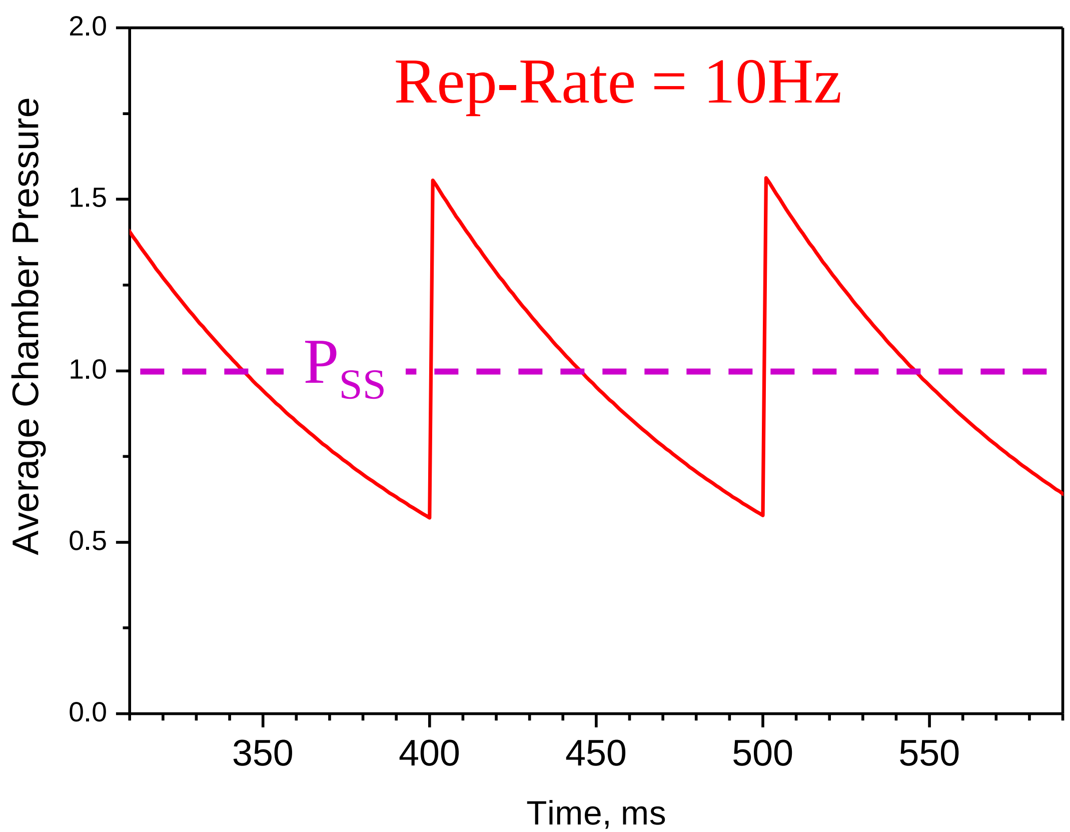
V = Volume

S = Pumping Speed = S_2

Typical example, V=100 ℓ, S=1000 ℓ/s $\tau = 0.1s$

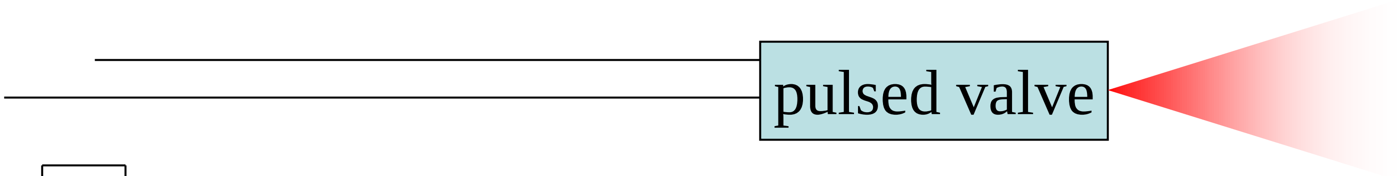
$P_{jet}=P_1 >> P_2=P_{chamber}$

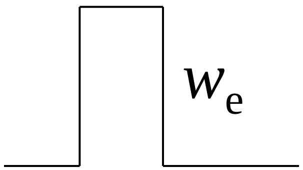




practical pulsed beam source

delay and opening time issue

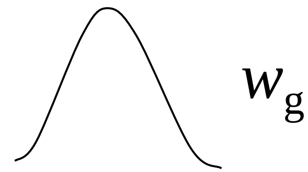




not equal to

not proportional to

may be anti-correlated with

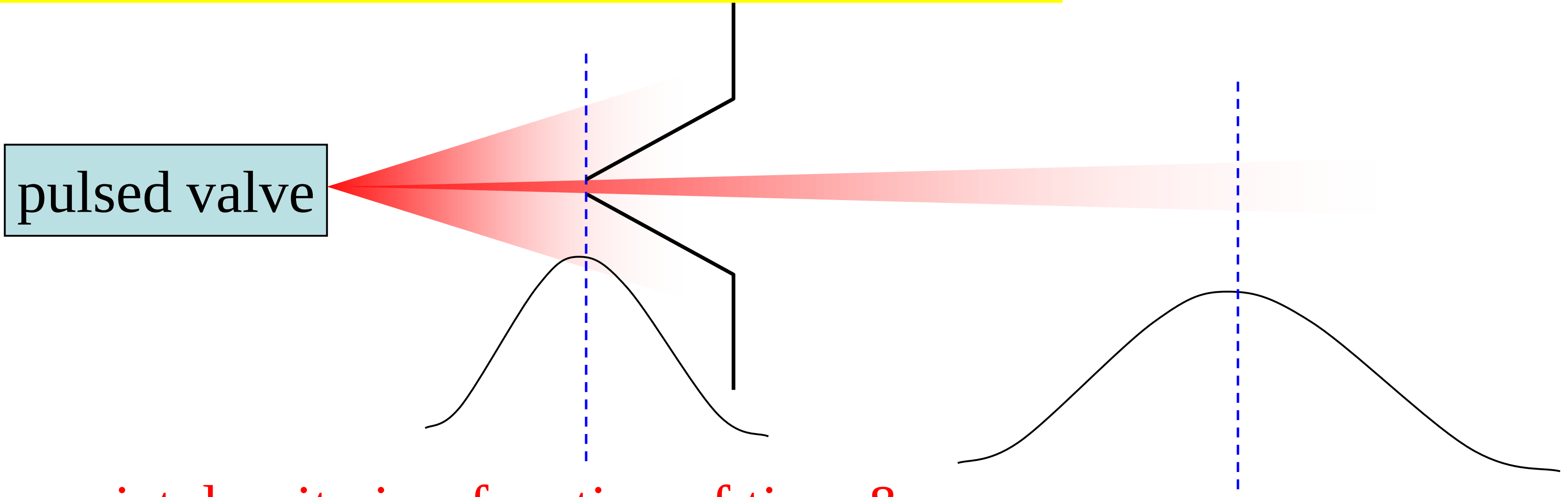


large delay time due to mechanical delay

bigger w_e or higher power $\Rightarrow$ Stronger Force $\Rightarrow$ shorter delay time

possible smaller w_g

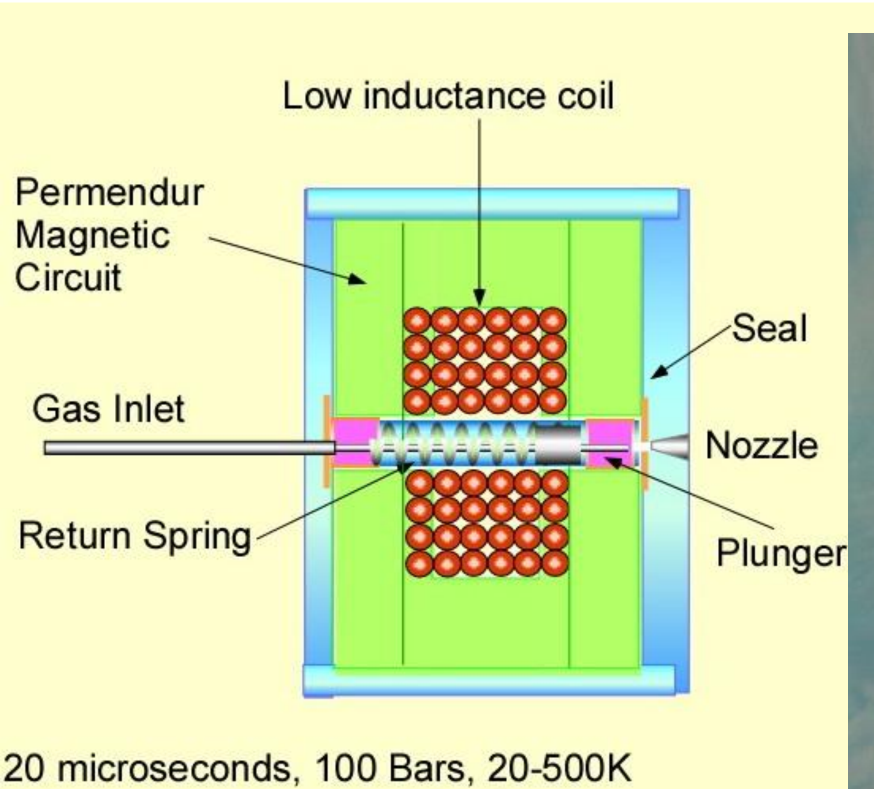
skimmed beam: skimmer interaction

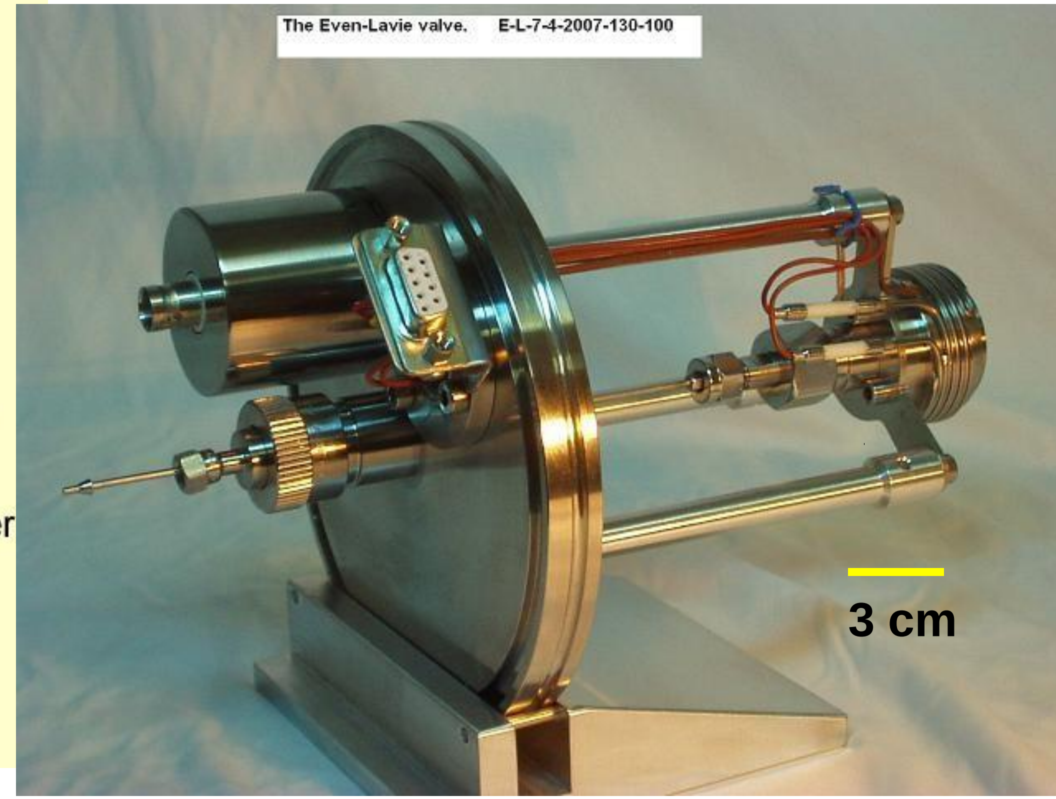


jet density is a function of time & space

attenuation is also a function of time & space

structure of a pulsed valve: miniaturization is the key

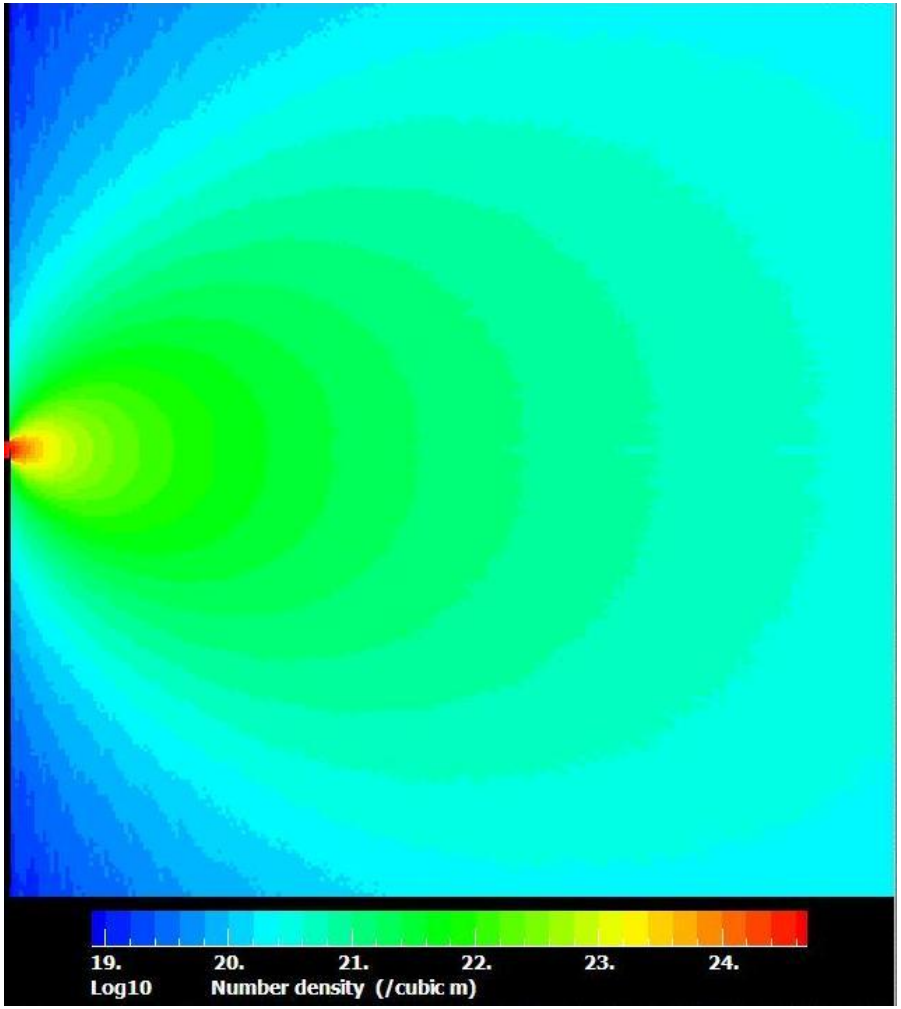


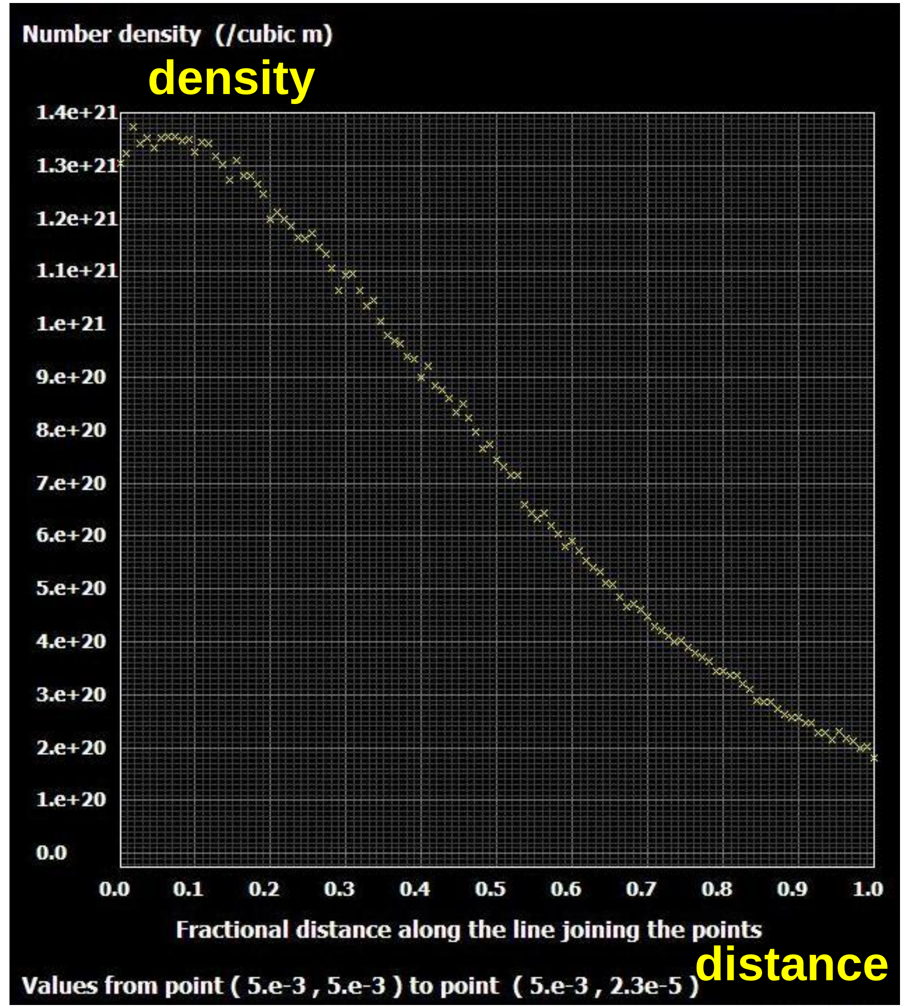


simulated sonic nozzle beam shapes

Monte Carlo method (DSMC)

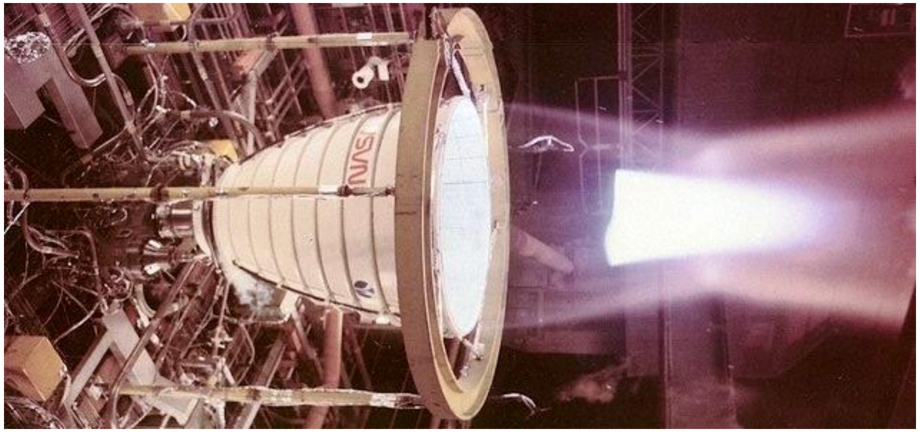
Program developed by Dr. Graham Bird and is free http://www.gab.com.au/



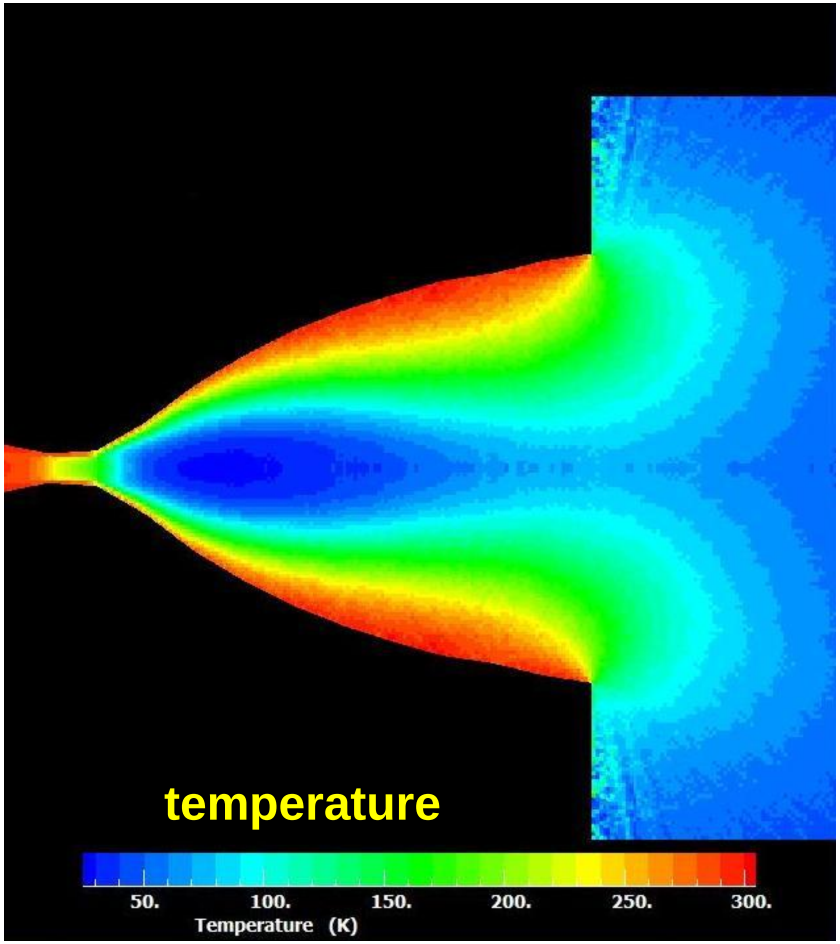


wide beam (55^0 FWHM); low on axis intensity

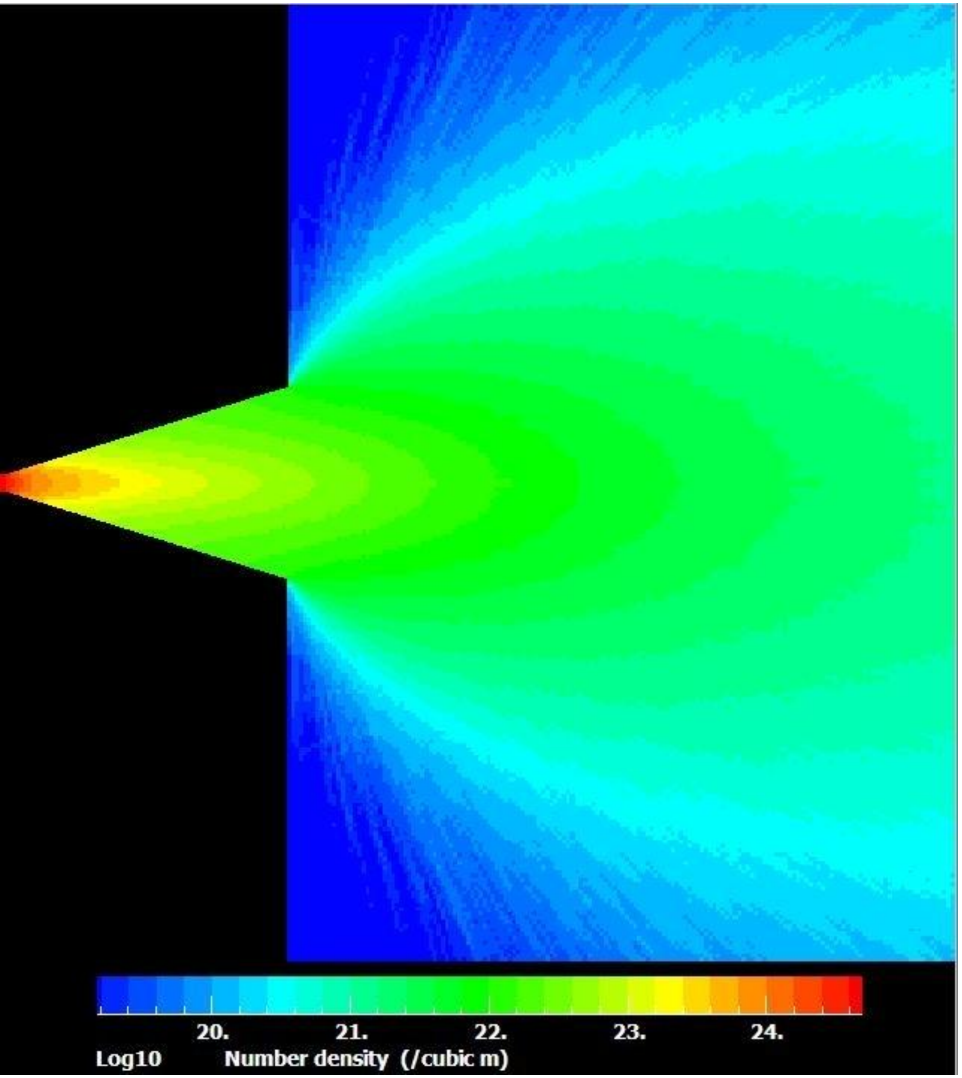
De Lavalle (or Bell) Nozzle

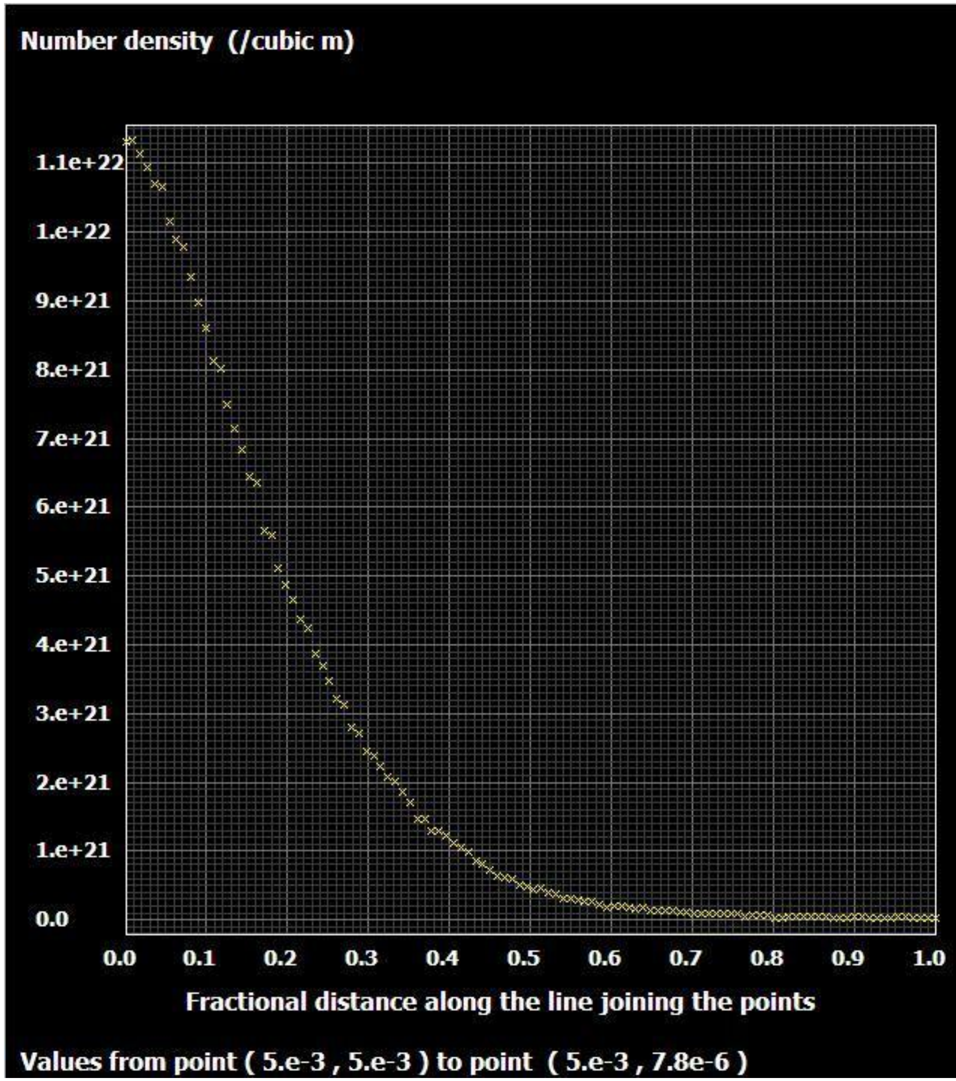


1. Designed for Maximum Thrust.
2. Exit Temperature is quite high.
3. A bad source for supersonic beams.



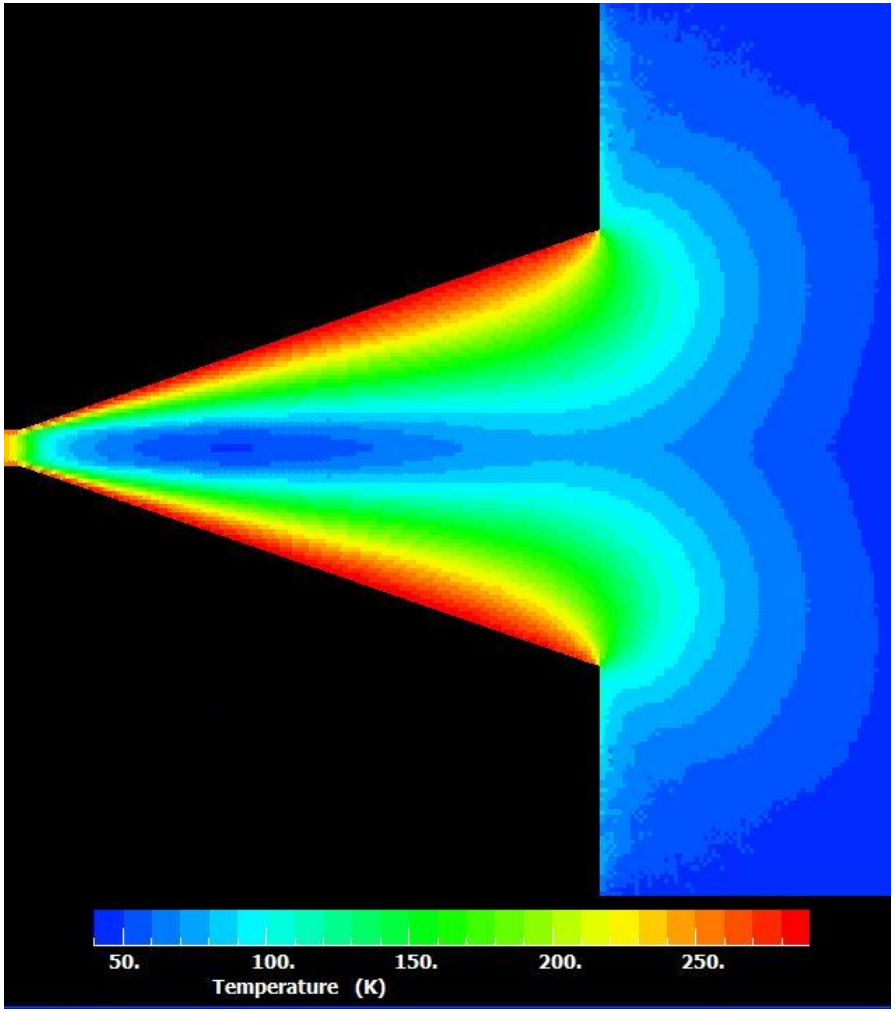
40^0 Conical Nozzle Simulation

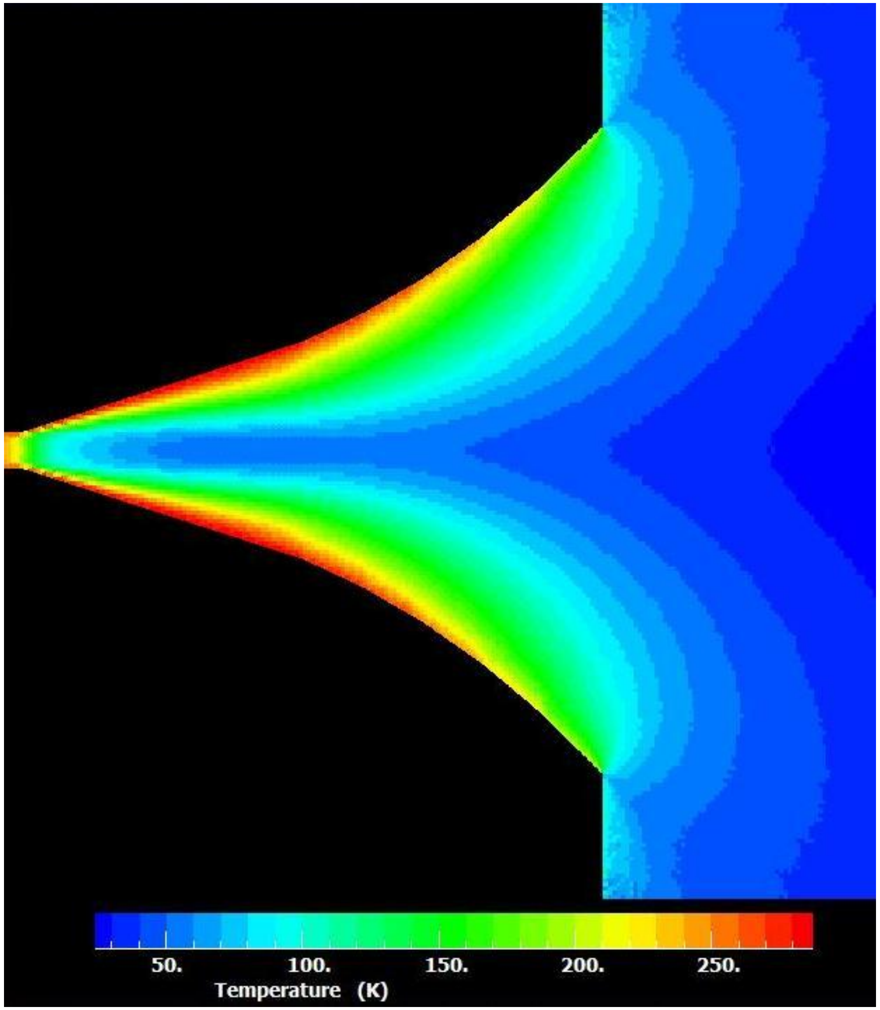




narrow beam (20^0 FWHM); higher on axis beam intensity (x8 over sonic nozzle)

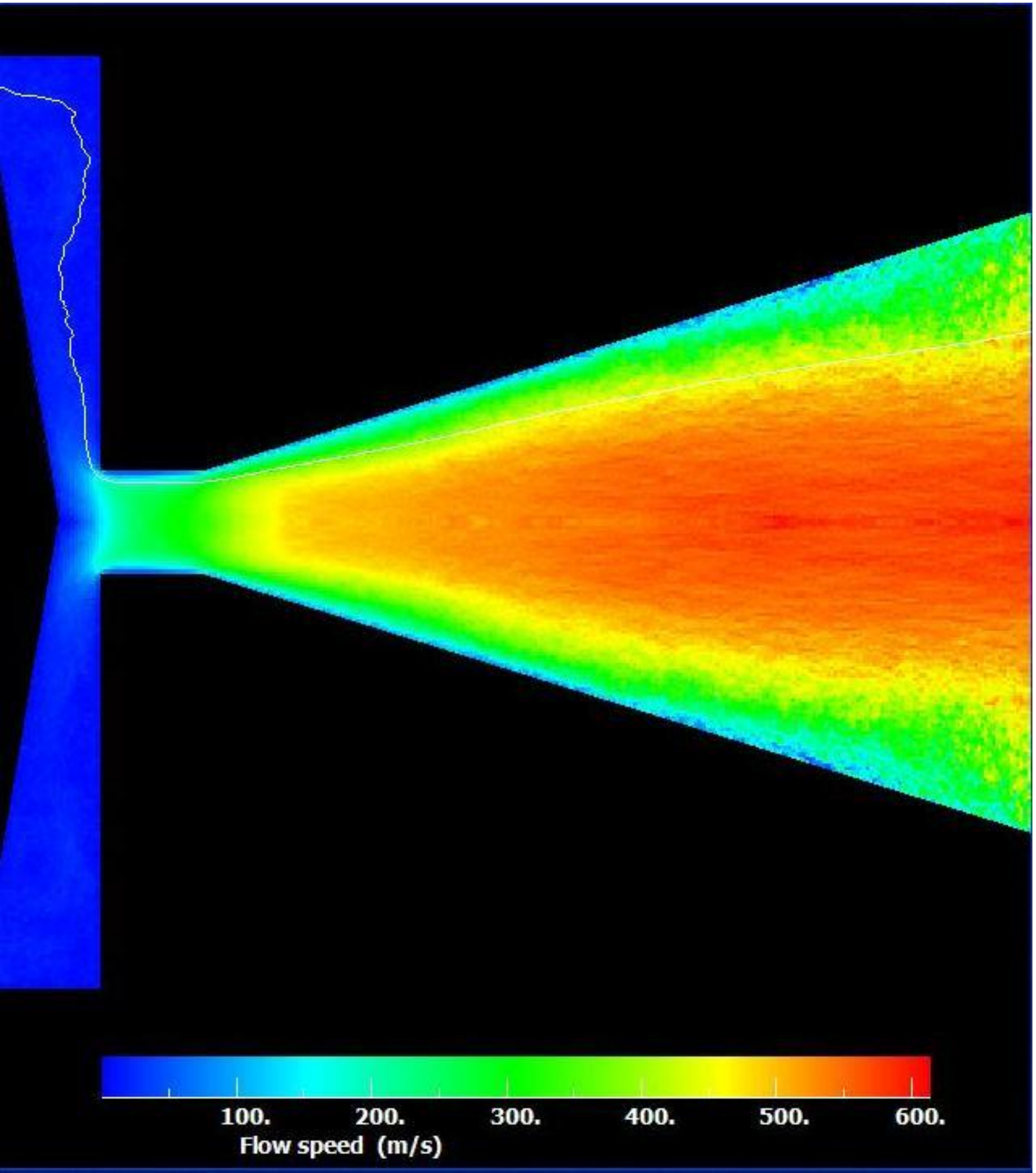
Comparison between conical and trumpet shaped nozzles





Low temperature achieved where the jet is at high density; important for clustering

acceleration in nozzles

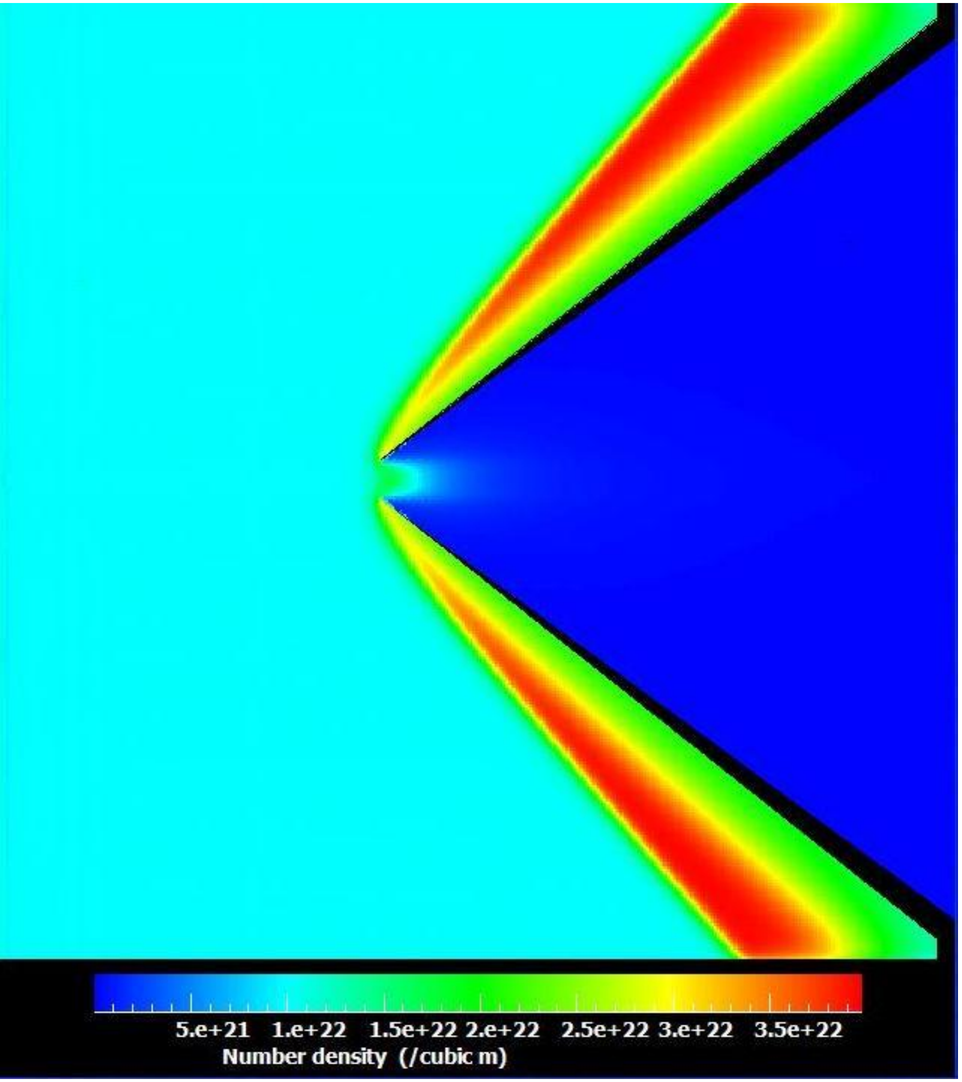


1. expansion shown for Argon
2. the gas reaches 600m/s over a distance of 2 nozzle diameters in 1 μs
3. the acceleration is enormous:

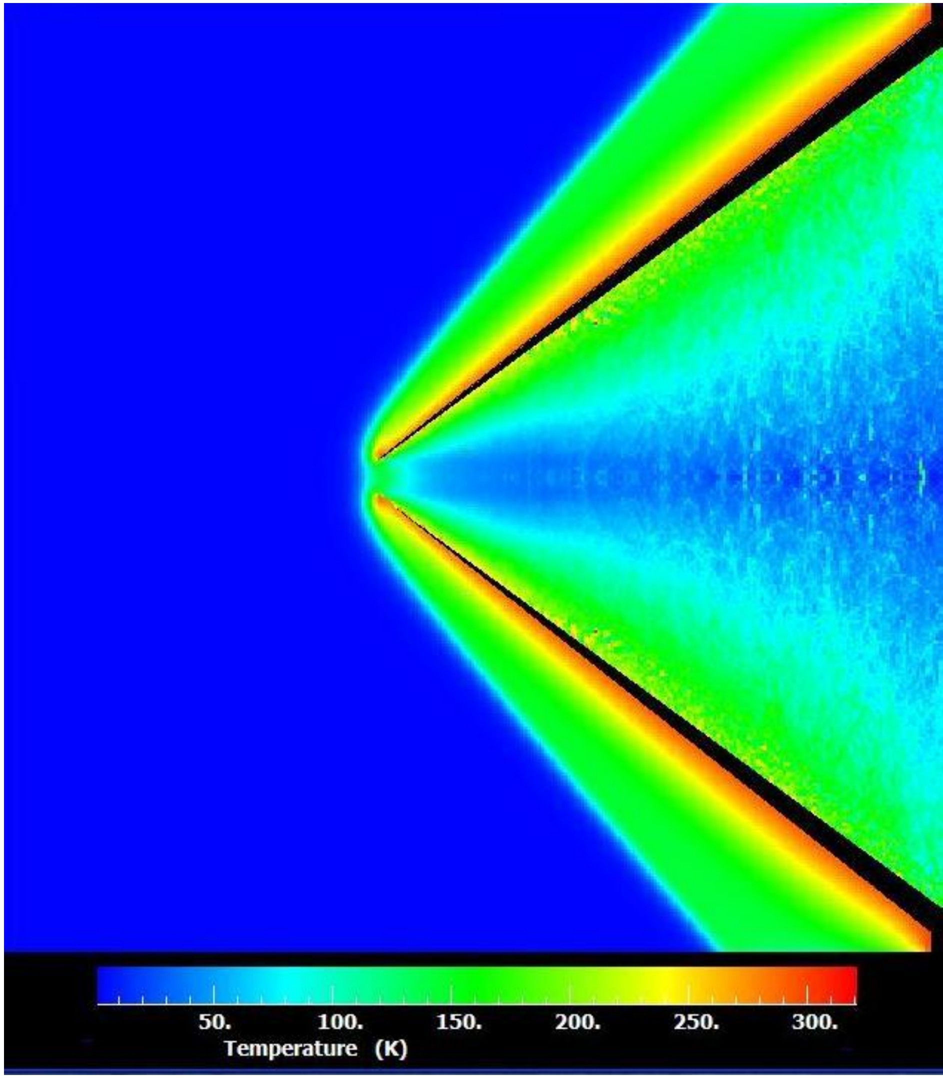
   $a>5*10^8$ m/s^2 for Argon
   $a>5*10^9$ m/s^2 for Helium

   Interesting inertial effects in spectroscopy??

skimmers: Campargue type at low intensity beams

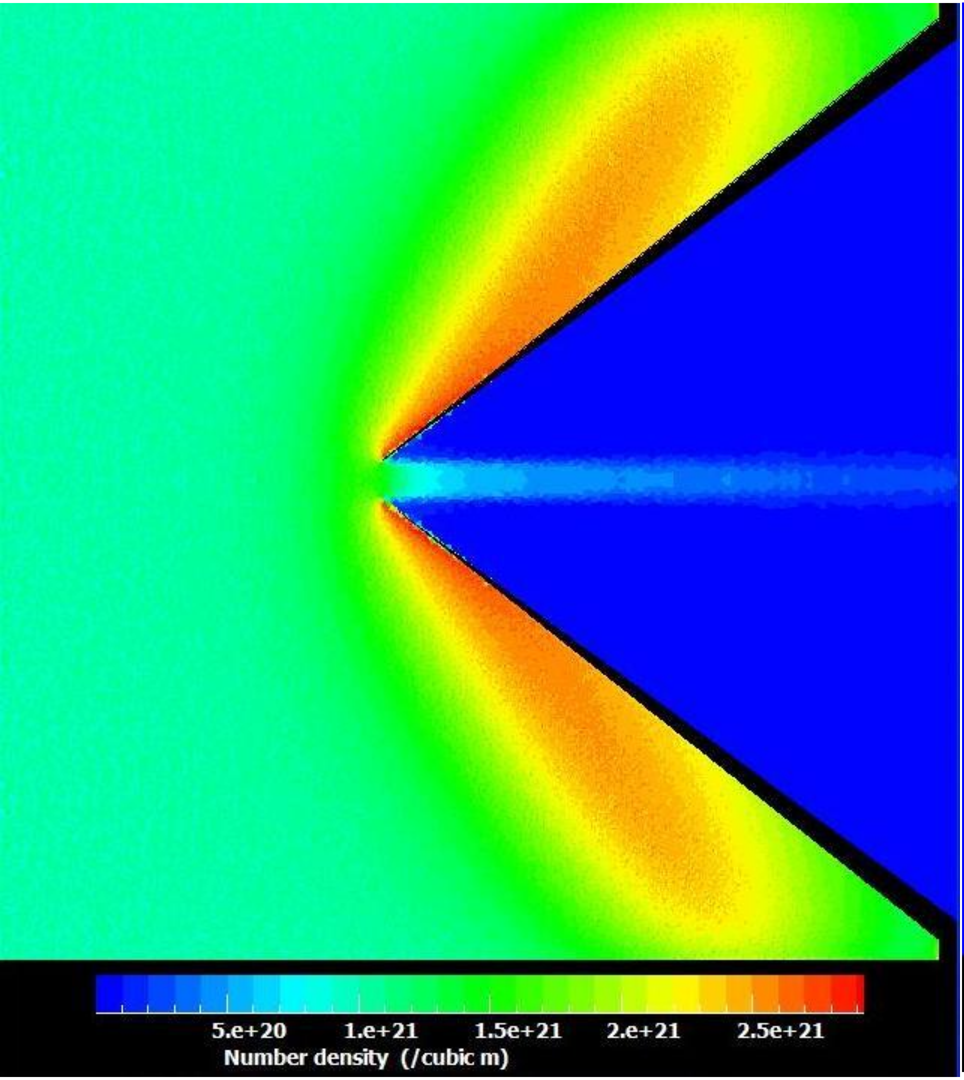


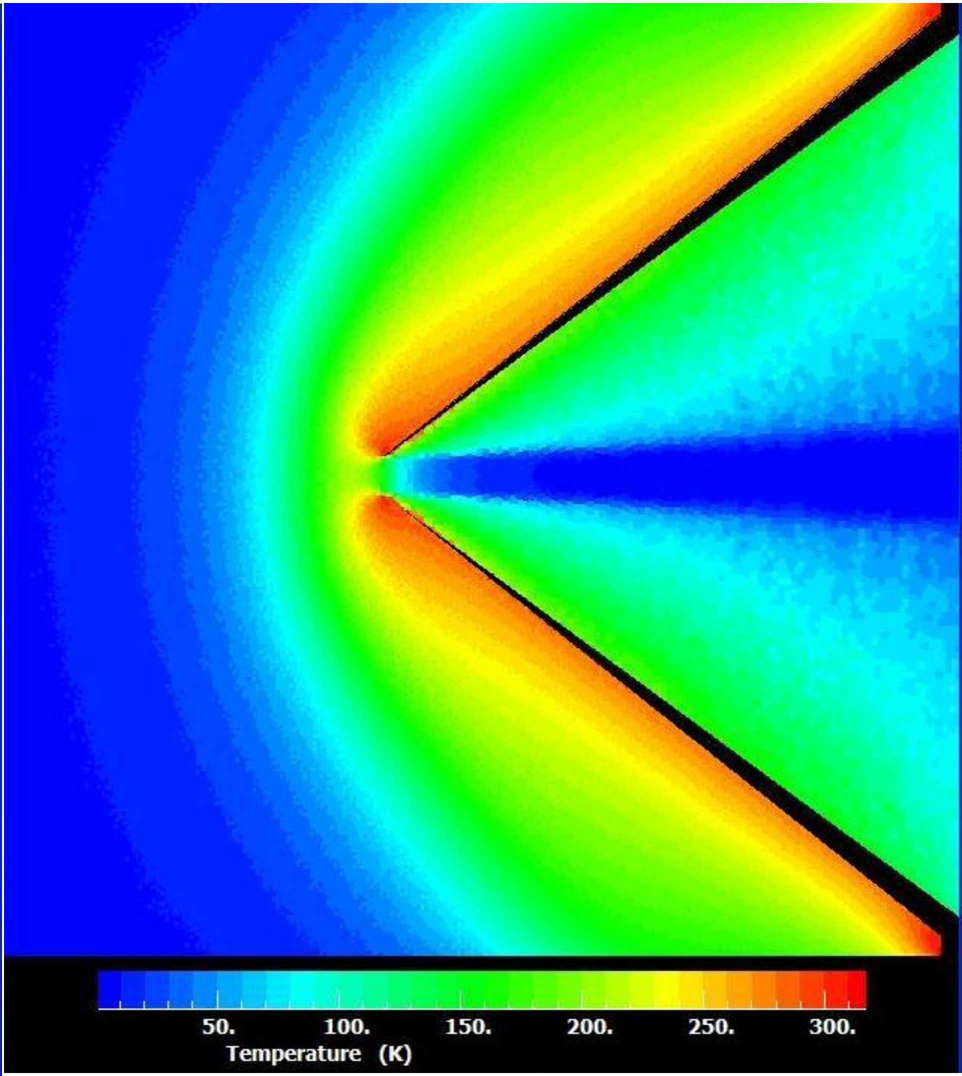
density



temperature

Campargue type skimmer in high density beams

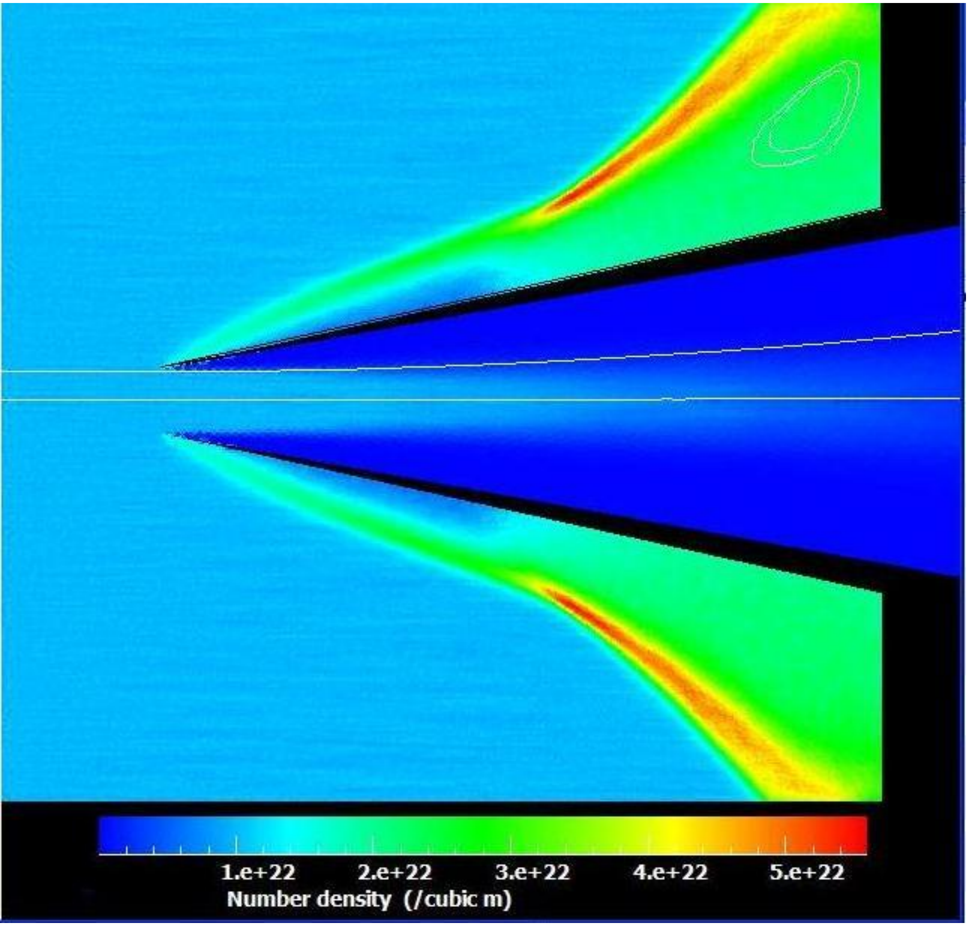




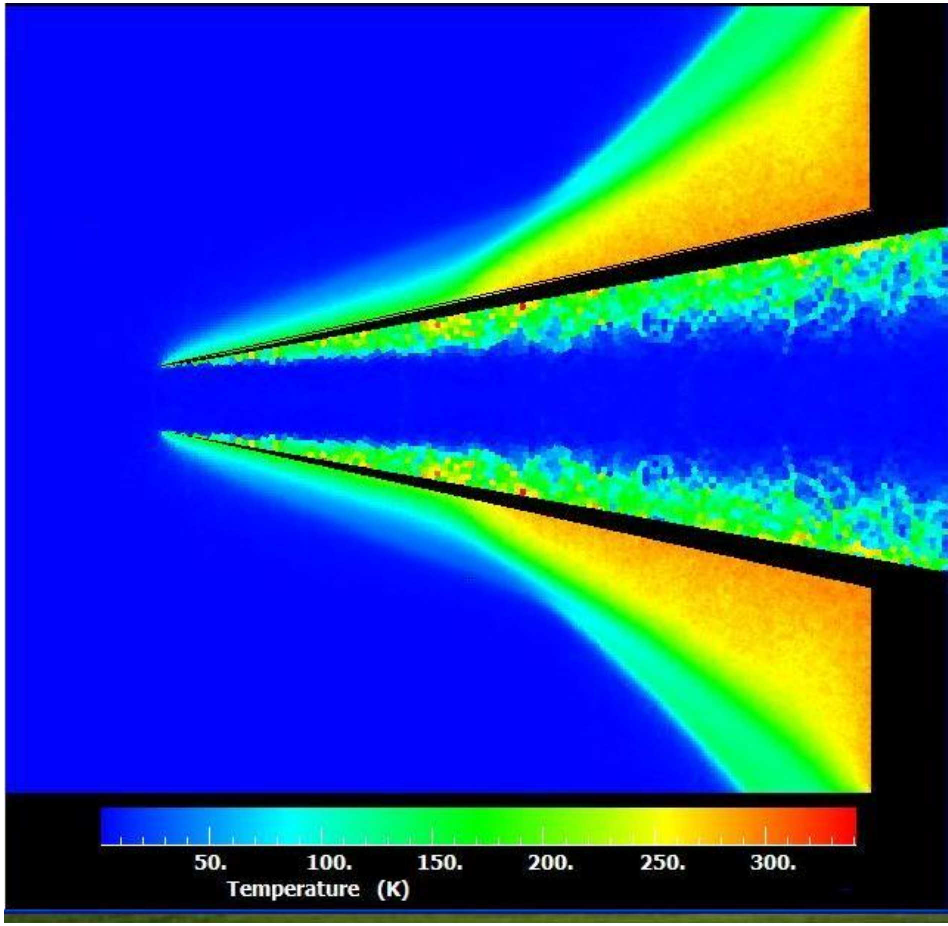
density **temperature**

long conical skimmer at high beam intensity

large entrance hole, 25^0 full angle, 50 mm length.

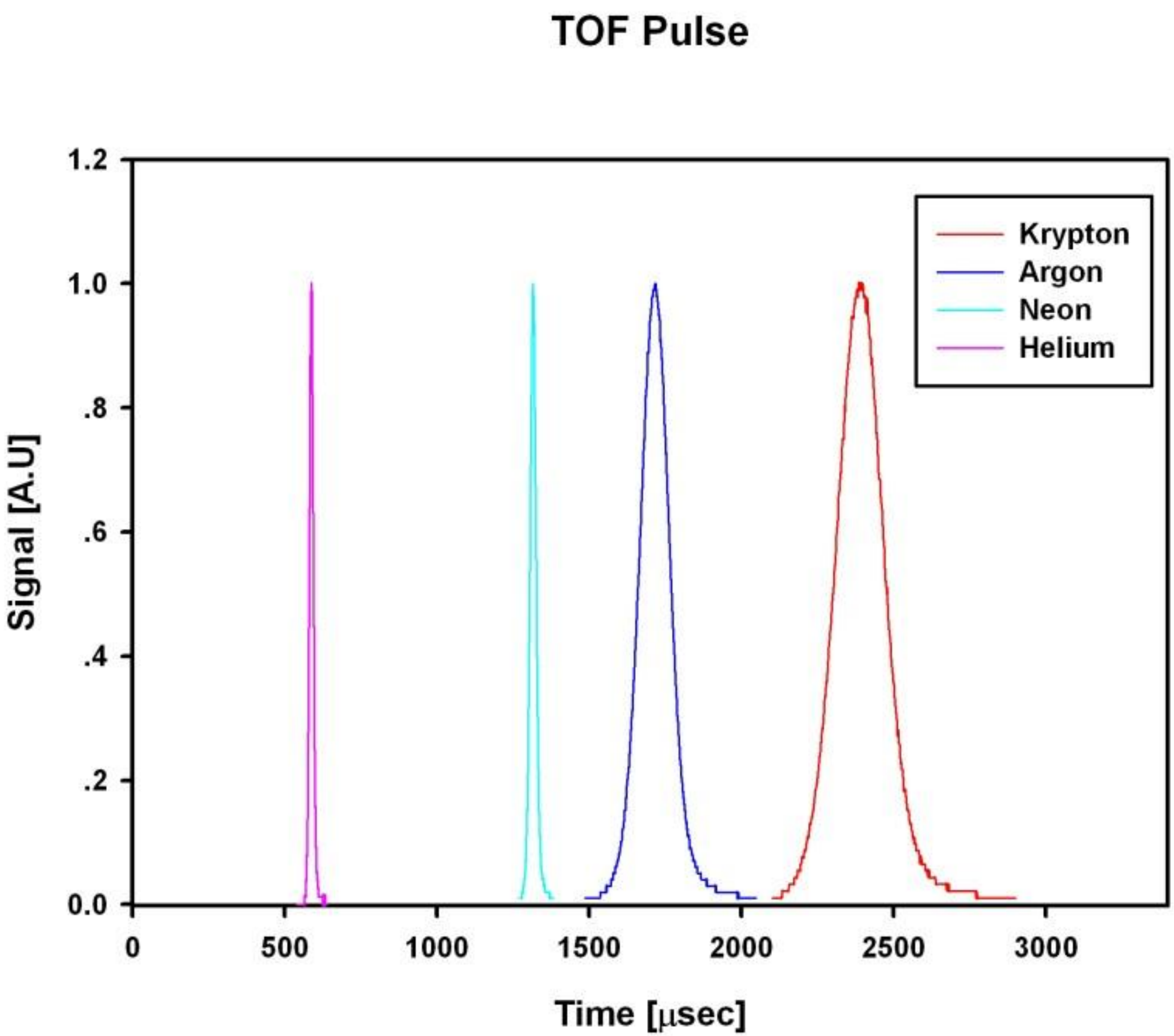


density



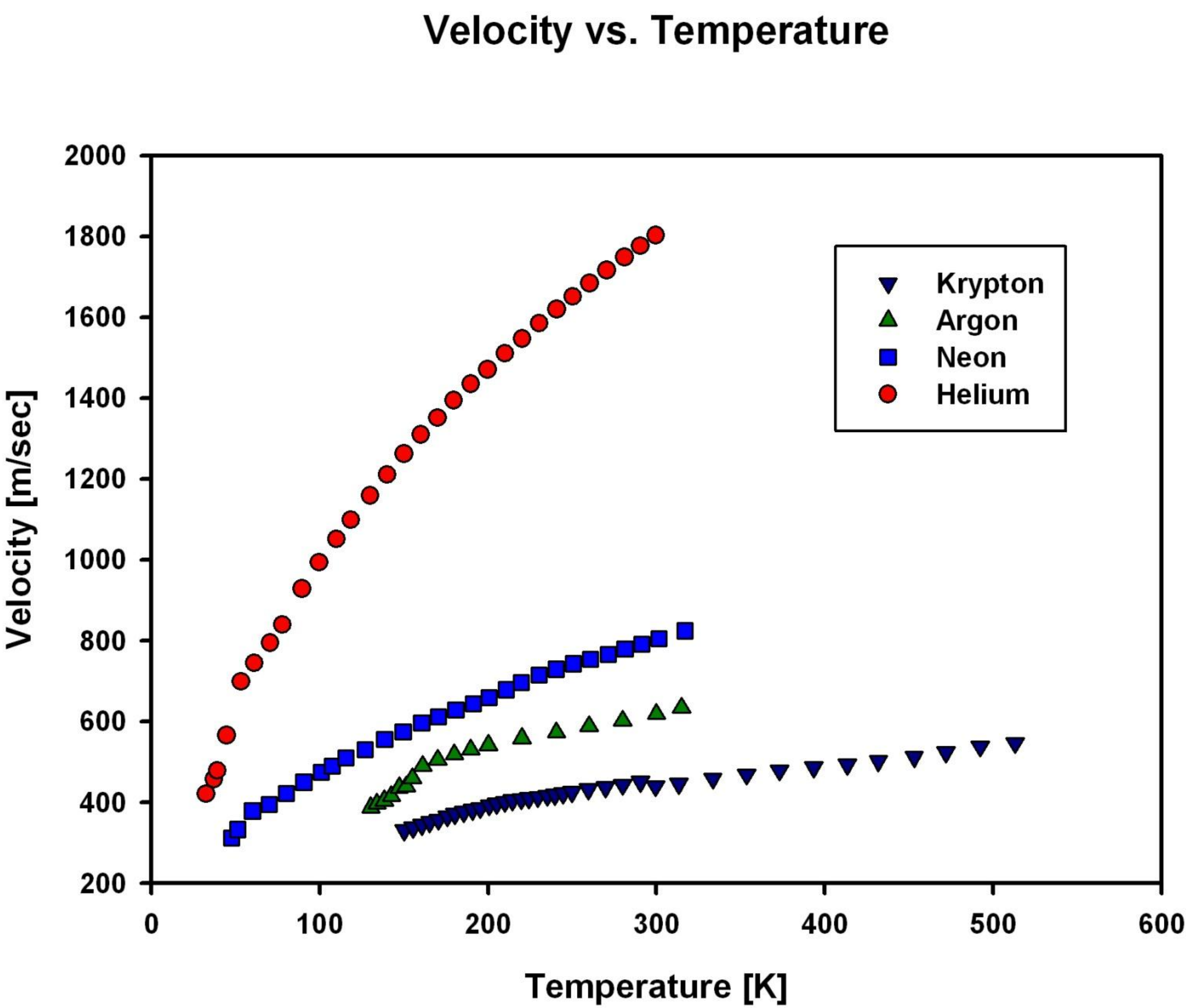
temperature

arrival time distribution after ~1 meter flight.



velocity of supersonic jets

J. Chem. Phys. 118, (19),8690 (2003)



few examples of atom beam applications for fundamental questions

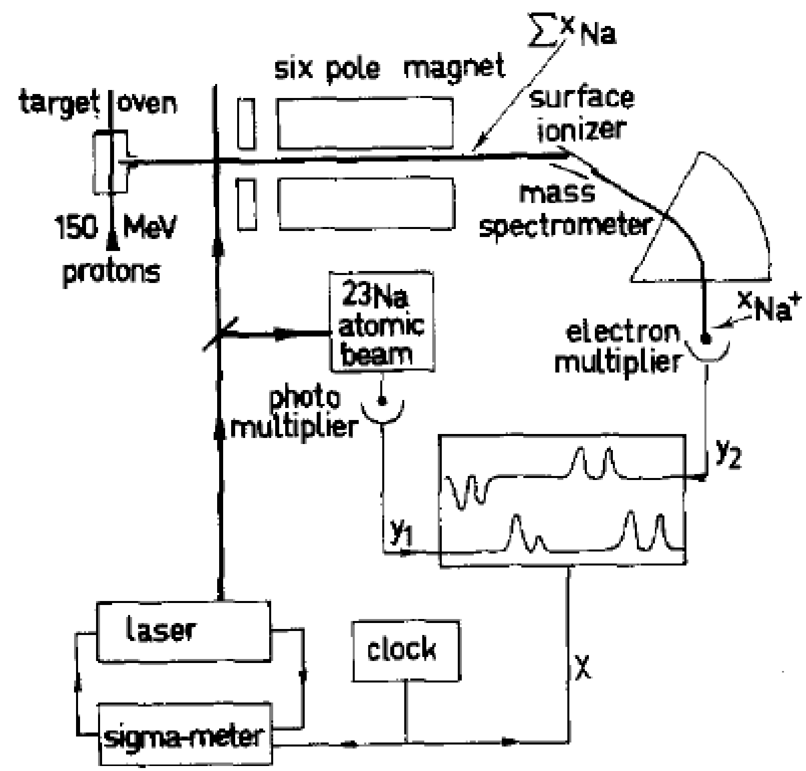
hyperfine spectroscopy HFS of Na isotopes measuring nuclear magnetic and quadrupole moments

isotope production:

spallation reaction with ^{27}Al + 150 MeV p from an accelerator

$^{27}Al\ (p,3pxn)^{25-x}Na$

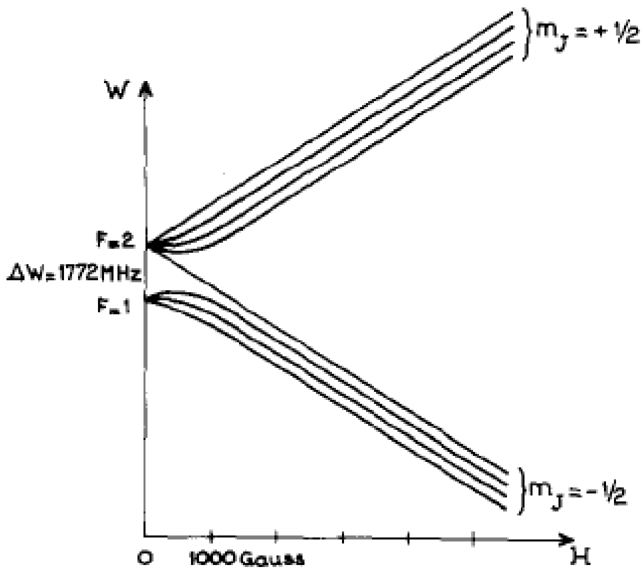
^{23}Na from atomic beam as reference



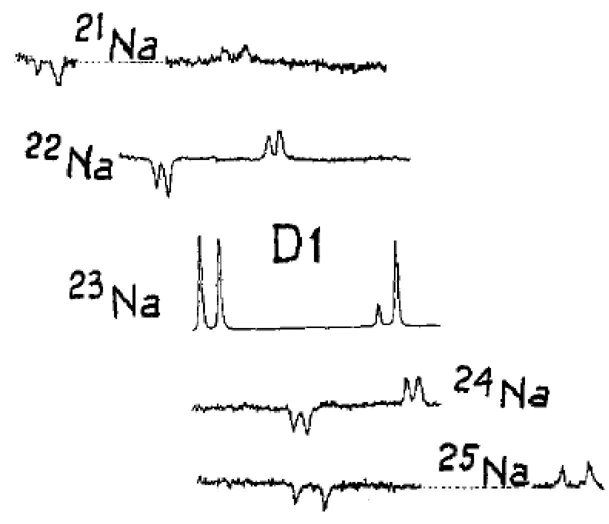
selecting a single HFS state
with an electrostatic six-pole magnet

a magnetic 6-pole focuses atoms in the sublevel $m_J = +1/2$ of the ground state, it defocuses atoms in the sublevel $m_J = -1/2$

thus the HFS level with $m_J = +1/2$ can selectively be monitored



HFS transitions for Na d-lines

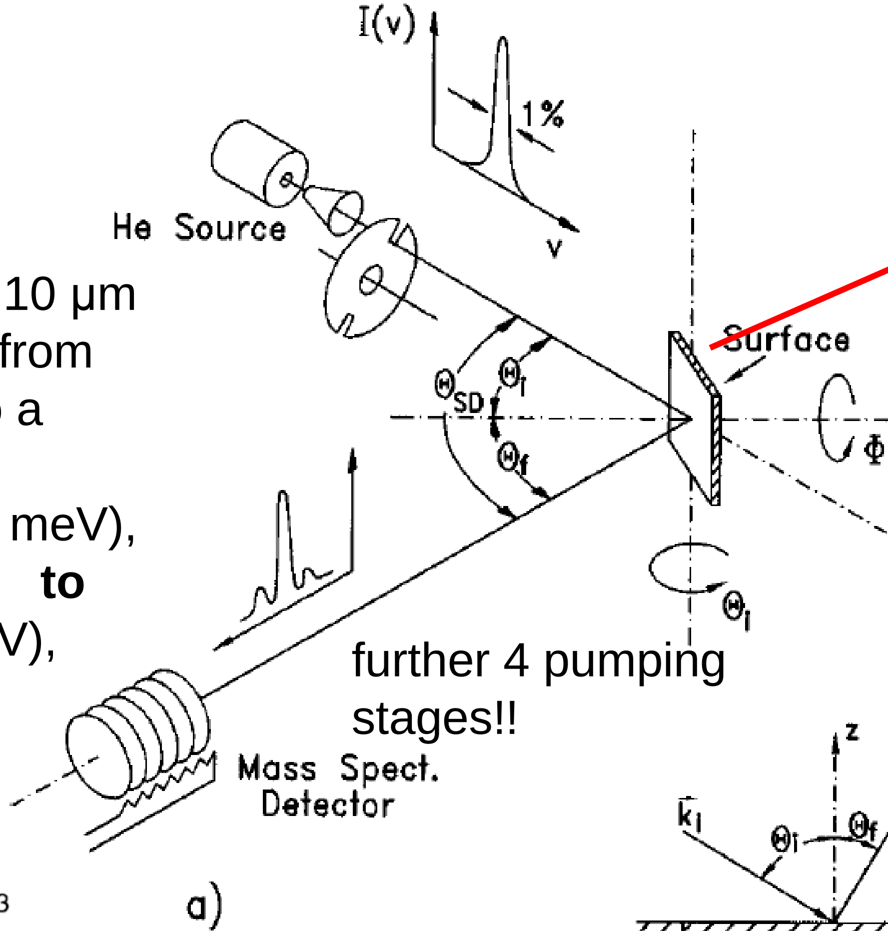


scale 10^{-3} cm^{-1}

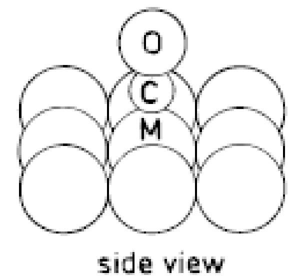
Duong et al., in *Laser Spectroscopy* II, Springer lecture notes 43 (1975)

Helium atom scattering

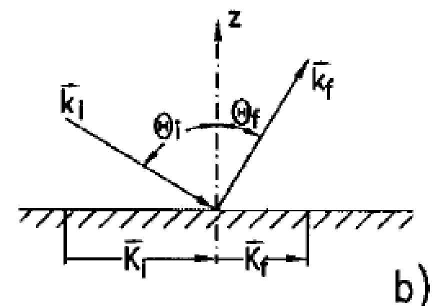
30 to 200 bar Helium, 10 μm
temperature variation from
300 K to 40 K leads to a
variation **from**
v_{mean} = 3000 m/s (120 meV),
k_i = 16 $Å^{-1}$, λ_{dB} = 0.3 Å **to**
v_{mean} = 700 m/s (8 meV),
k_i = 4 $Å^{-1}$, λ_{dB} = 1.5 Å

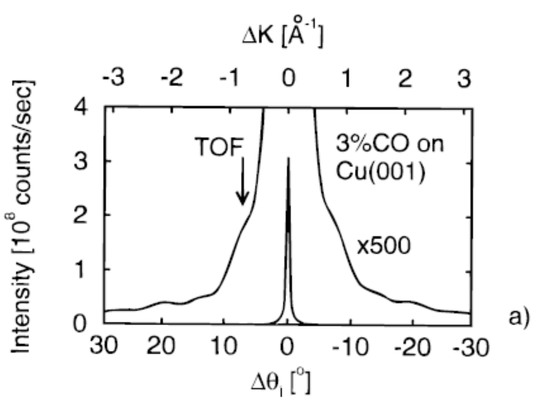


further 4 pumping stages!!



CO on fcc(001) Cu at 10 $^{-11}$ mbar!!





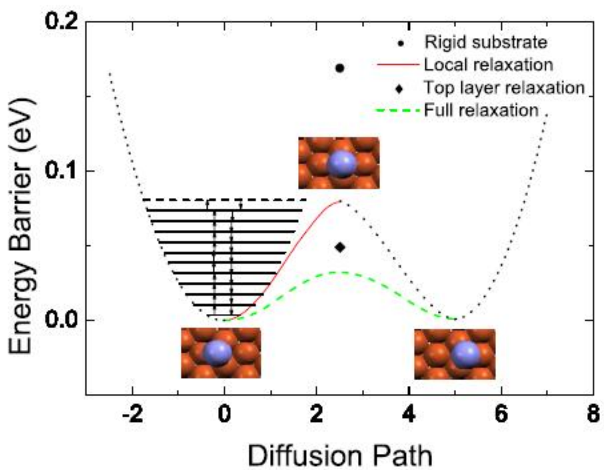
Hofmann, Toennies, Chemical Reviews 96, 1996, 1307

Helium atom scattering

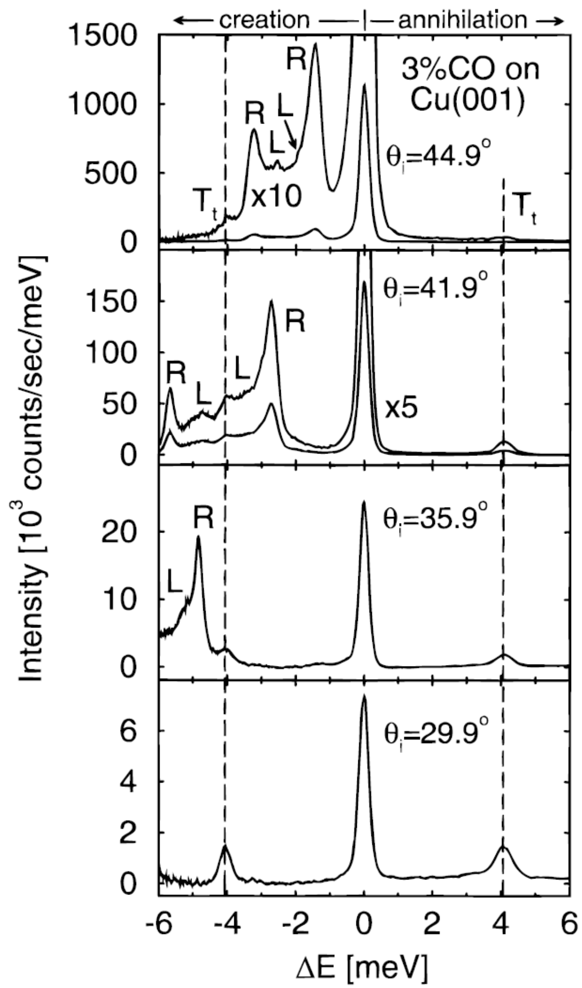
$$\hbar\omega = \frac{\hbar^2}{2m}(k_i^2 - k_f^2)$$

$$\Delta \mathbf{K} = k_f \sin\theta_f - k_i \sin\theta_i$$

with k_i and k_f initial and final wave vectors,
m probe mass
Θ_i and Θ_f inc. and final scattering angles

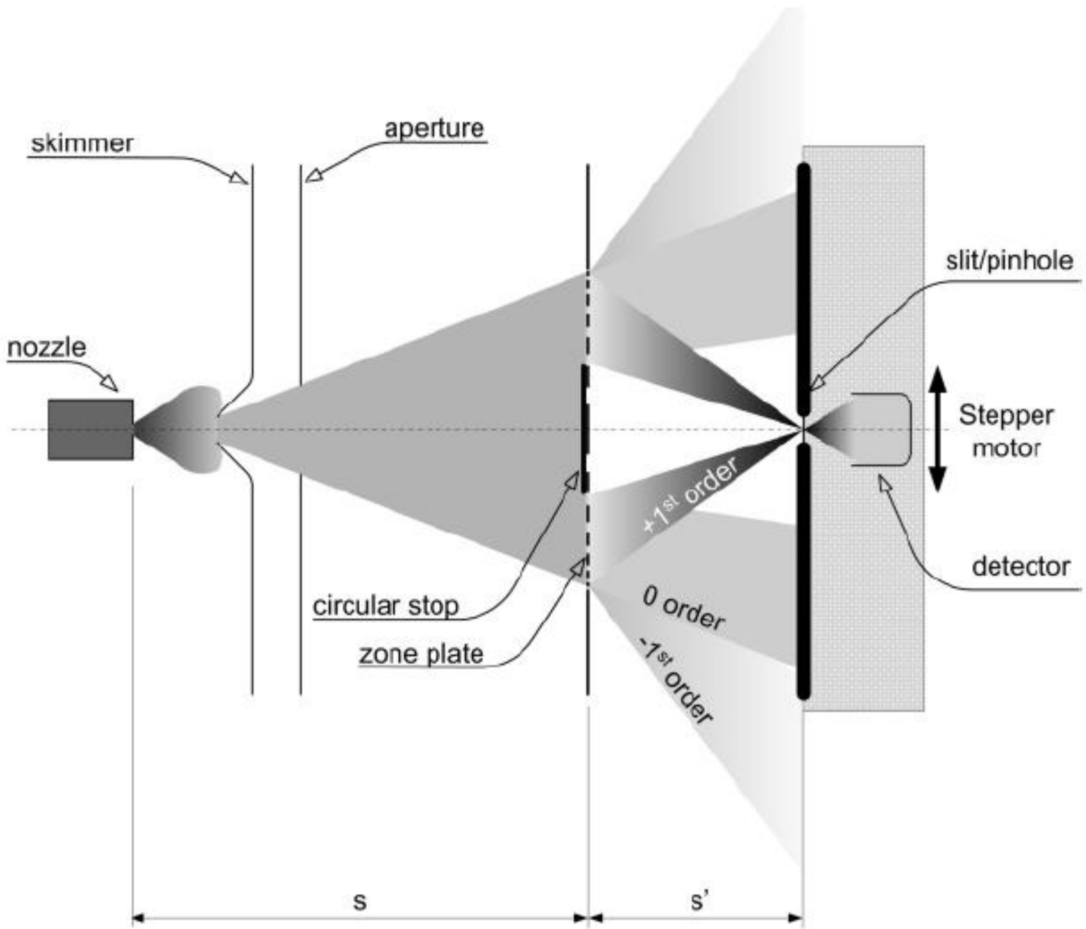


T_i: T mode, resonant hopping



creation *annihilation*
of a vibrational quantum (R,L: phonons)
from the time-of-flight measurement

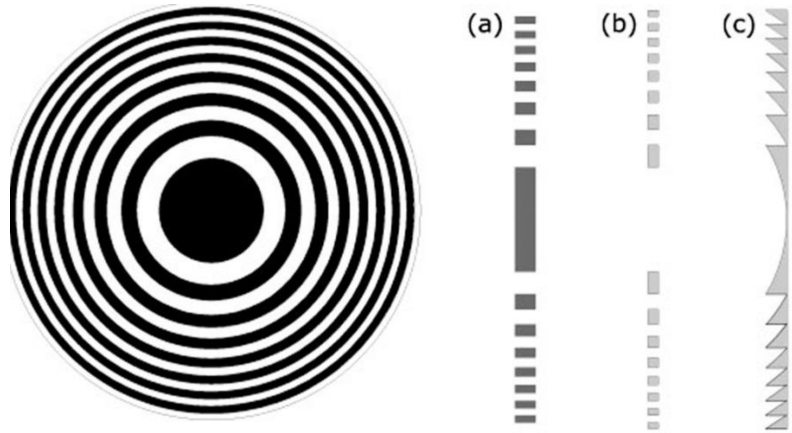
focussing of a neutral He beam by diffraction
doing optics with an atom beam

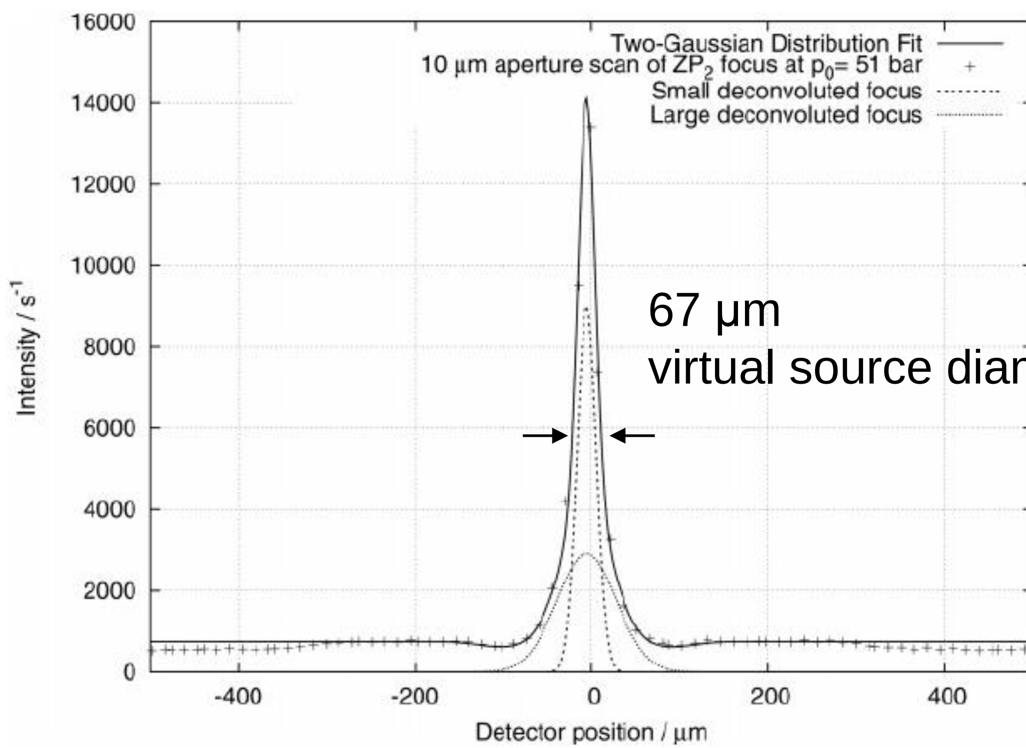


nozzle 10 μm
v = 1865 m/s
λ = 0.5 Å

focussing of a neutral He beam by diffraction
Fresnel zone plate

Nickel zone plate
540 µm diameter
2700 free standing zones
center blocked to supress 0^{th} order

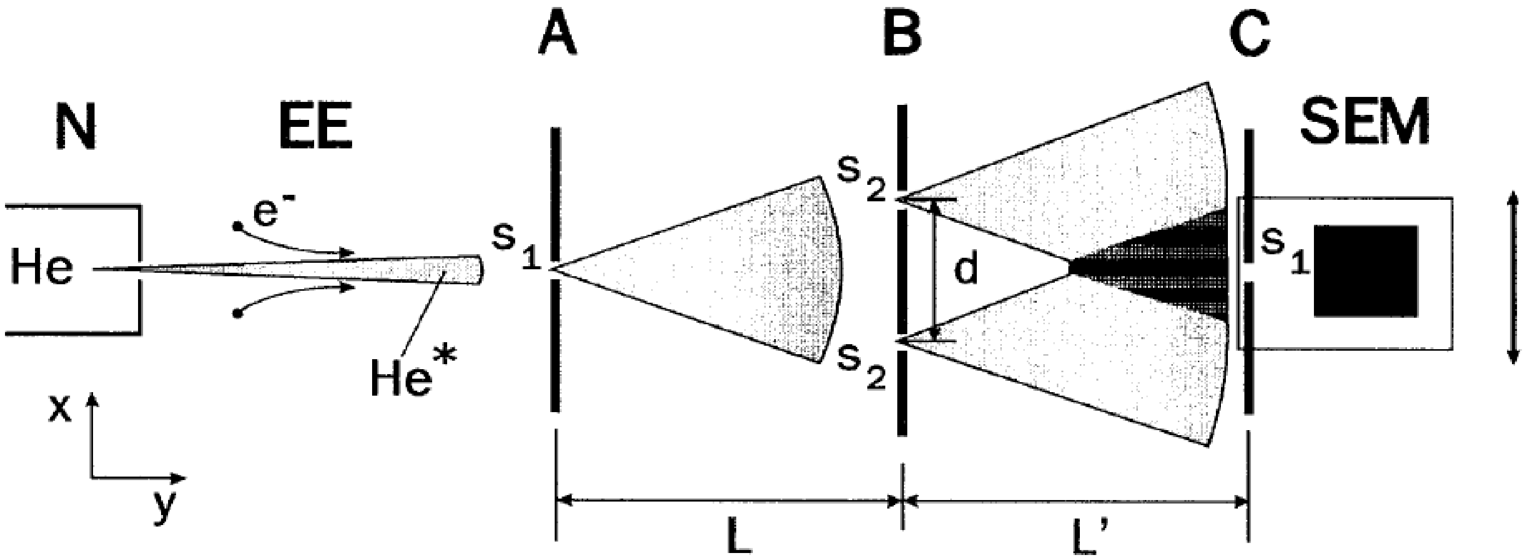


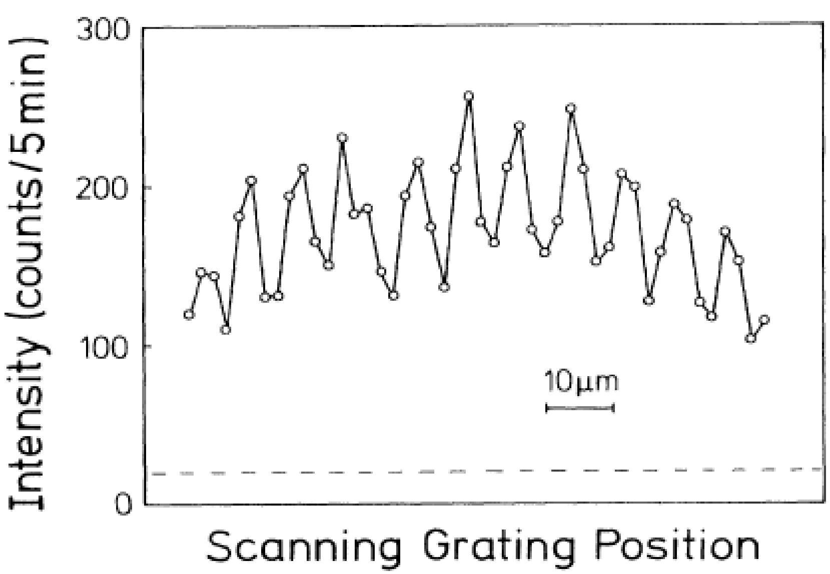


67 µm
virtual source diameter

Reisinger et al.,
J. Phys. Chem. A 111,
2007, 12620

Young double-slit experiment with Helium atoms





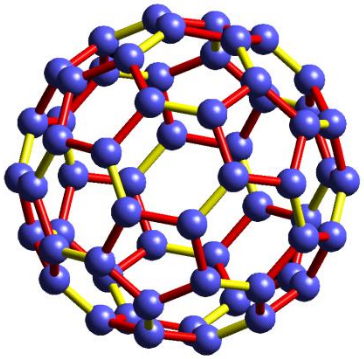
λ_{dB} = 1.03 Å tuned by oven temperature set to 83 K

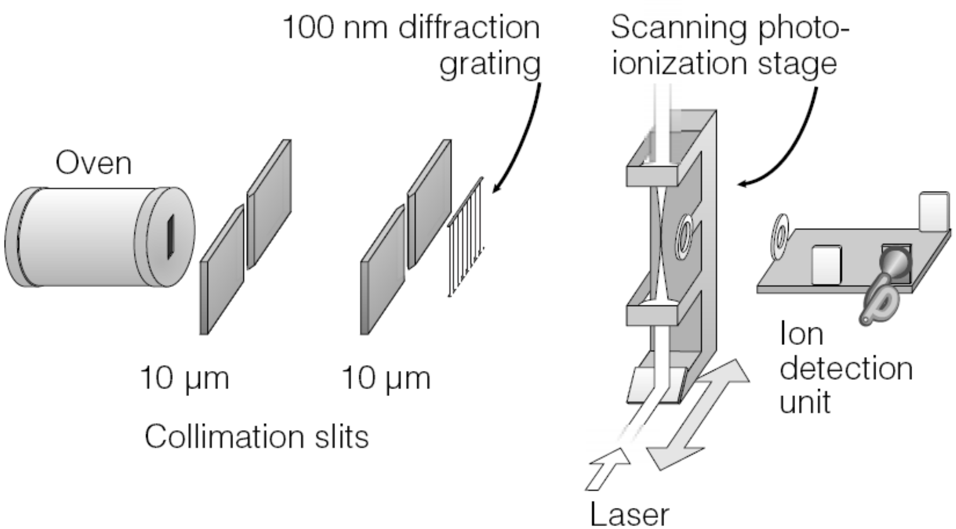
thermal de Broglie wavelength

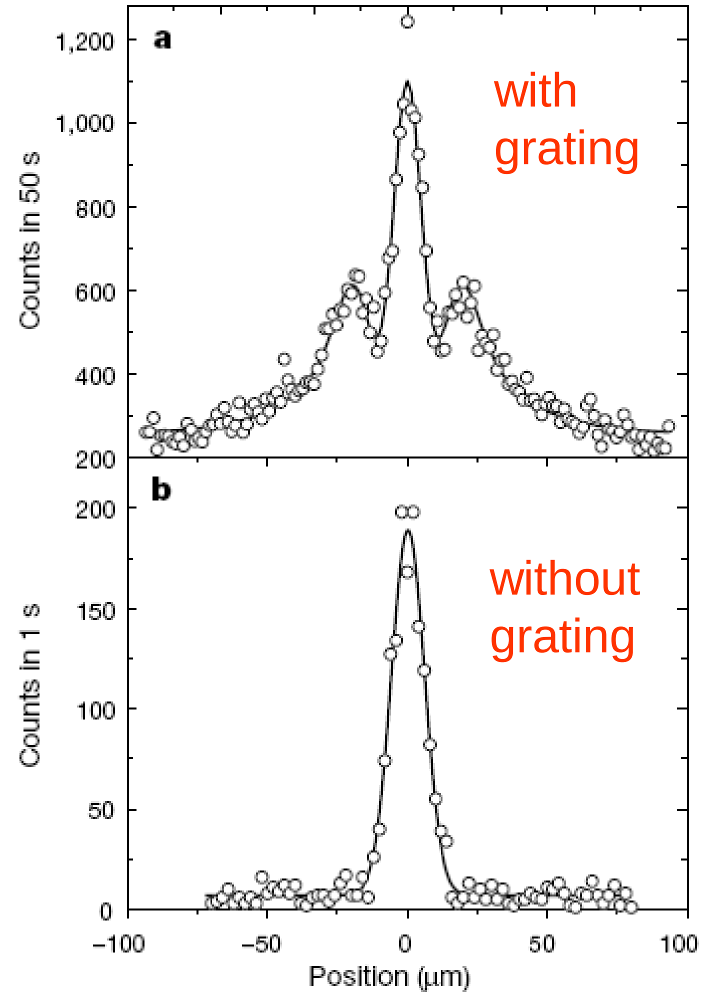
$$\lambda_{dB} = \frac{h}{\sqrt{2\pi m k_B T}}$$

Carnal and Mlynek, Phys. Rev. Lett. 21, 2689 (1991)

de Broglie wave interference of C_{60} molecules







C_{60} parameters: $v = 220$ m/s, $\lambda_{dB} = 2{,}5$ pm
grating 50 nm width, 100 nm separation

Arndt, Zeilinger etc.,
Nature 401, 680 (1999)