lecture 18.11.2010

we had two weeks ago:

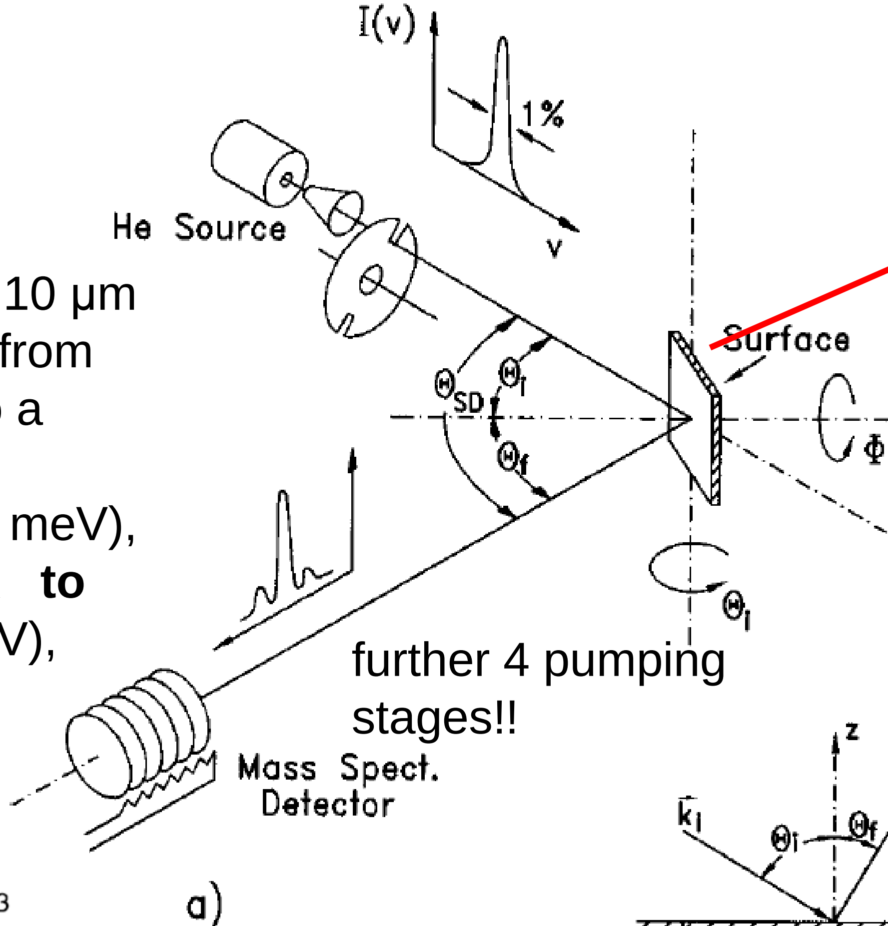
- selected examples with supersonic beams
- atom beam diffraction

today:

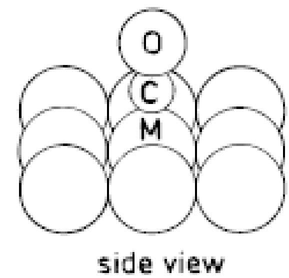
- some more atom diffraction
- radiation pressure as means to cool atom ensembles
- cooling schemes
- optical molasses
- Bose Einstein condensation

Helium atom scattering

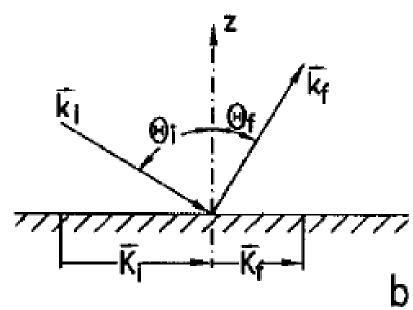
30 to 200 bar Helium, 10 µm temperature variation from 300 K to 40 K leads to a variation **from**
v_{mean} = 3000 m/s (120 meV), k_i = 16 Å^{-1}, λ_{dB} = 0.3 Å **to**
v_{mean} = 700 m/s (8 meV), k_i = 4 Å^{-1}, λ_{dB} = 1.5 Å

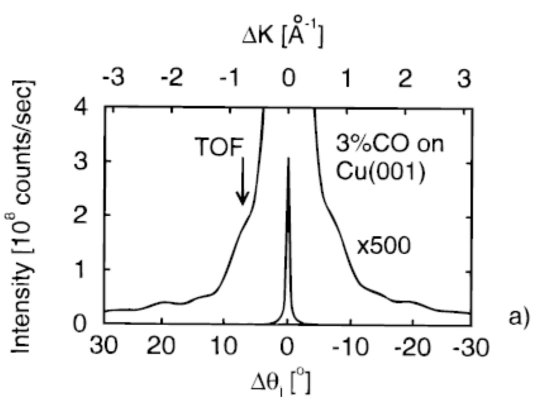


further 4 pumping stages!!



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

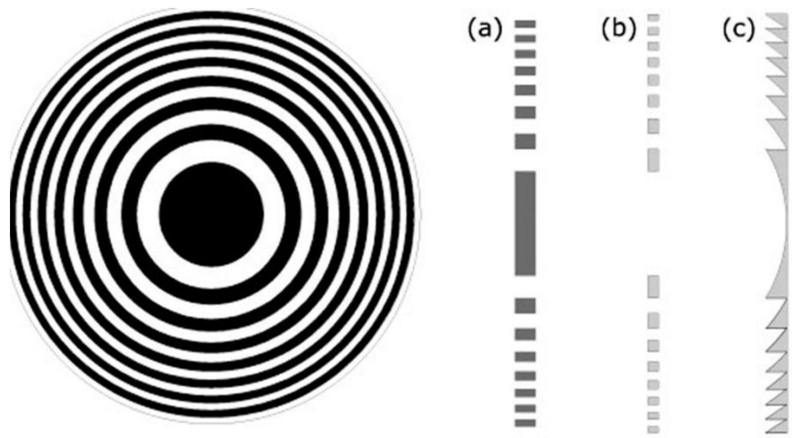




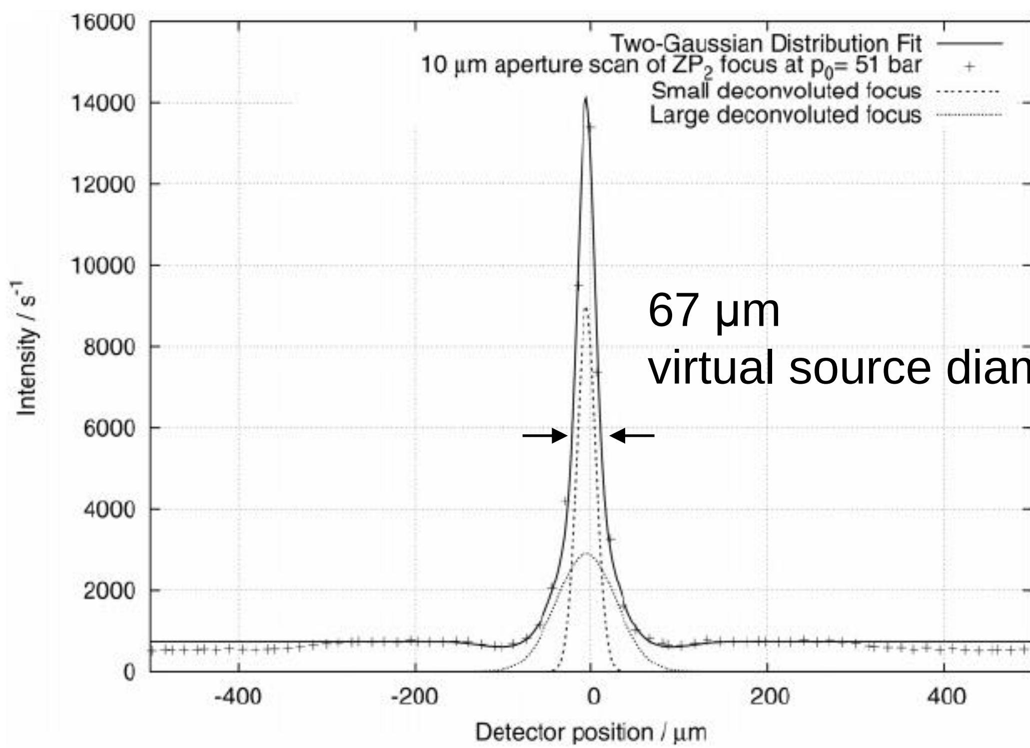
Hofmann, Toennies, Chemical Reviews 96, 1996, 1307

focussing of a neutral He beam by diffraction
Fresnel zone plate

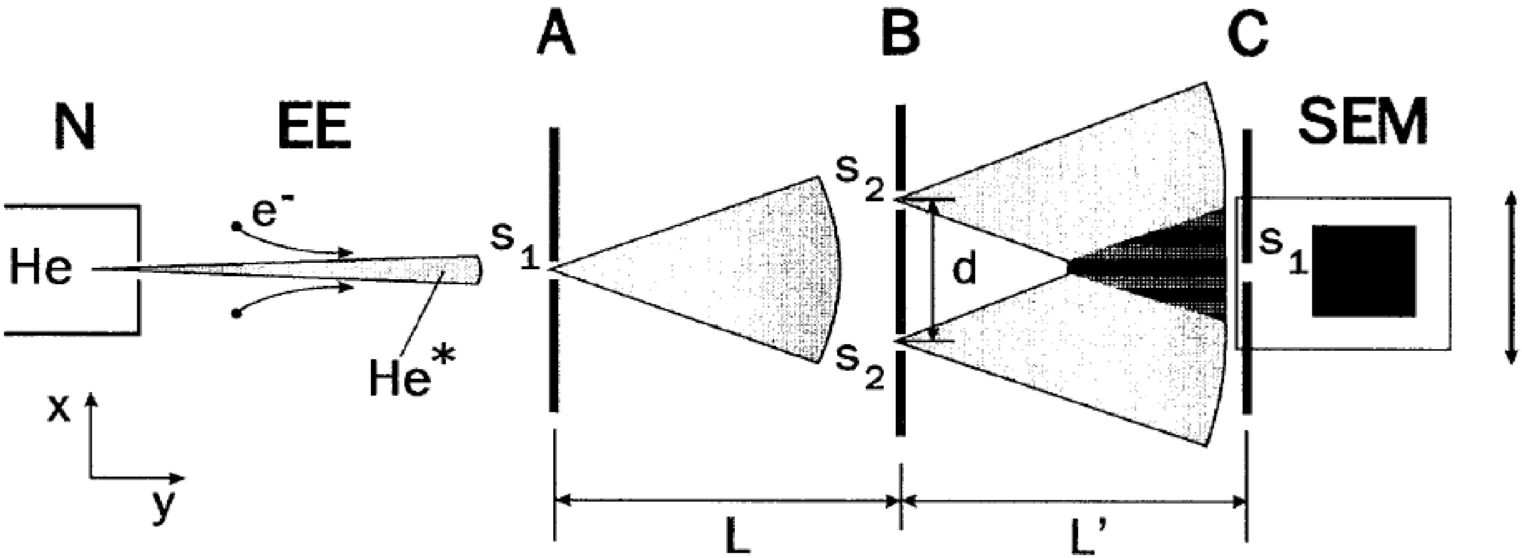
Nickel zone plate
540 μm diameter
2700 free standing zones
center blocked to supress 0th order

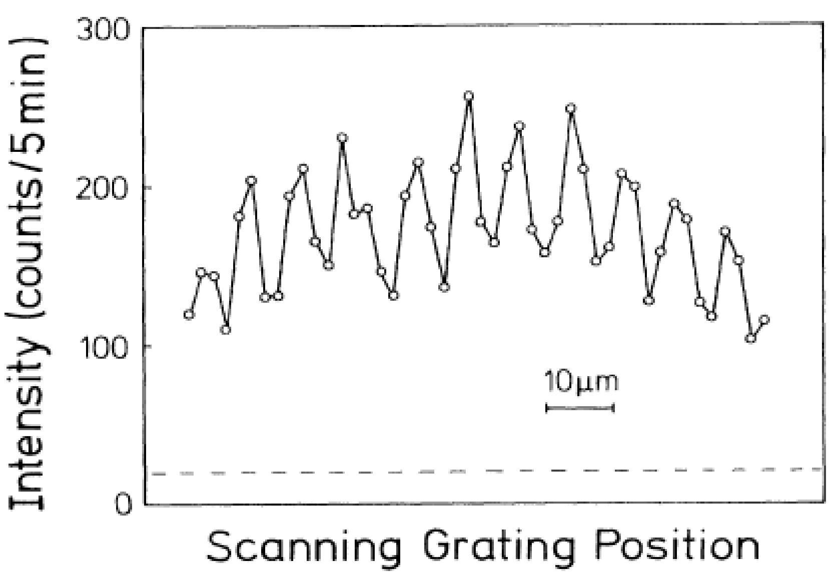


Reisinger et al.,
J. Phys. Chem. A 111,
2007, 12620



Young double-slit experiment with Helium atoms





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

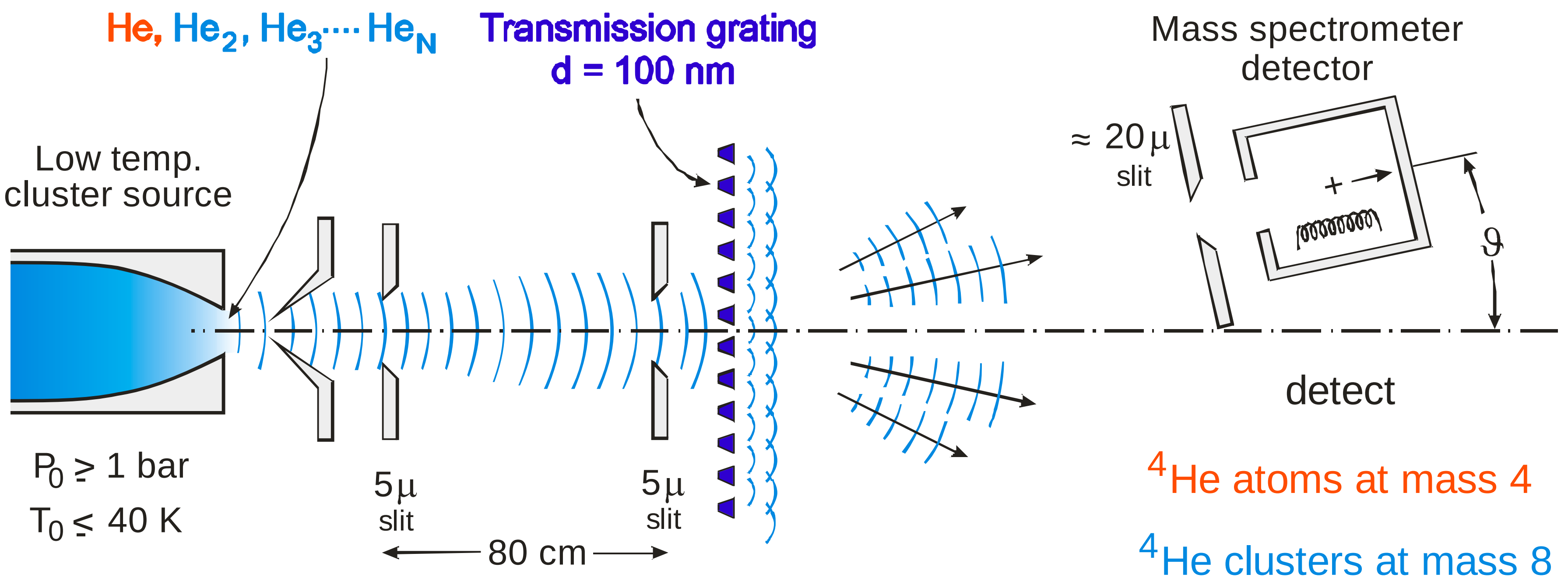
thermal de Broglie wavelength

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

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

Non - destructive Diffraction Grating "Mass Spectrometer"

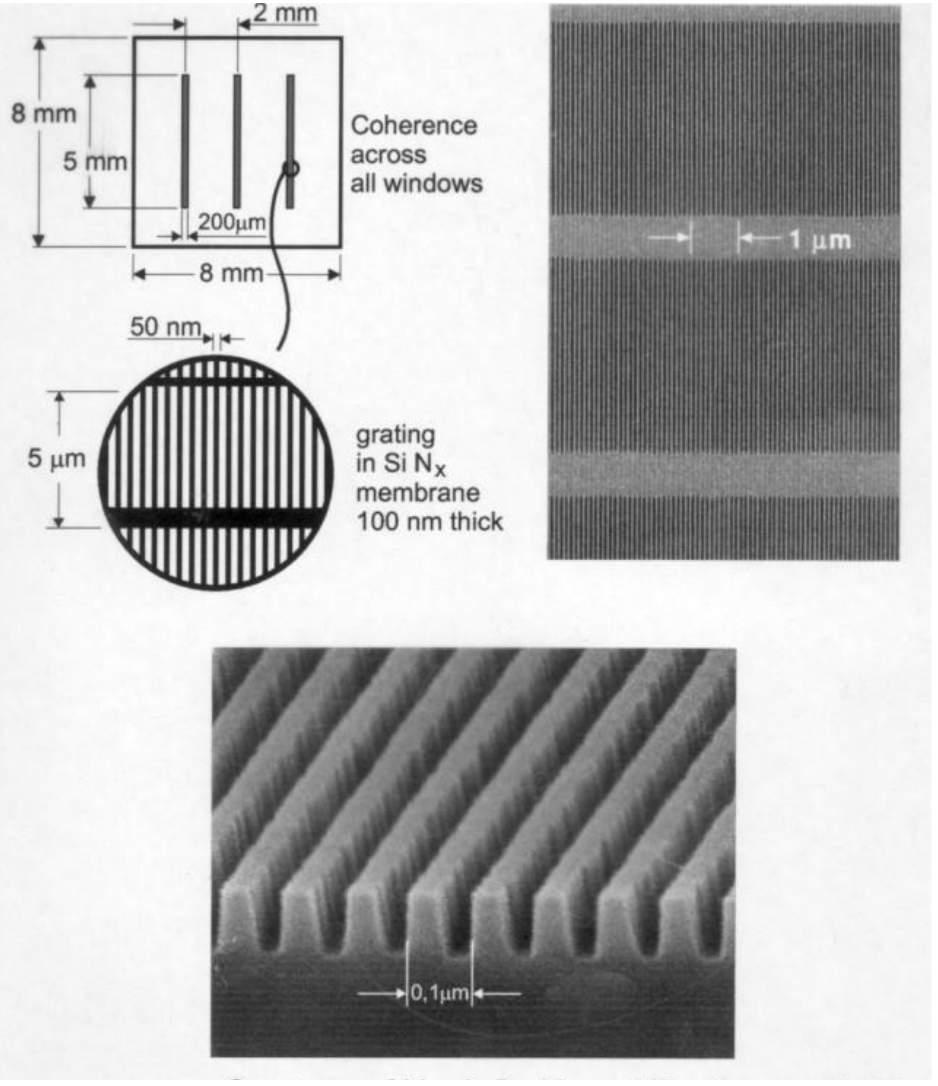
Previous: Na atoms, Pritchard et al (1988); He*, Mlynek et al (1991)



Can discriminate against atoms with mass spectrometer set at mass 8 and larger

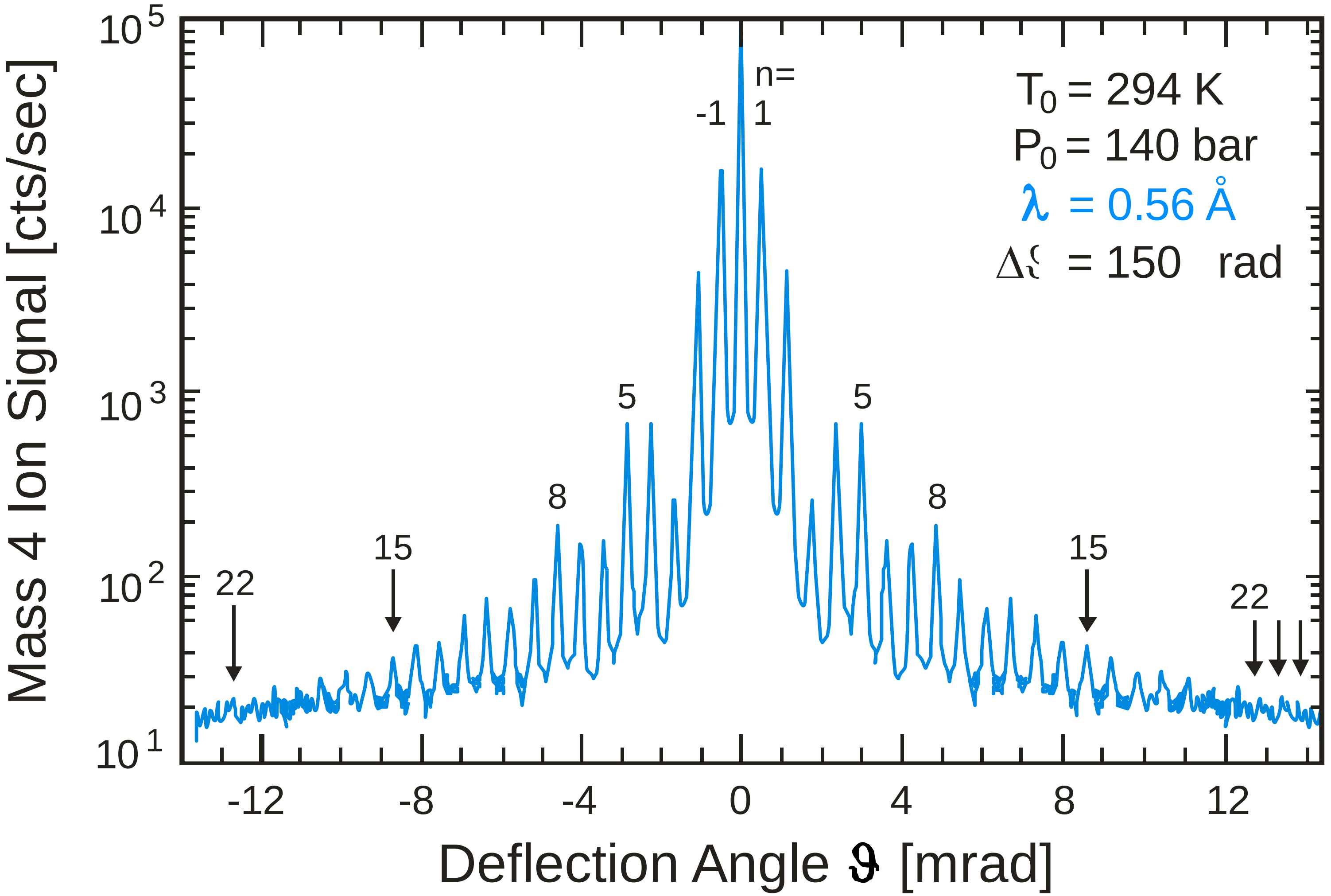
from J. P. Toennies

electron microscope pictures of SiN_x transmission gratings



Courtesy of Prof. H. Smith and Dr. Tim Savas, M. I. T.

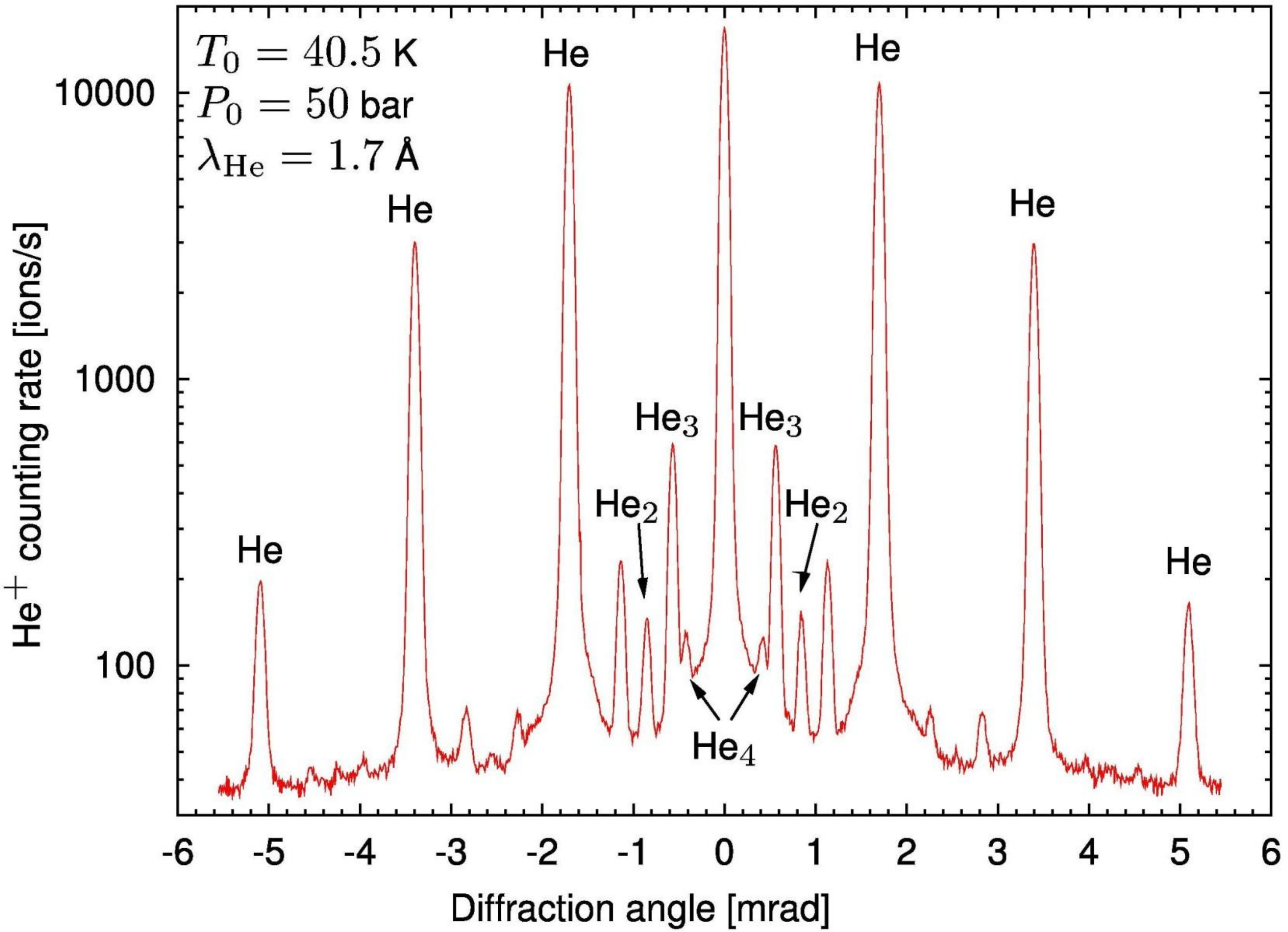
He Atom Diffraction Pattern for 300 K Beam



$$\text{Bragg: } \vartheta \simeq \frac{n\lambda}{d} = \frac{0.56\ \text{Å}}{1000\ \text{Å}}\ (n{=}1) = 0.56 \cdot 10^{-3}\ \text{rad.}$$

from J. P. Toennies

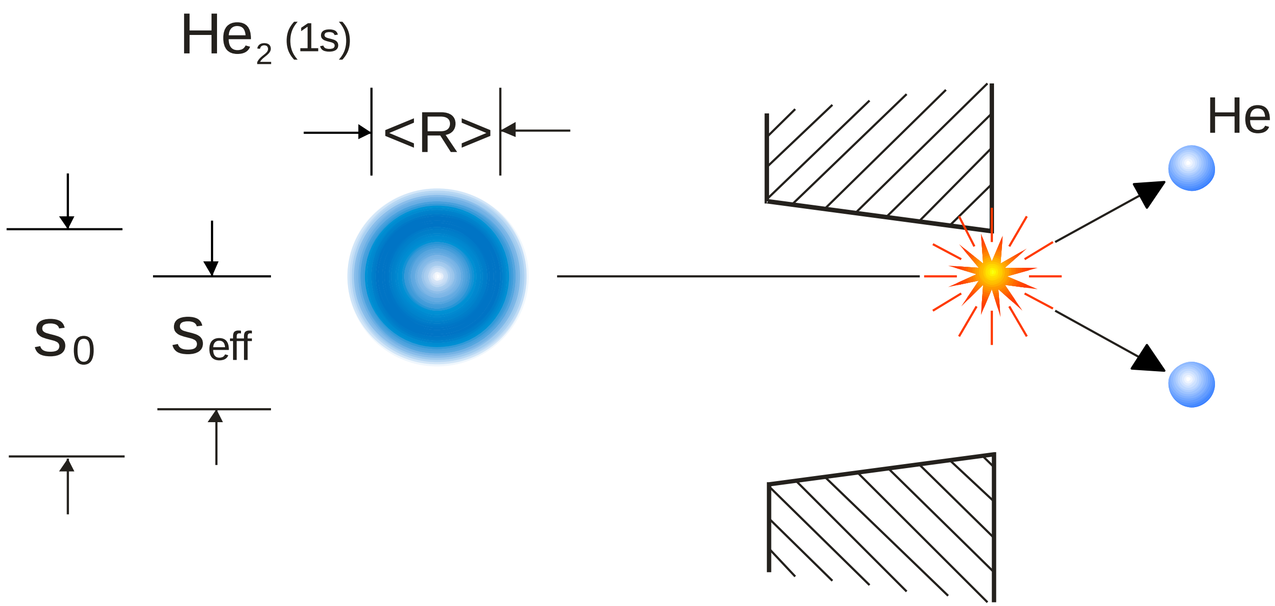
at low source temperatures new diffraction peaks appear



The first unambiguous detection of ^{4}He dimer ($E_b = 1.3$ mK)

W. Schöllkopf and J. P. Toennies, Science **266**, 1345 (1994)

Measure Size of Dimer from Cross Section on Scattering from Grating Bars



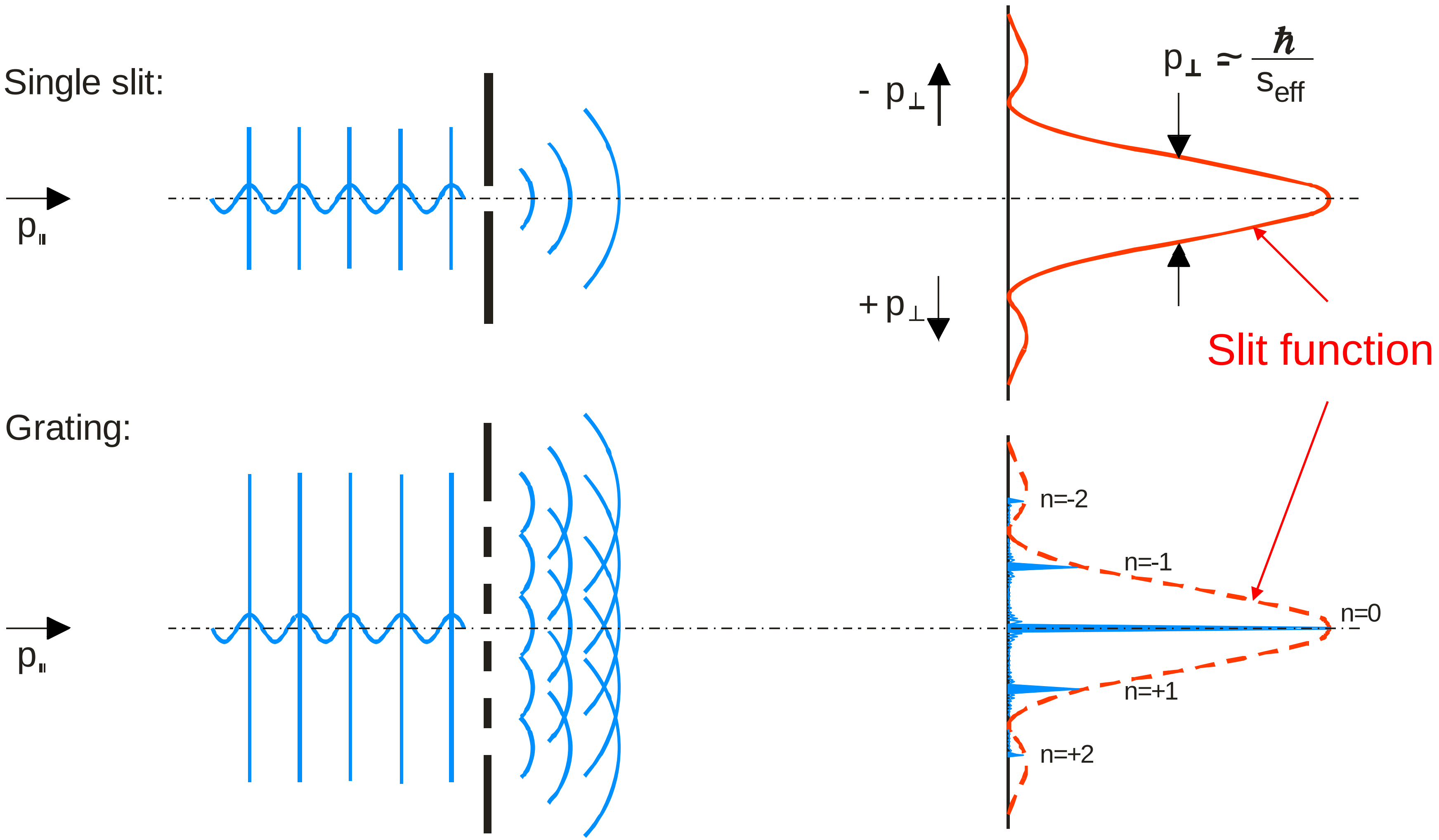
Break-up reduces effective slit width

$$s_0 - s_{eff} \simeq \frac{\langle R \rangle}{2} :$$

Hegerfeldt and Köhler, PRL 84 (2000)

from J. P. Toennies

Single Slit Diffraction is Envelope of Grating Diffraction

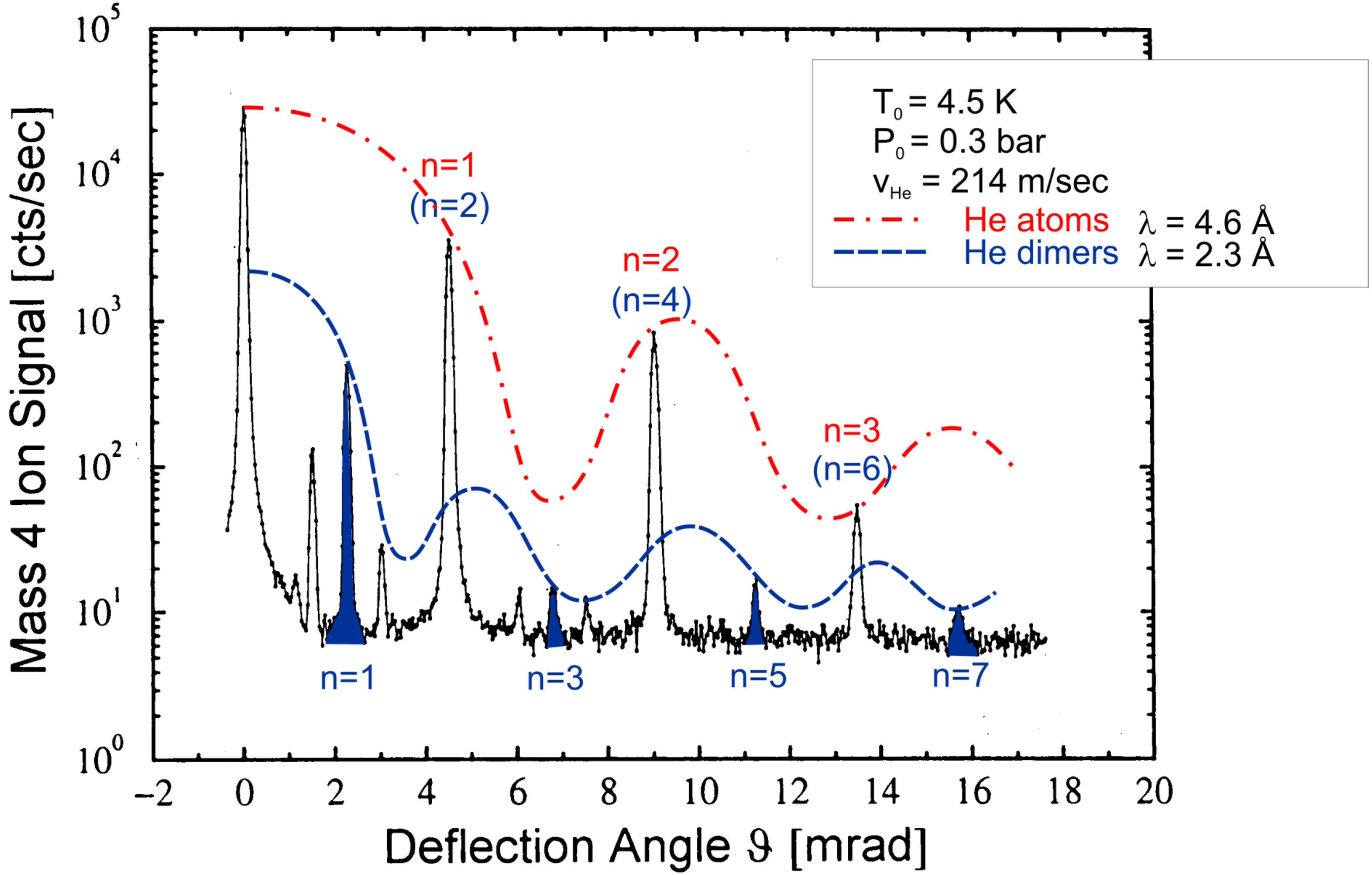


2003-07-17-T1-Schr.

Matter Waves: Feynmann: Lecture Notes in Physics

from J. P. Toennies

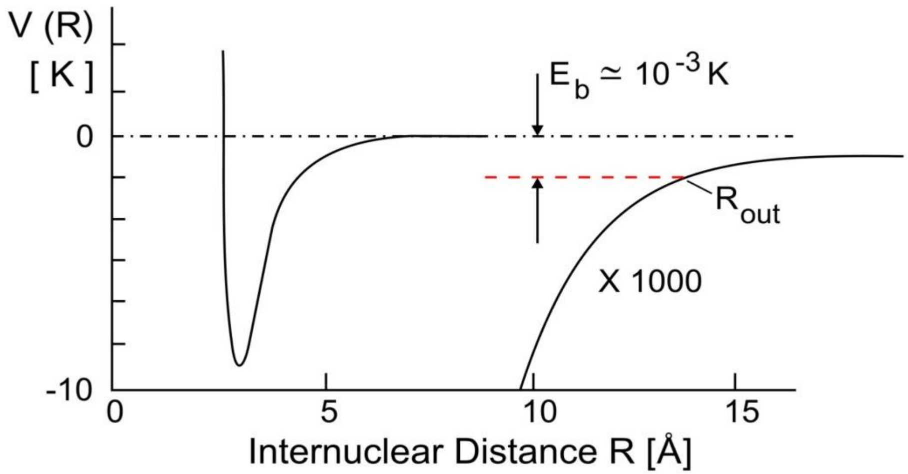
The He Dimer Diffraction Pattern and Slit Function



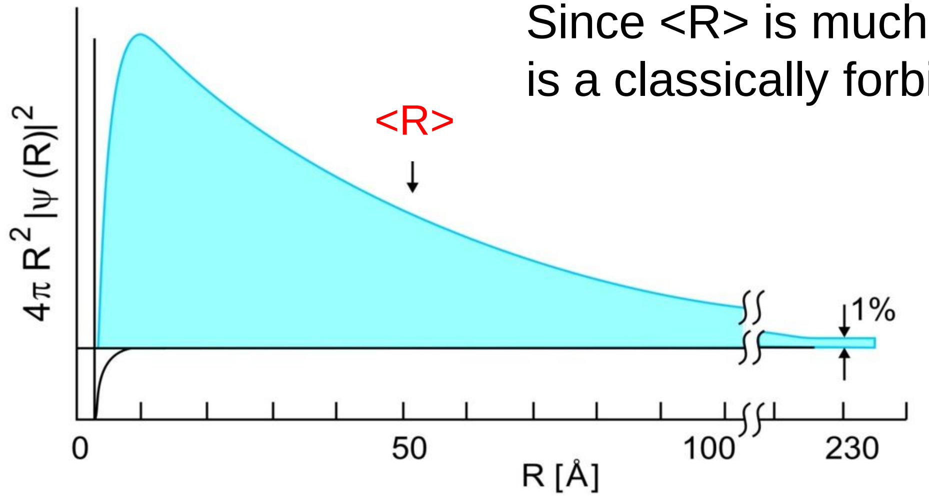
Grisenti, Schöllkopf, Toennies, Hegerfeld, Köhler and Stoll, Phys. Rev. Lett. 85, 2284 (2000)

2003-07-14-T1-Ba

the ^{4}He dimer: the world‘s weakest bound and largest ground state molecule



Since <R> is much greater than R_{out} the dimer is a classically forbidden molecule



Scattering length: $a \simeq 2 \langle R \rangle \approx 100$ Å

Cross section: $\sigma (T \rightarrow 0) = 8 \pi a^2 = 259{,}000$ Å^2

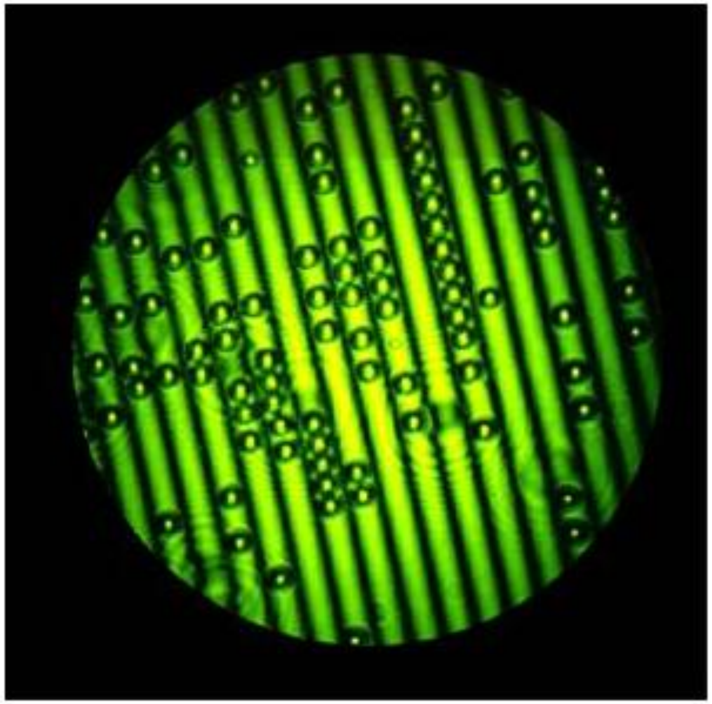
A frail GIANT!

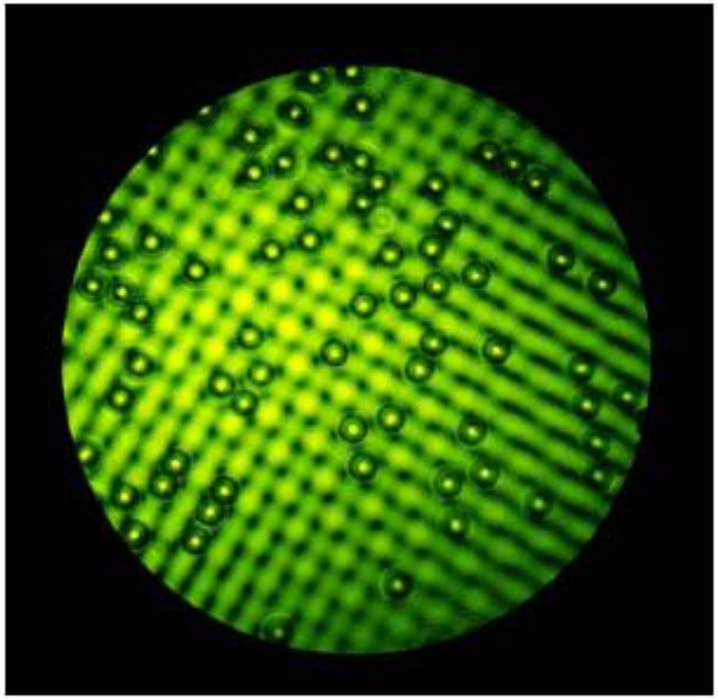
from J. P. Toennies


radiation pressure
useful for atom cooling
Komet Hale-Bopp
Strahlungsdruck

optical gratings generated by interfering laser beams

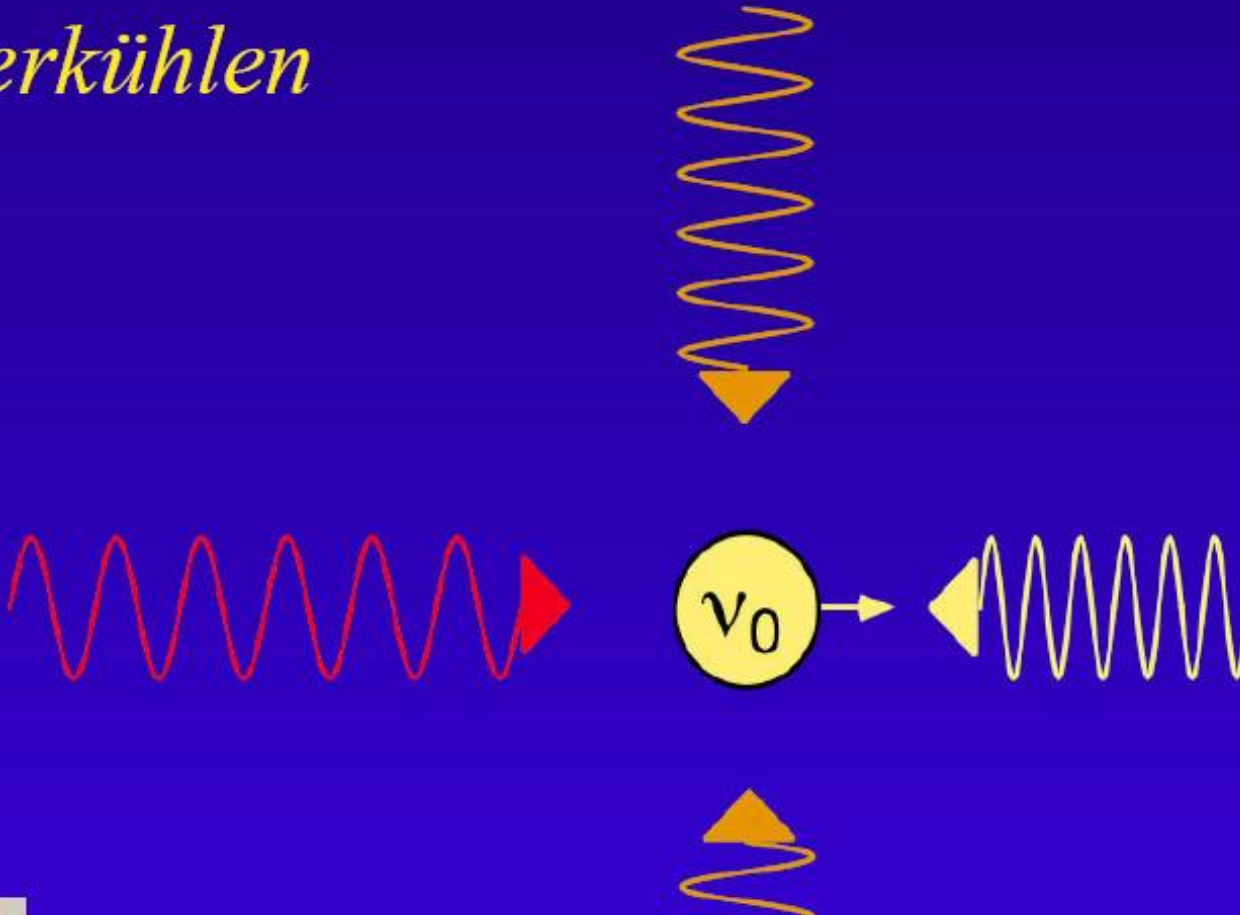
4 µm polysterene spheres soluted in water





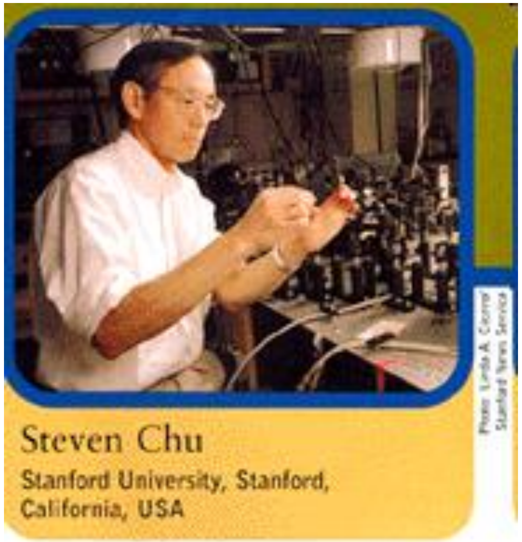
optical forces confine the particles

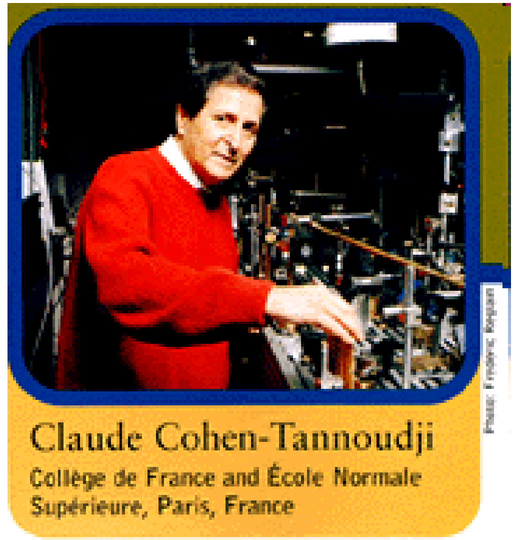
Laserkühlen

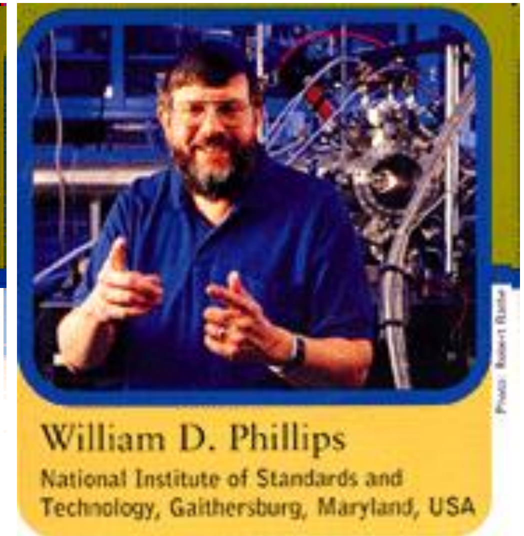


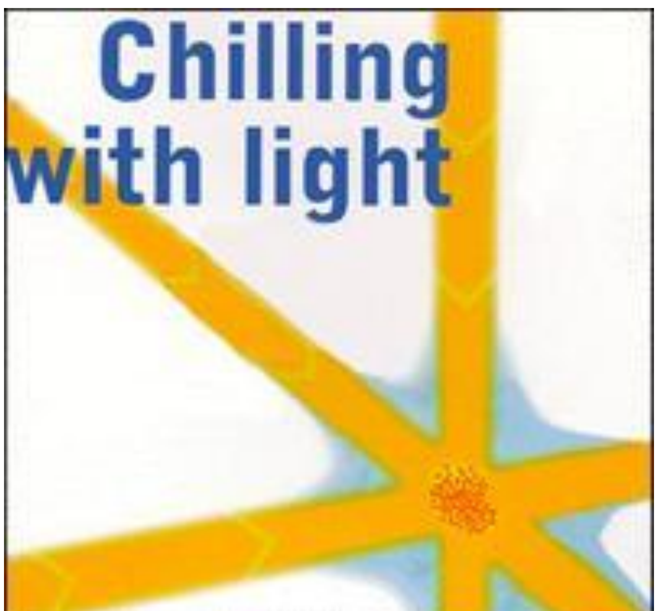
T.W. Hänsch and A.L. Schawlow, Opt. Comm. 13, 68 (1975)

Nobel price in physics 1997









This year's Nobel laureates in physics have developed methods of cooling and trapping atoms by using laser light. Their research is helping us to study fundamental phenomena and measure important physical quantities with unprecedented precision.

from the Nobel homepage

see blackboard script

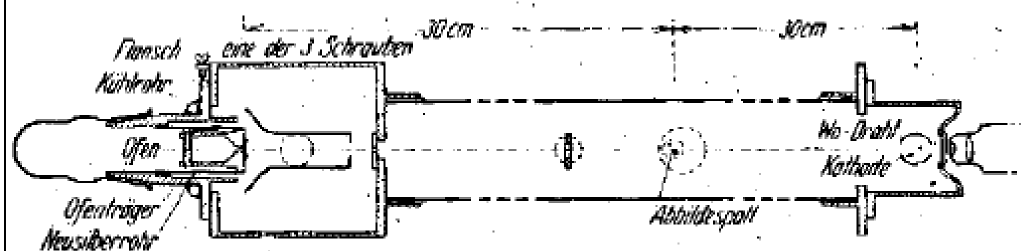
R. Frisch, Z. Phys. 86, 42-48 (1933).

(Untersuchungen zur Molekularstrahlmethode aus dem Institut für physikalische Chemie der Hamburgischen Universität. Nr. 30.)

Experimenteller Nachweis des Einsteinschen Strahlungsrückstoßes.

Von **R. Frisch** in Hamburg.

Mit 6 Abbildungen. (Eingegangen am 22. August 1933.)



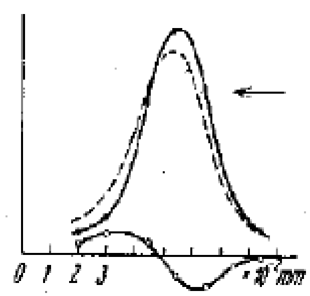


Fig. 5. Versuch mit seitlicher Beleuchtung.
Abszisse: Stellung des Auffängers.
Ordinate: Elektrometerausschlag.
—●— Intensität ohne Beleuchtung.
—○— Wirkung der Beleuchtung.
- - - - Summe dieser beiden, also Intensität mit Beleuchtung.
Der Pfeil deutet die Richtung des Lichteinfalls an.

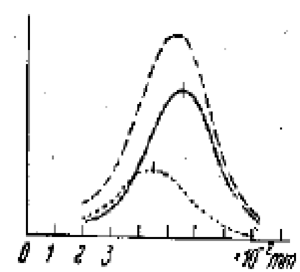
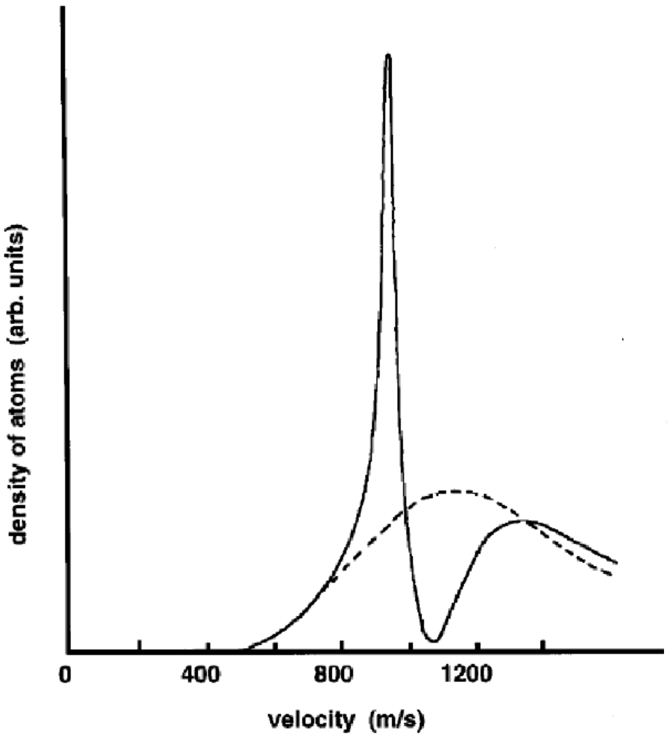
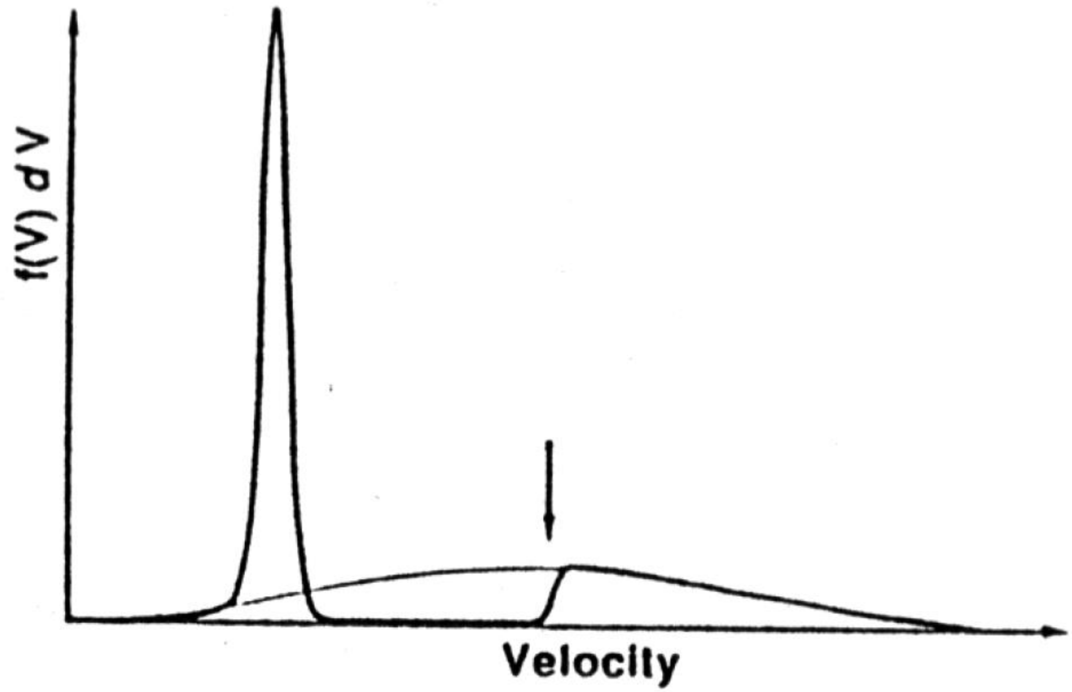


Fig. 6.
- - - - Strahl mit Beleuchtung.
—— $^2/_3$ vom Strahl ohne Beleuchtung.
······ Differenz dieser beiden, also Verteilung der abgelenkten Atome.

velocity distribution after irradiation with frequency

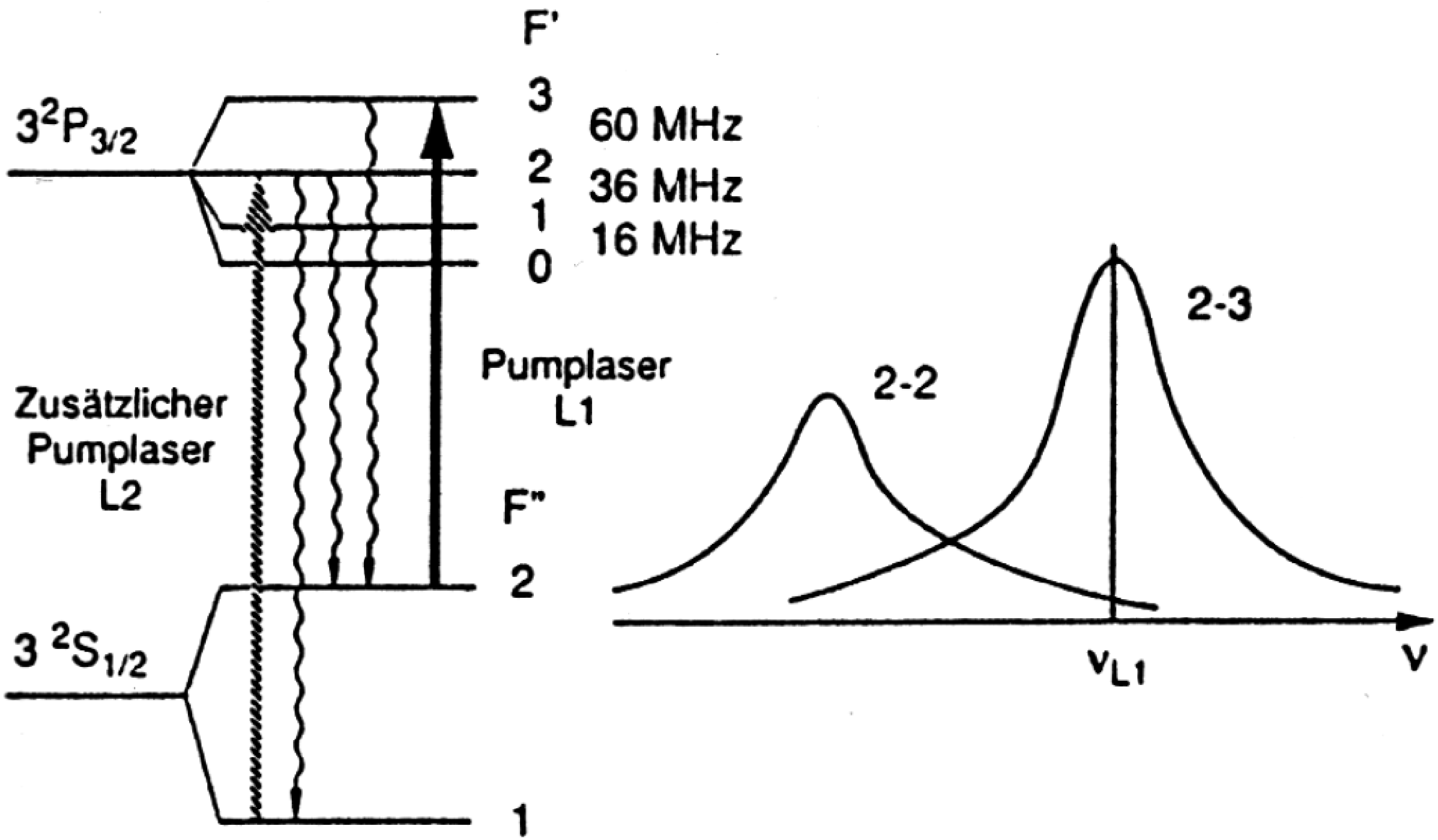
fixed **chirped**





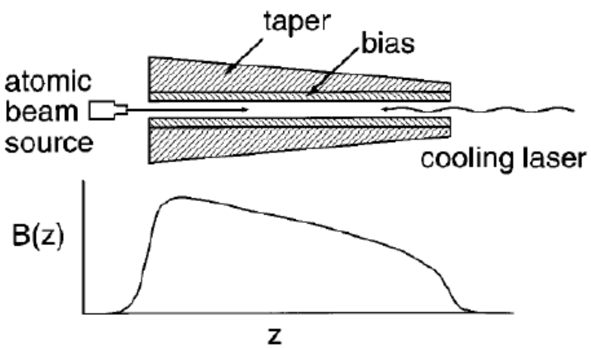
Phillips RMP 1998

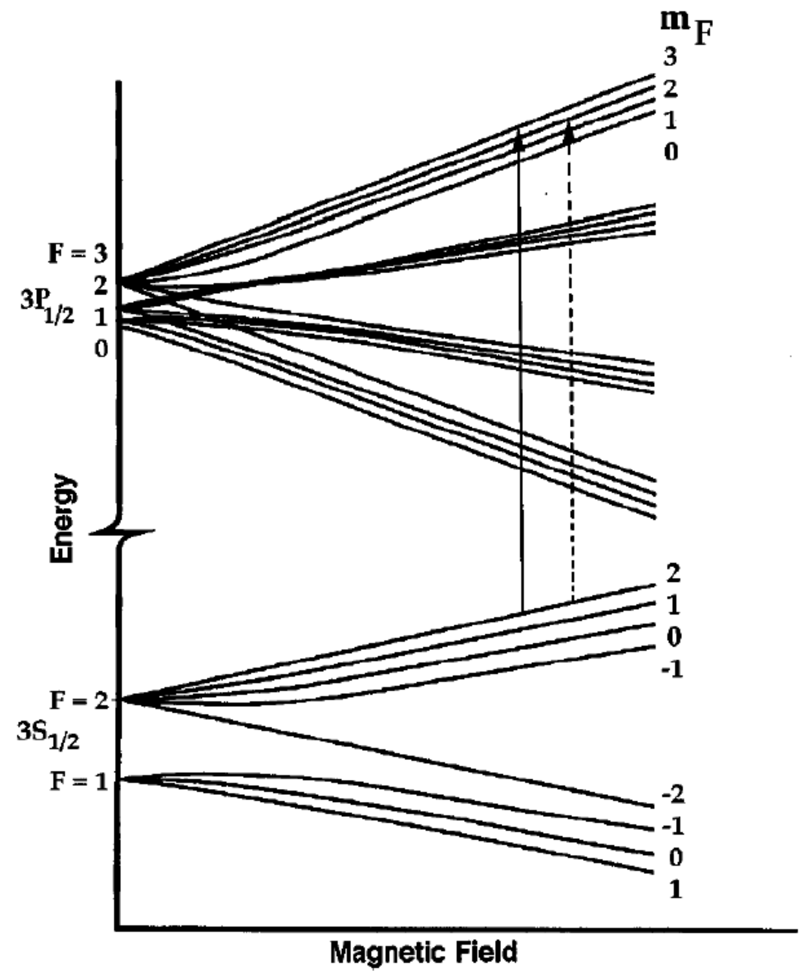
so far: idealized two-level system
in reality: HFS levels involved, e.g. Na $3^2S_{1/2}$ - $3^2S_{3/2}$



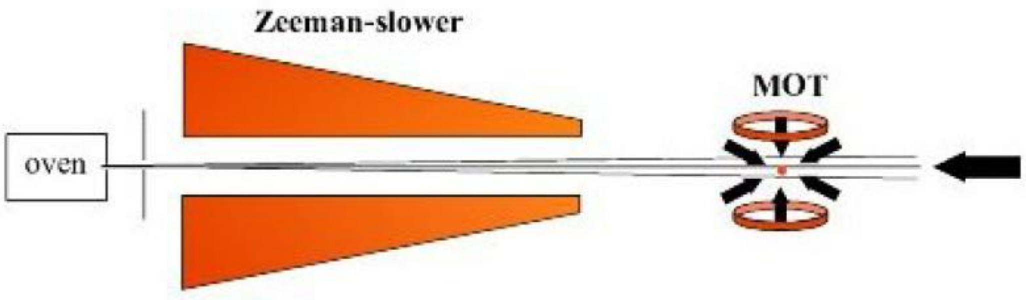
magnetic field helps to separate the levels

Zeeman cooler



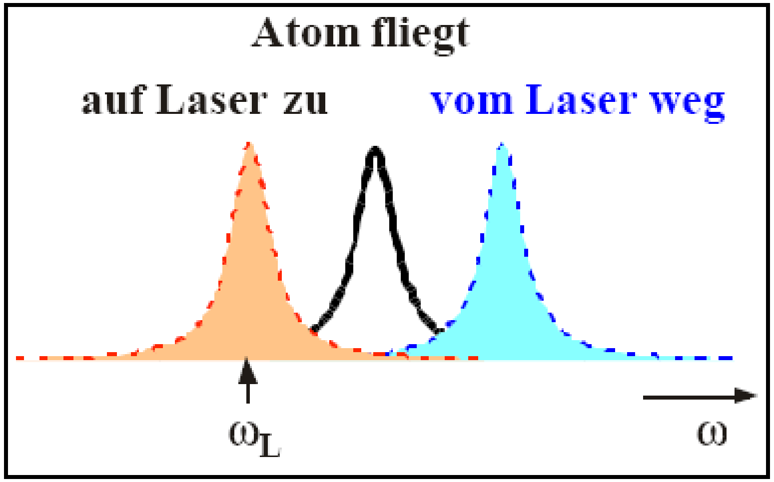


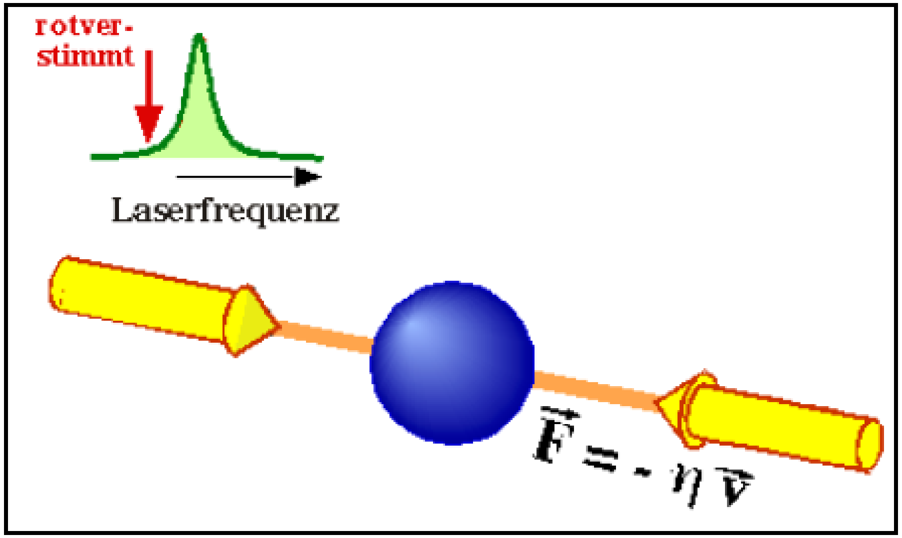
- Zirkular polarisiertes Licht σ^+
- Übergang:
  $3S_{1/2}(m_F = 2) \leftrightarrow 3P_{3/2}(m_F = 3)$
- Wahrscheinlichkeit für falschen Übergang extrem gering

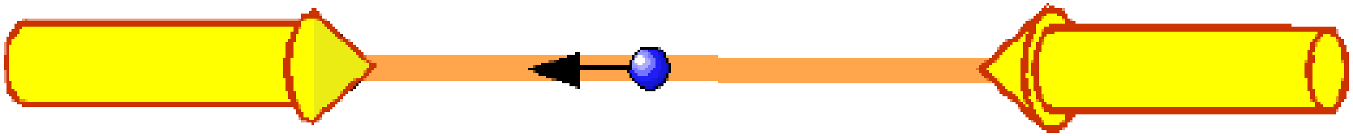


Phillips RMP 1998

Doppler cooling







resonant for laser

→ strong absorption

→ strong force

not resonant for laser

→ weak absorption

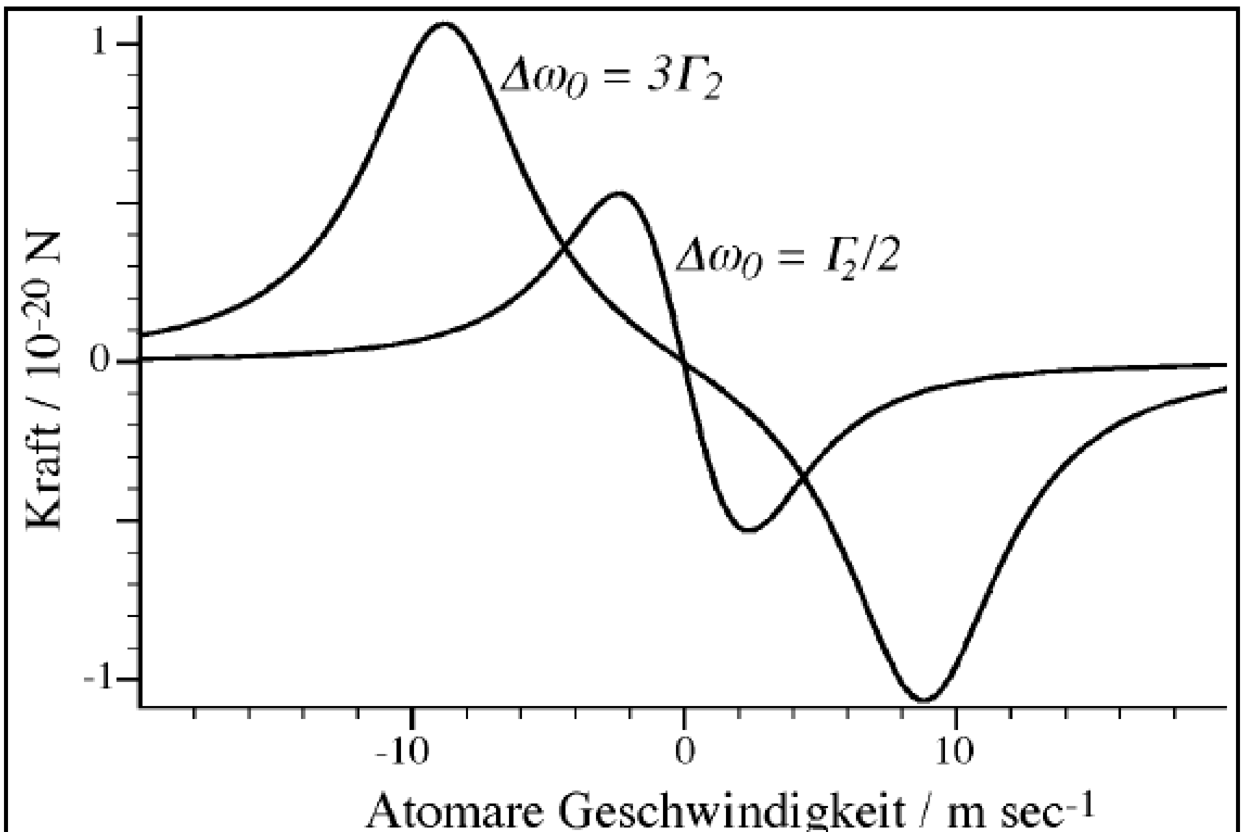
→ weak force

force on the optical melasse

$$F_{om} = \hbar\, k\, \Gamma_1\, \omega_x^2 \left(\frac{1}{\Gamma_1^2 + 4(\Delta\omega_0 + kv)^2} - \frac{1}{\Gamma_1^2 + 4(\Delta\omega_0 - kv)^2} \right)$$

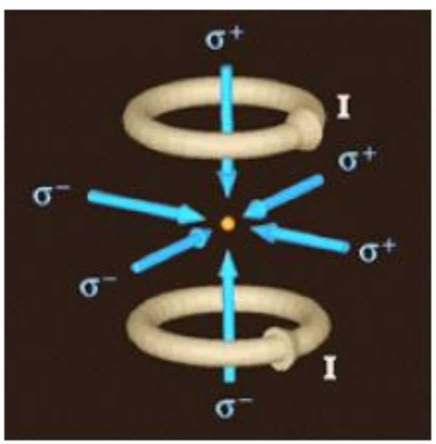
with: Γ the inverse radiation life time, ω_x^2 proportional to laser intensity, Δω difference between laser and atomic resonance frequency

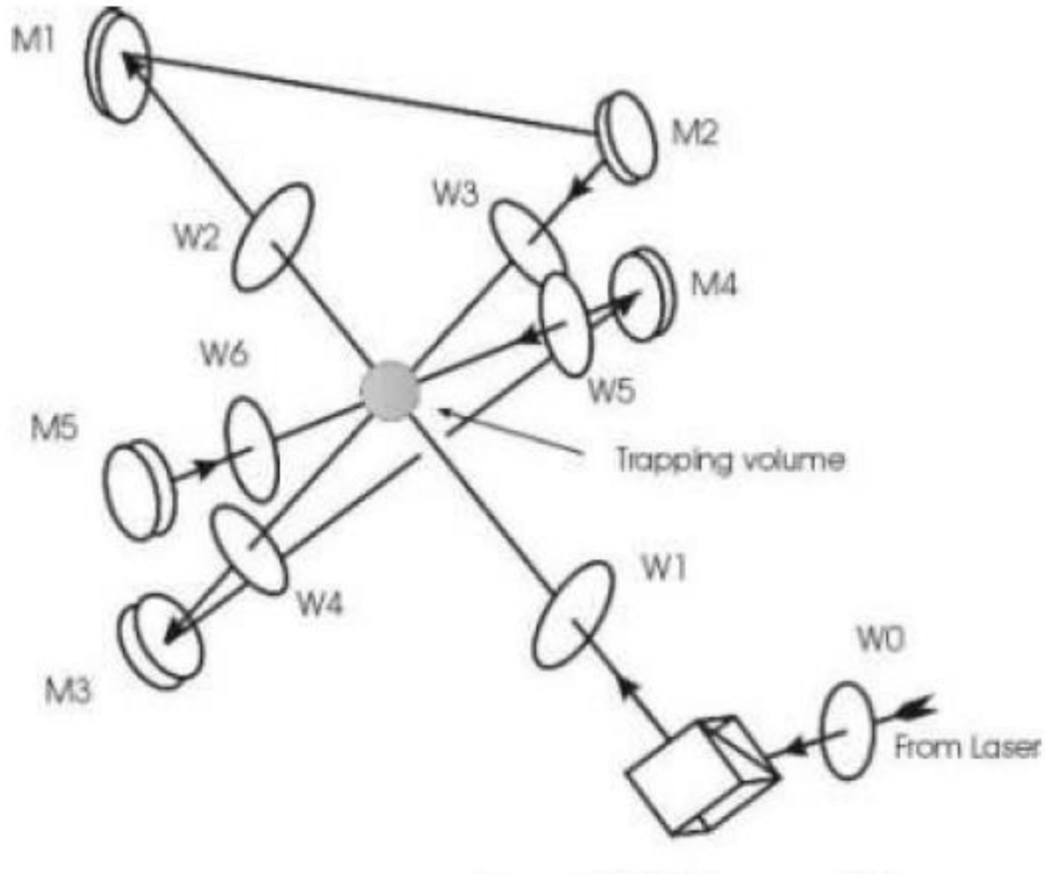
force



velocity

generating a molasses

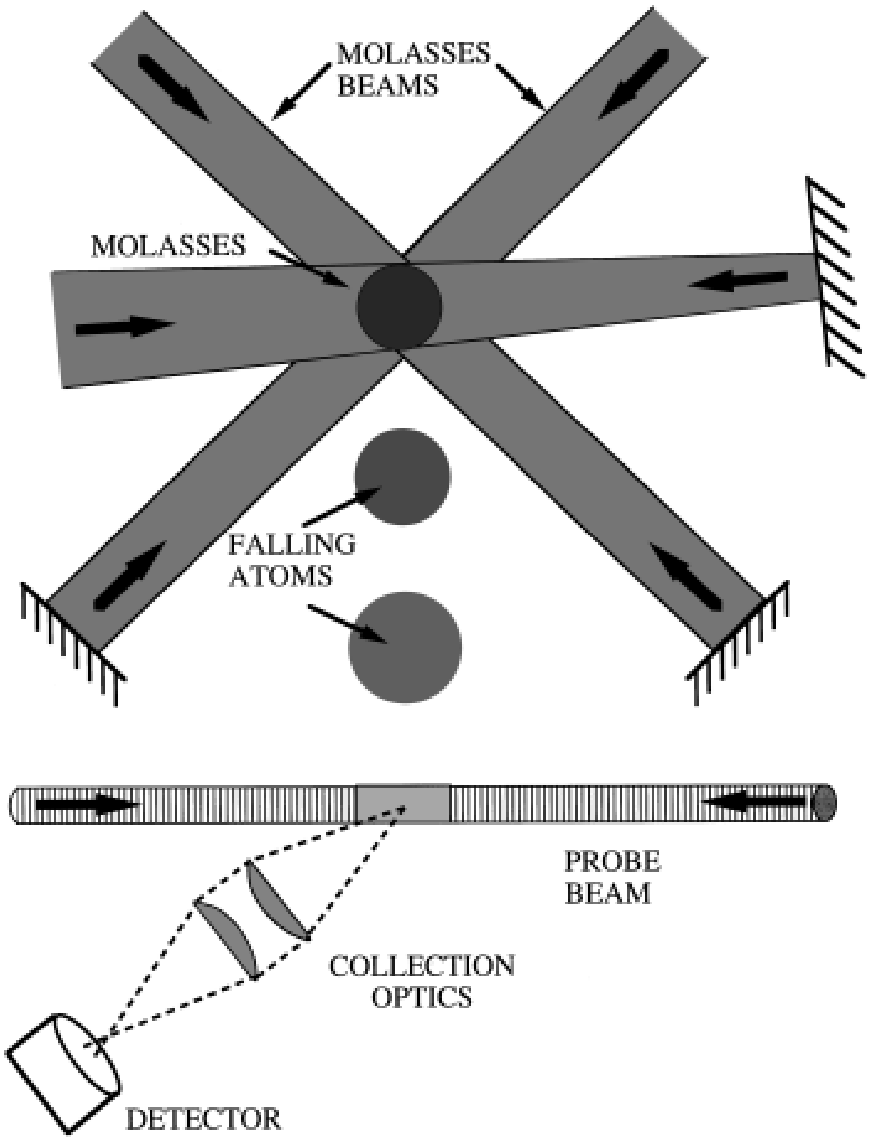




MOT assembly


experimental realization
FOM Amsterdam

how to measure the temperature



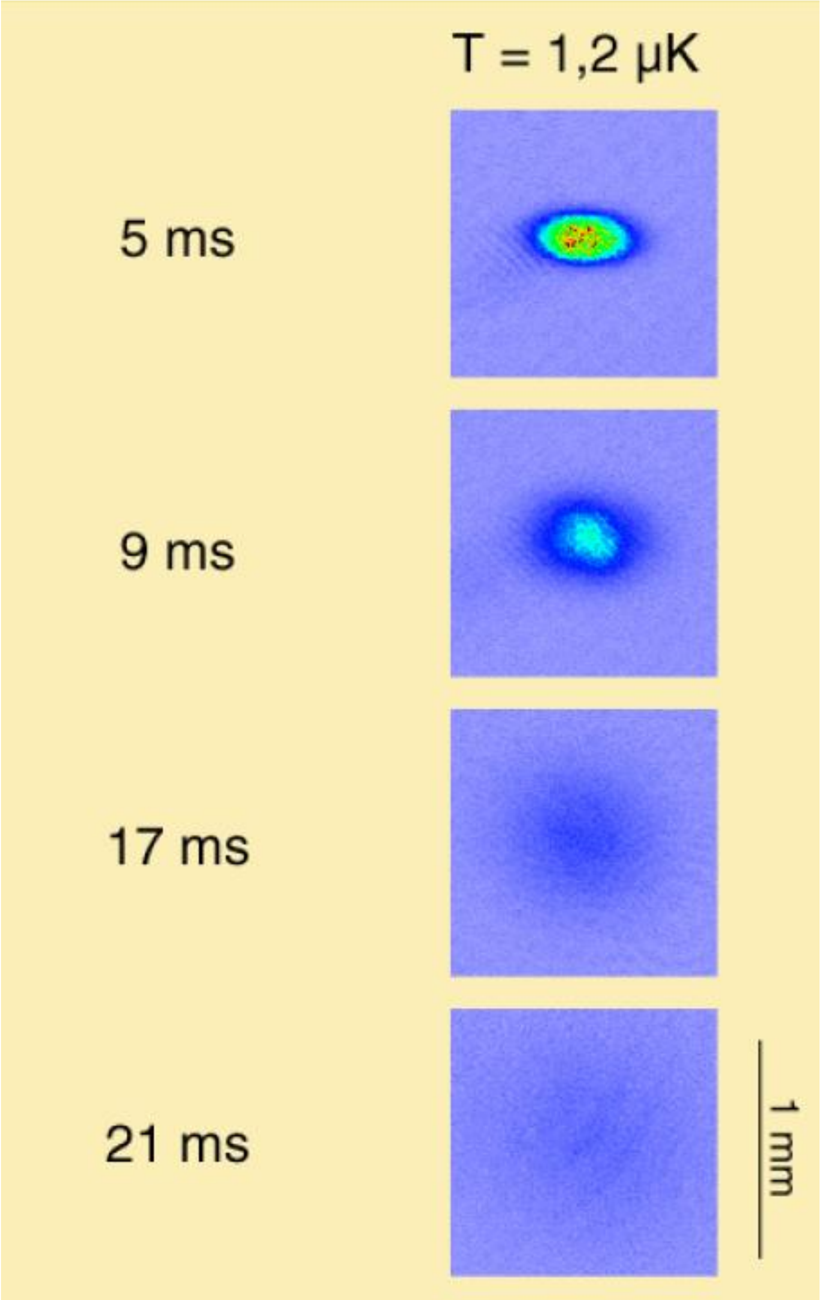
Phillips RMP 1998

how to measure temperatures in the μK - range?

switching off the trap potential

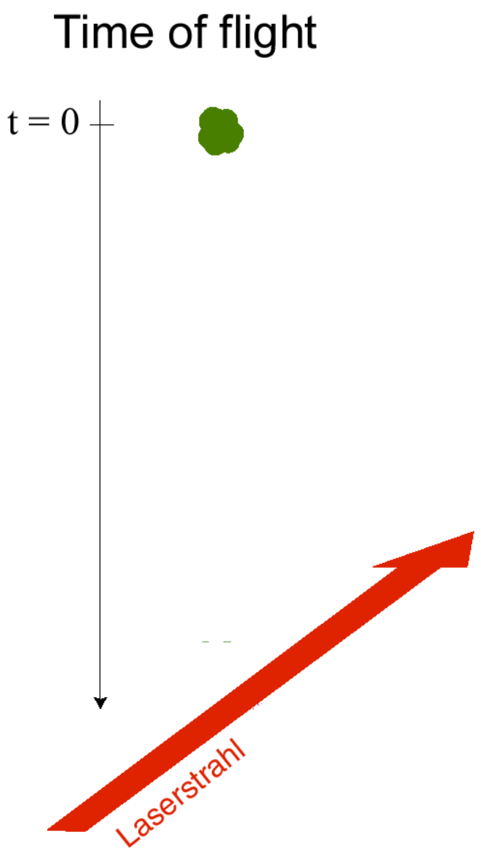
free expansion of the ultracold gas

expansion velocity depends on temperature



how to measure temperatures in the μK - range?

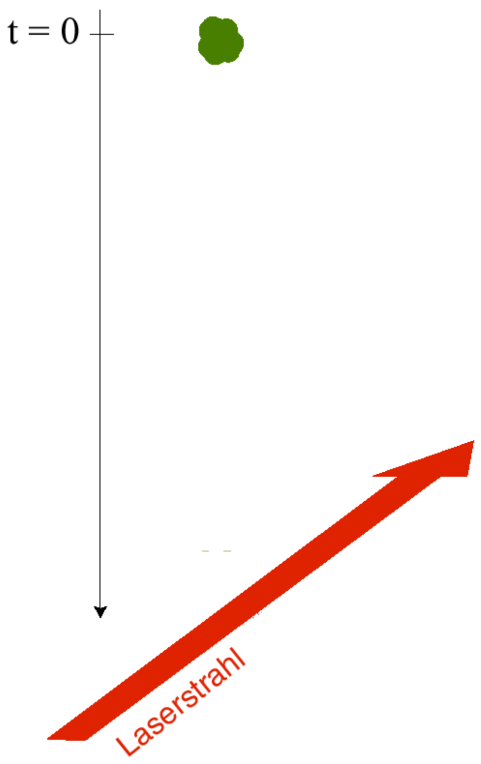
or by a time-of-flight measurement



how to measure temperatures in the μK - range?

or by a time-of-flight measurement

Time of flight



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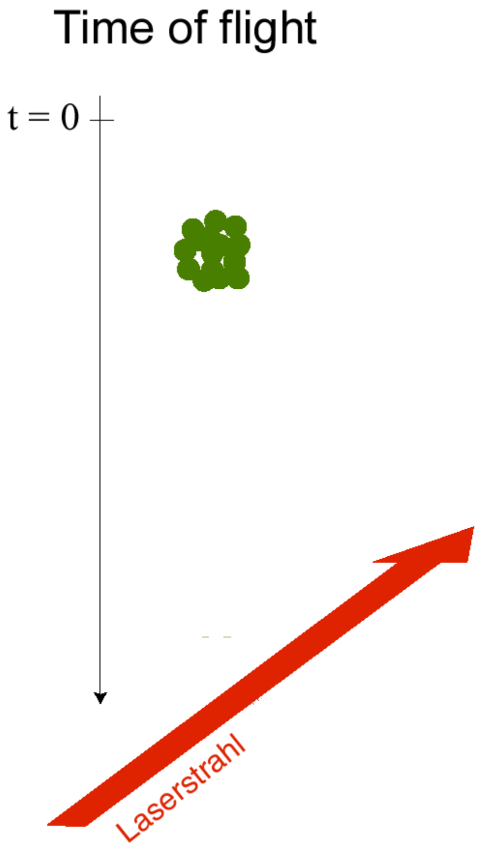

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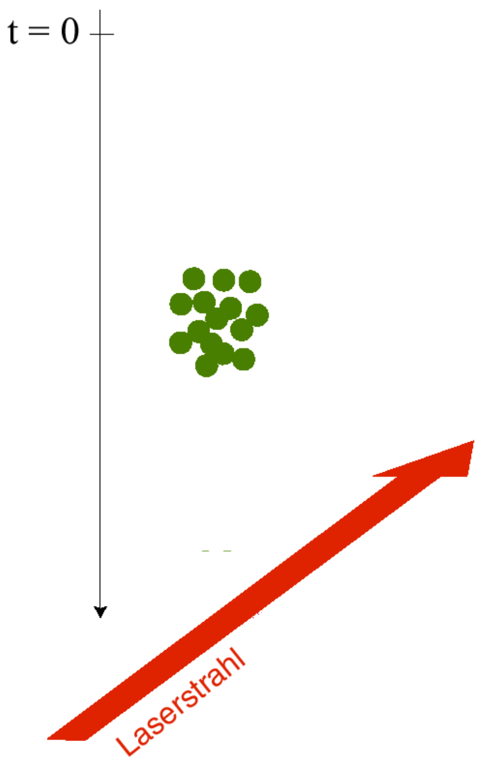
Time of flight



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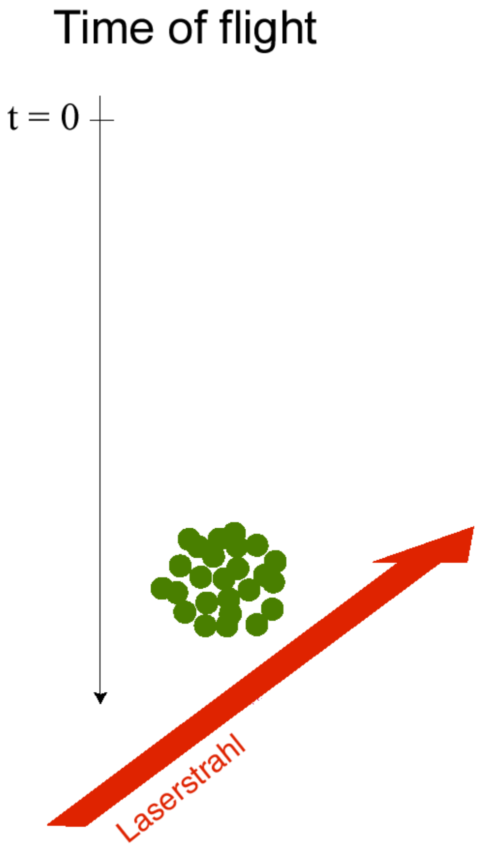

how to measure temperatures in the μK - range?

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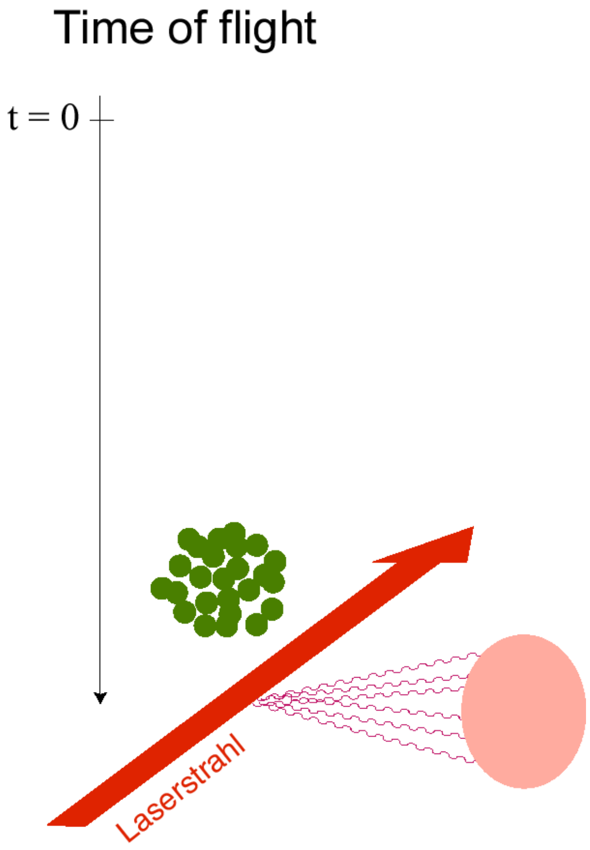
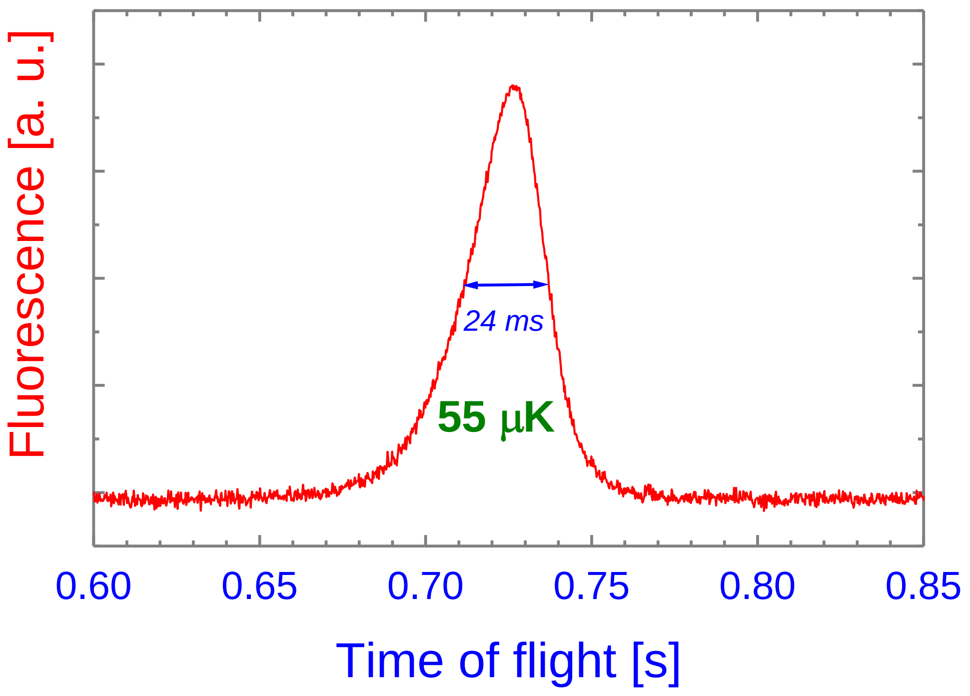
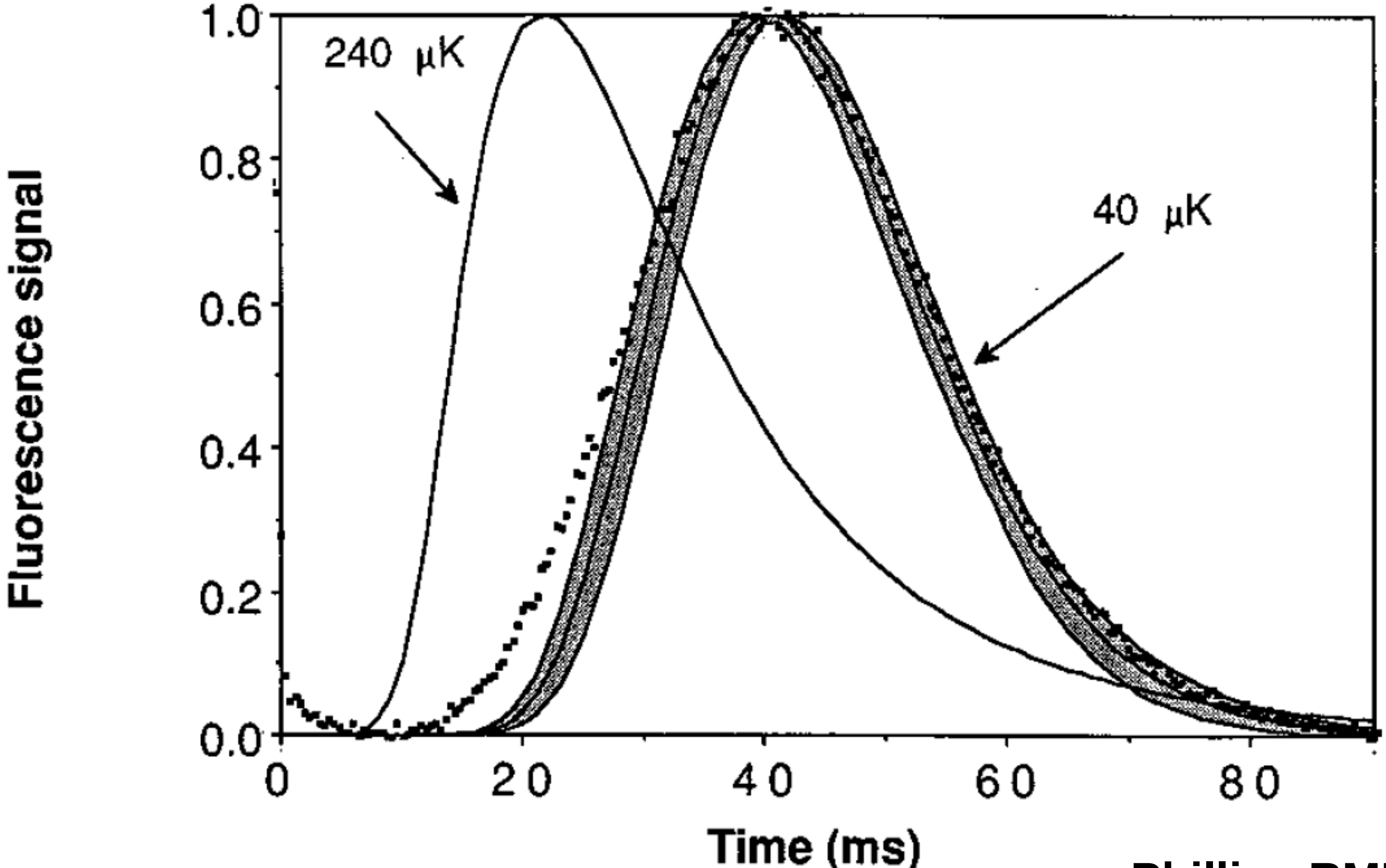




temperature distribution from time-of-flight measurement

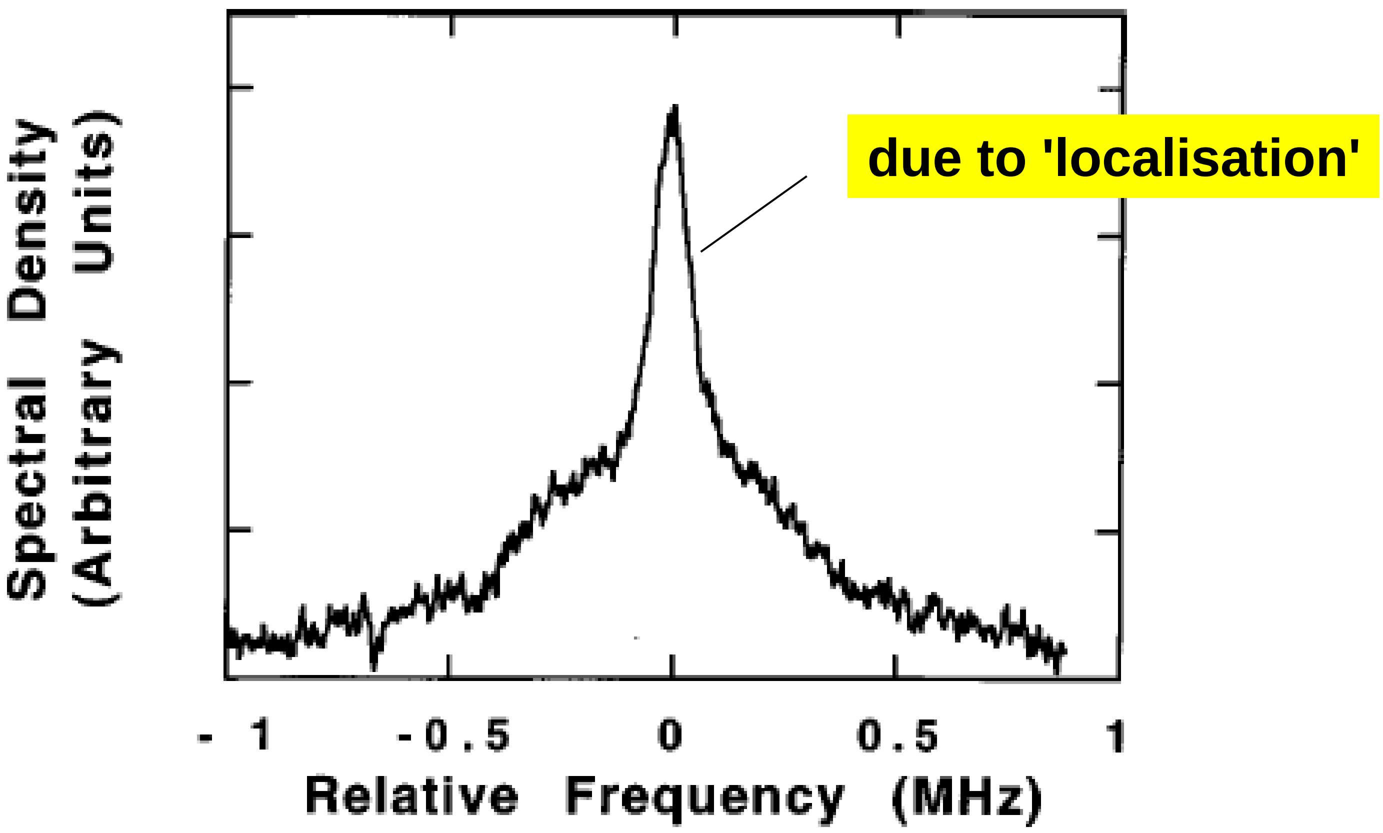
exp.: points, curves: theory.
40 μK curve: theoretical limit of Doppler cooling



Phillips RMP 1998

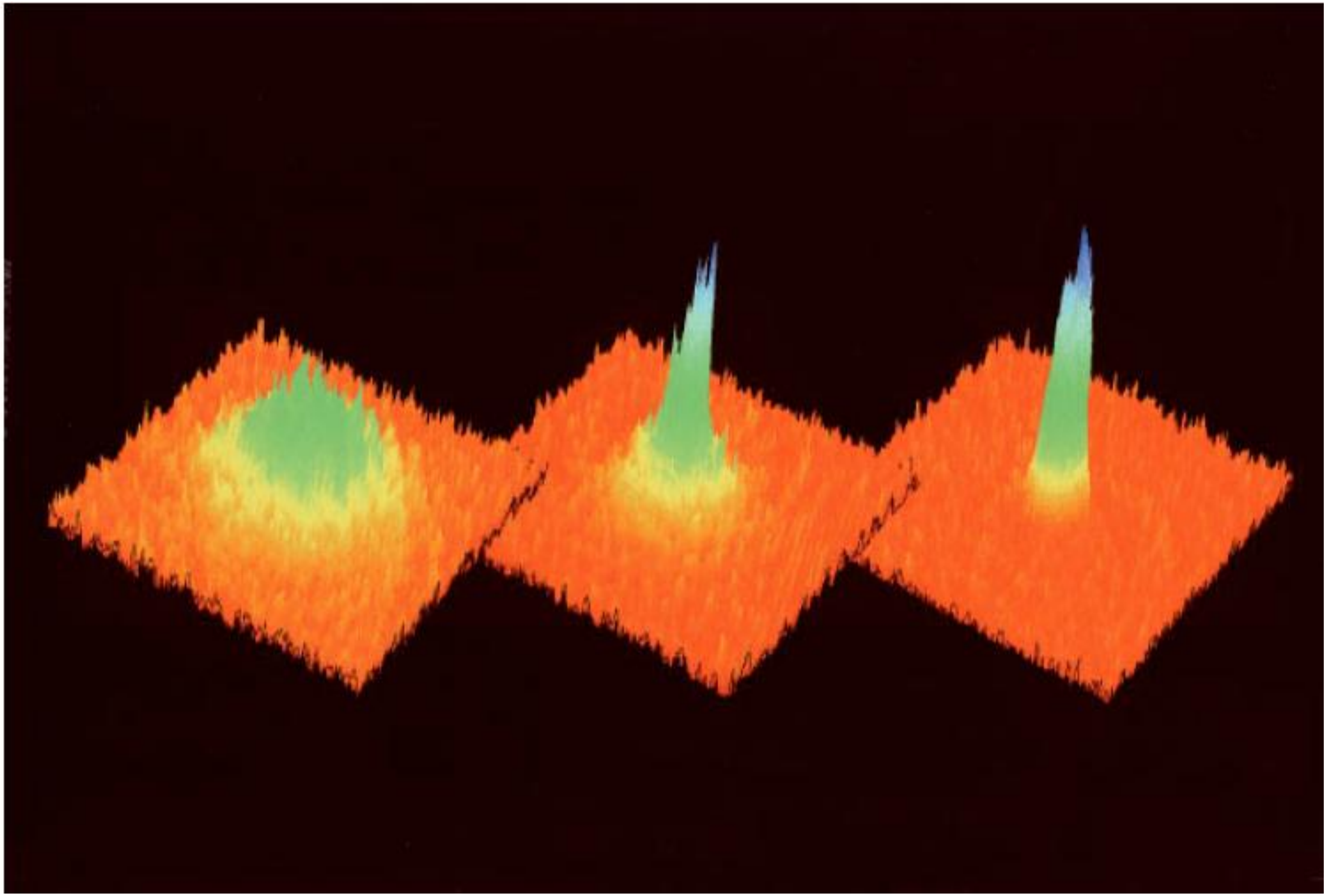
sub-Doppler cooling by evaporation

broad component: 84 μK thermal contribution

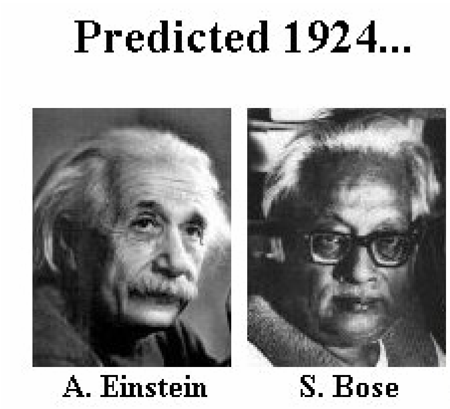


Phillips RMP 1998

2D velocity dirtribution of Na atoms
at different stages of evaporative cooling



a short history of Bose-Einstein condensation



- *1924 Bose schickt Einstein seine Arbeit über die Statistik von Photonen. Einstein übersetzt diese Arbeit.*
- *1924 Nur acht Tage später hat Einstein seine „Quantentheorie der einatomigen idealen Gase“ fertiggestellt.*
- *1925 Einstein setzt seine Arbeit über das ideale Gas mit Bose-Statistik fort und entdeckt zum ersten Mal das Phänomen der „Bose-Einstein-Kondensation“*
- *1995 Bose-Einstein-Kondensation in einem verdünnten Gas von ^{87}Rb Atomen wird zum ersten Mal von Eric Cornell und Carl Wieman (JILA) erzielt und wenige Monate später in ^{23}Na von Wolfgang Ketterle (MIT)*

Nobelpreis 2001 !

Eric Cornell has been in Rostock on the occasion of the DPG spring meeting 1996

1925.
I.

SITZUNGSBERICHTE

DER PREUSSISCHEN

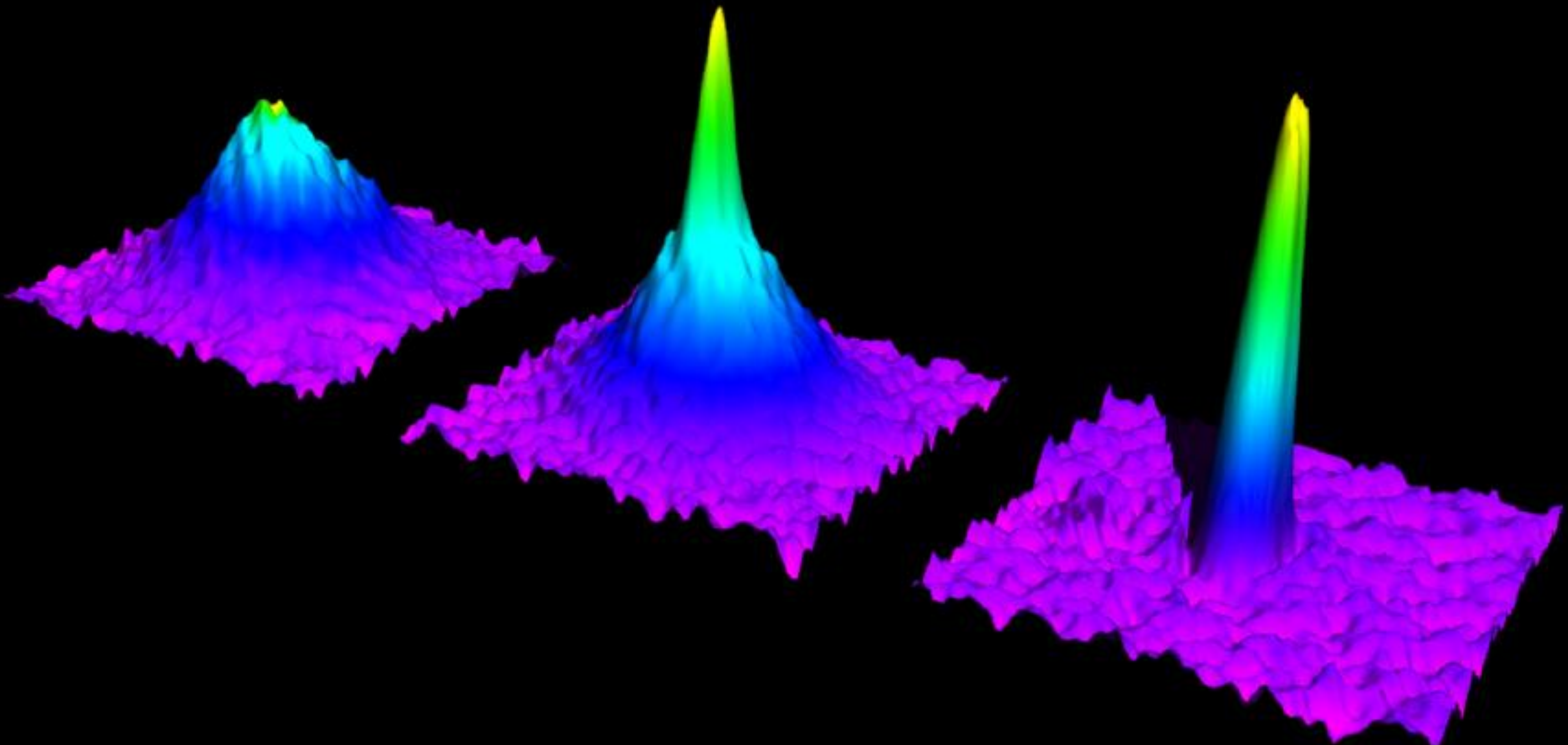
AKADEMIE DER WISSENSCHAFTEN.

Sitzung der physikalisch-mathematischen Klasse vom 8. Januar.

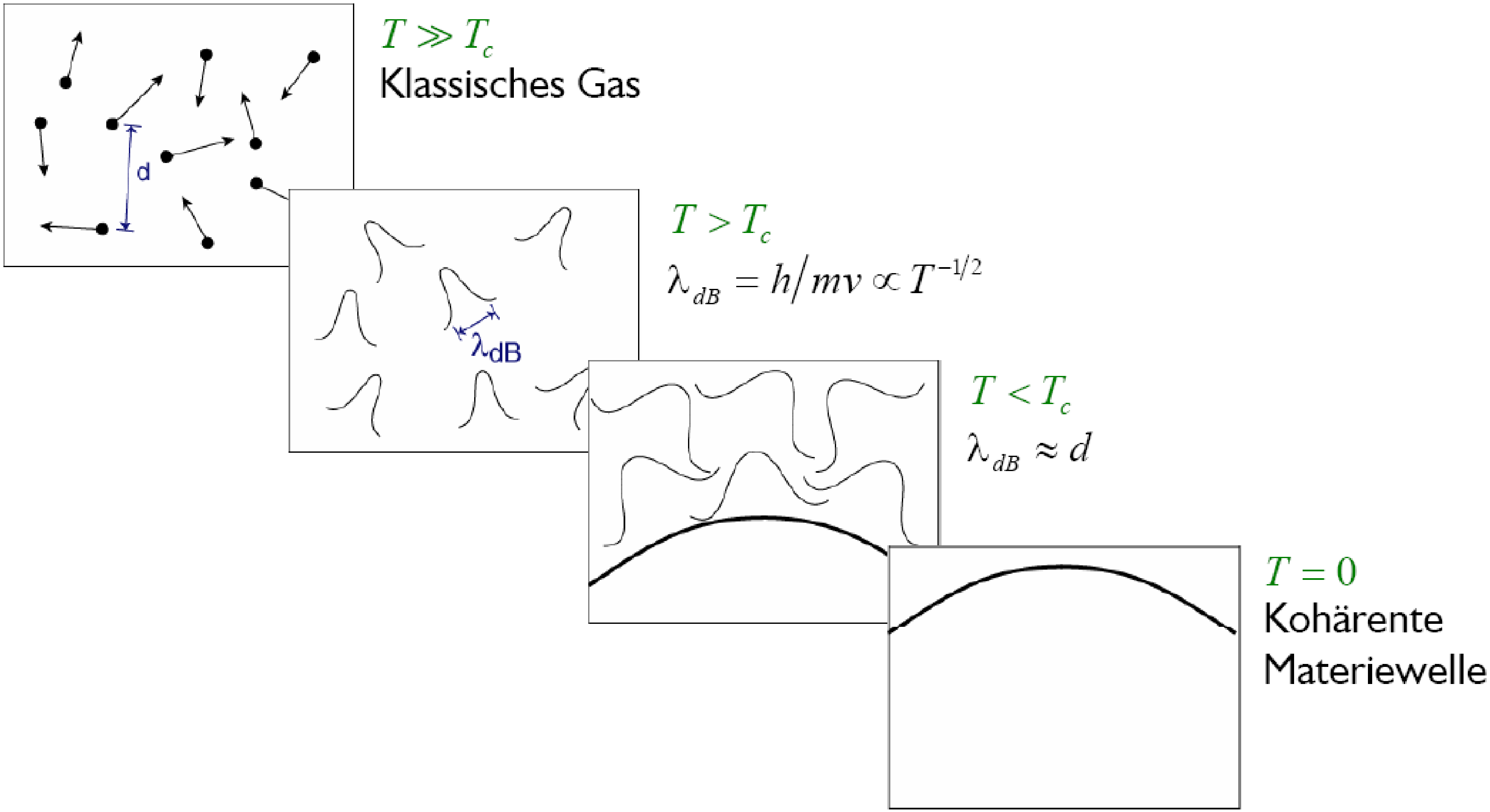
Quantentheorie des einatomigen idealen Gases.

Zweite Abhandlung.

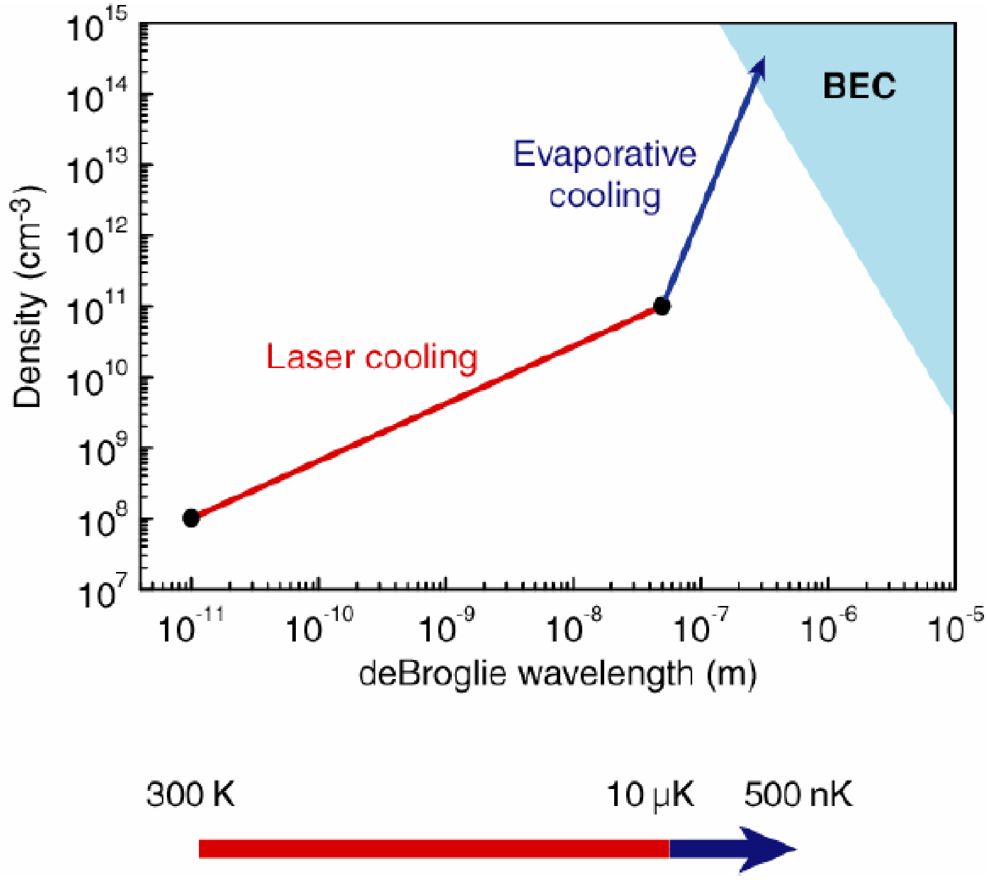
Von A. Einstein.



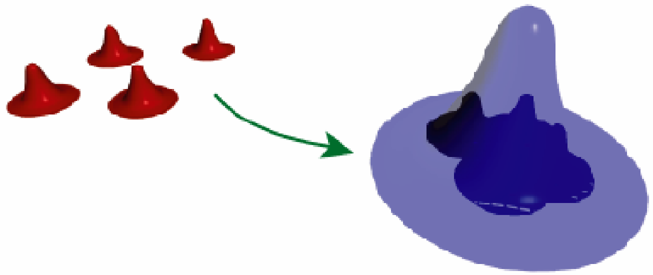
from a classical gas to a Bose-Einstein condensate



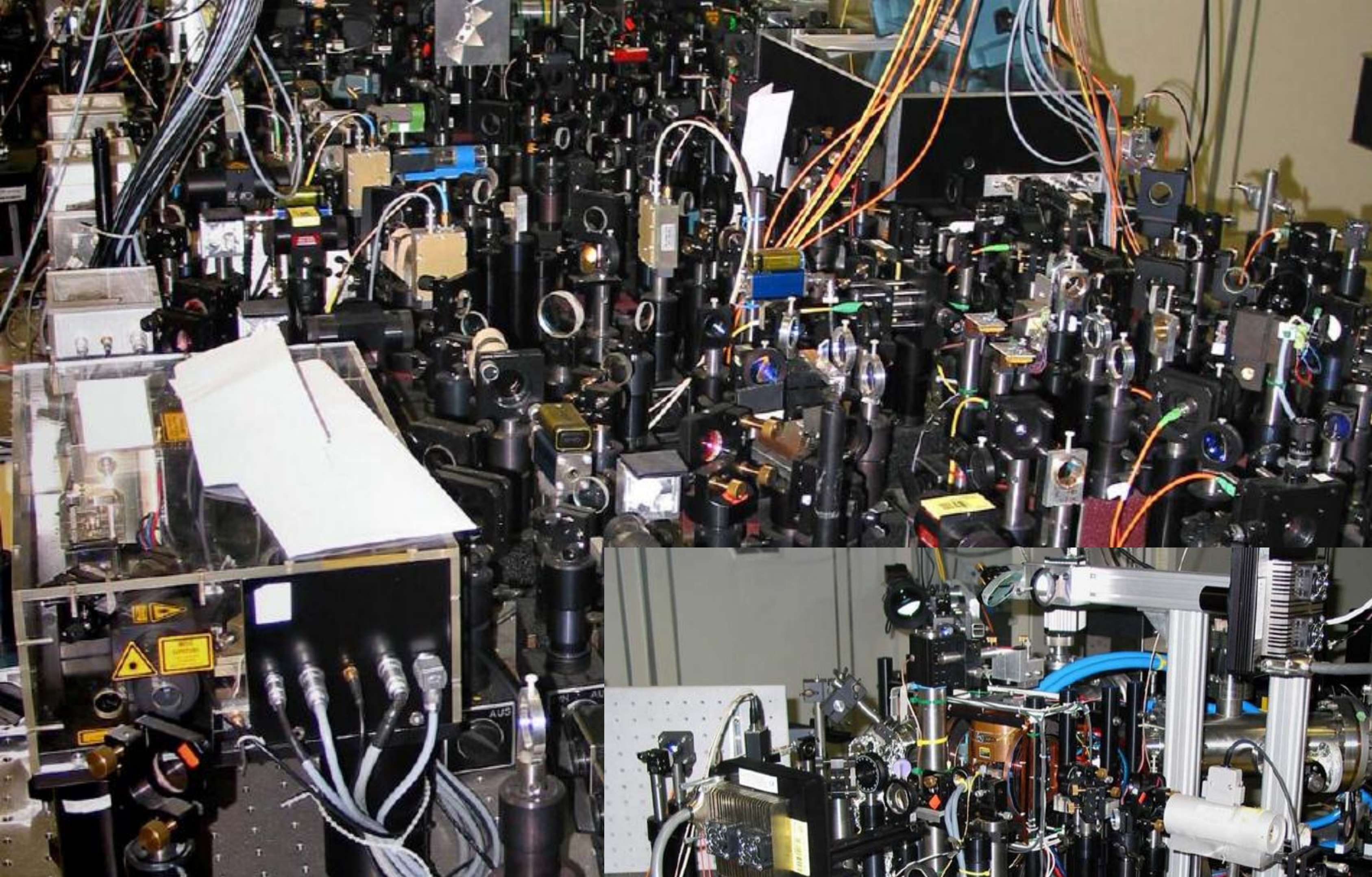
the long experimental way to BEC

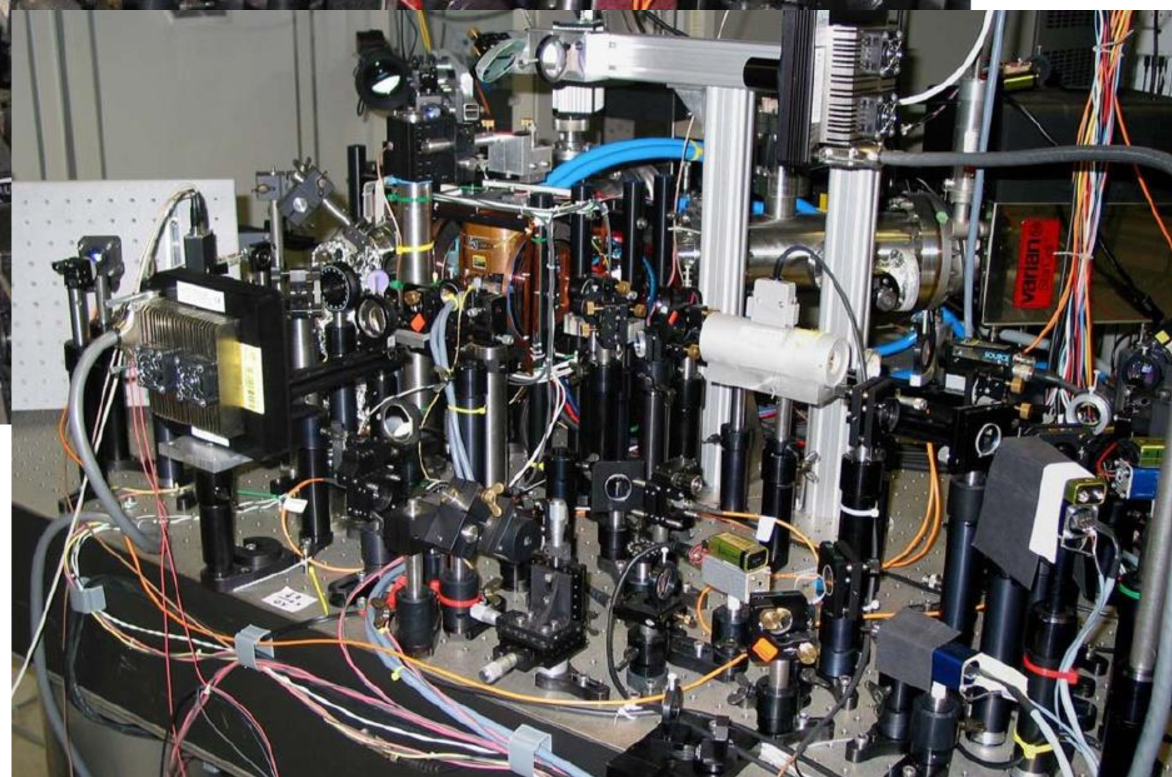


$$n \cdot \lambda^3 \approx 1$$



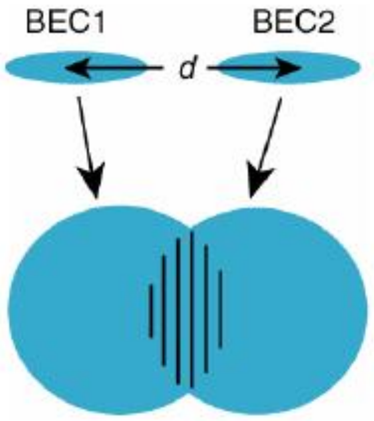
all the tools of atom cooling have to be used!


AUS



further studies of the BEC

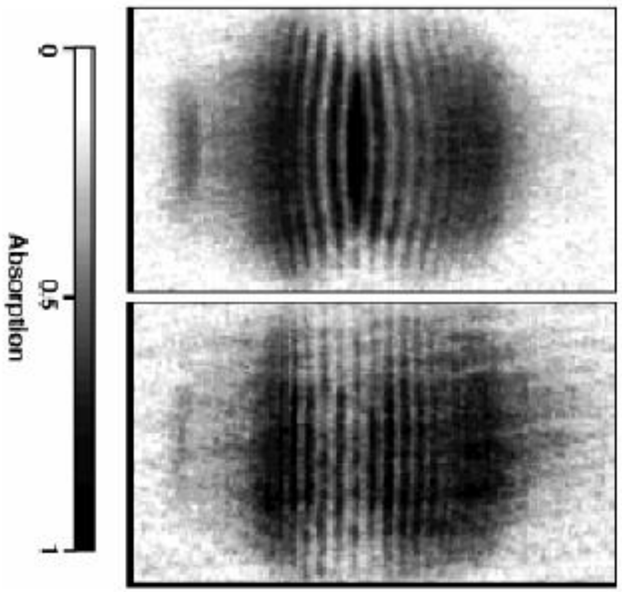
BEC can show interference



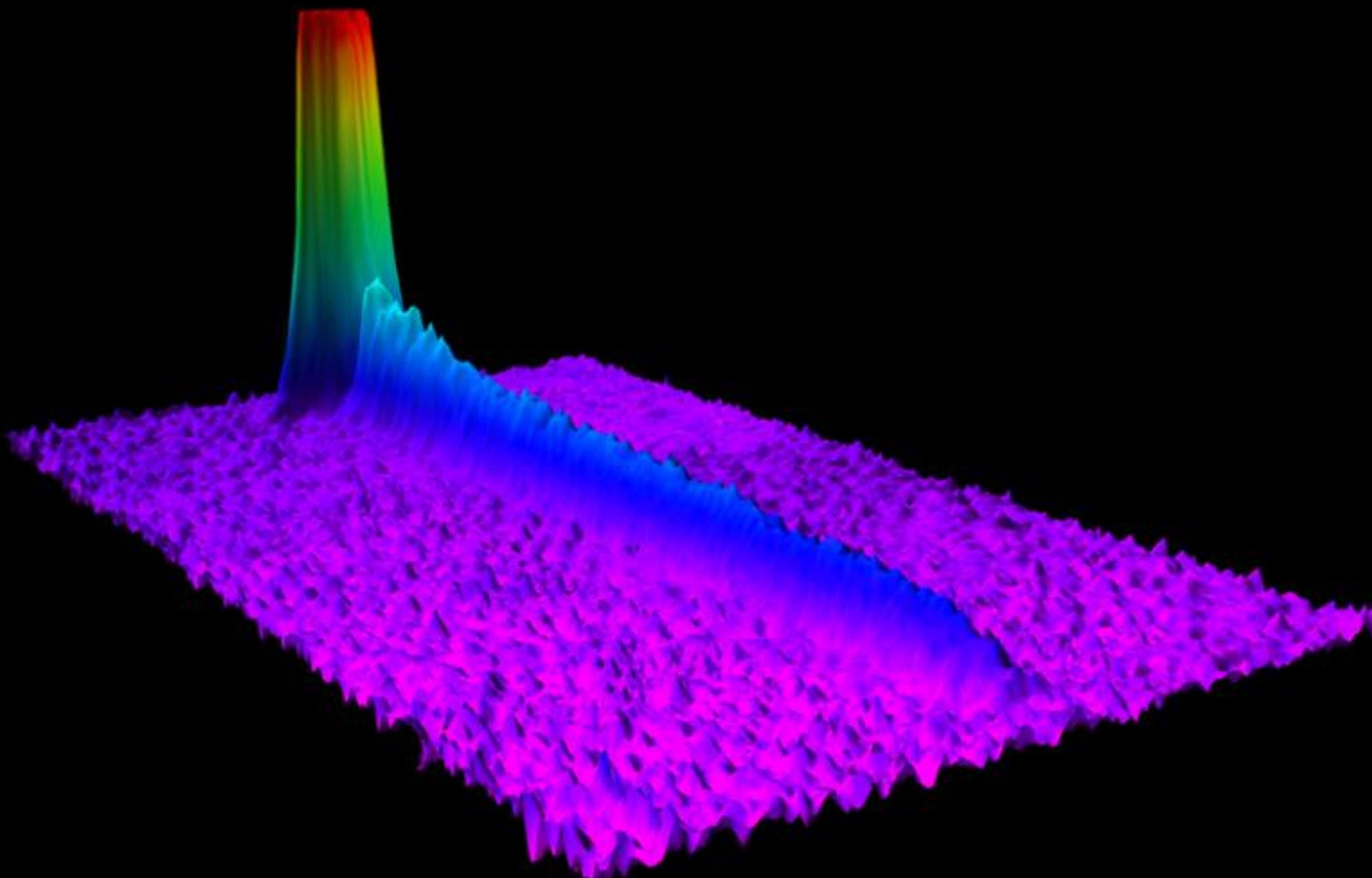
trapped

expanding

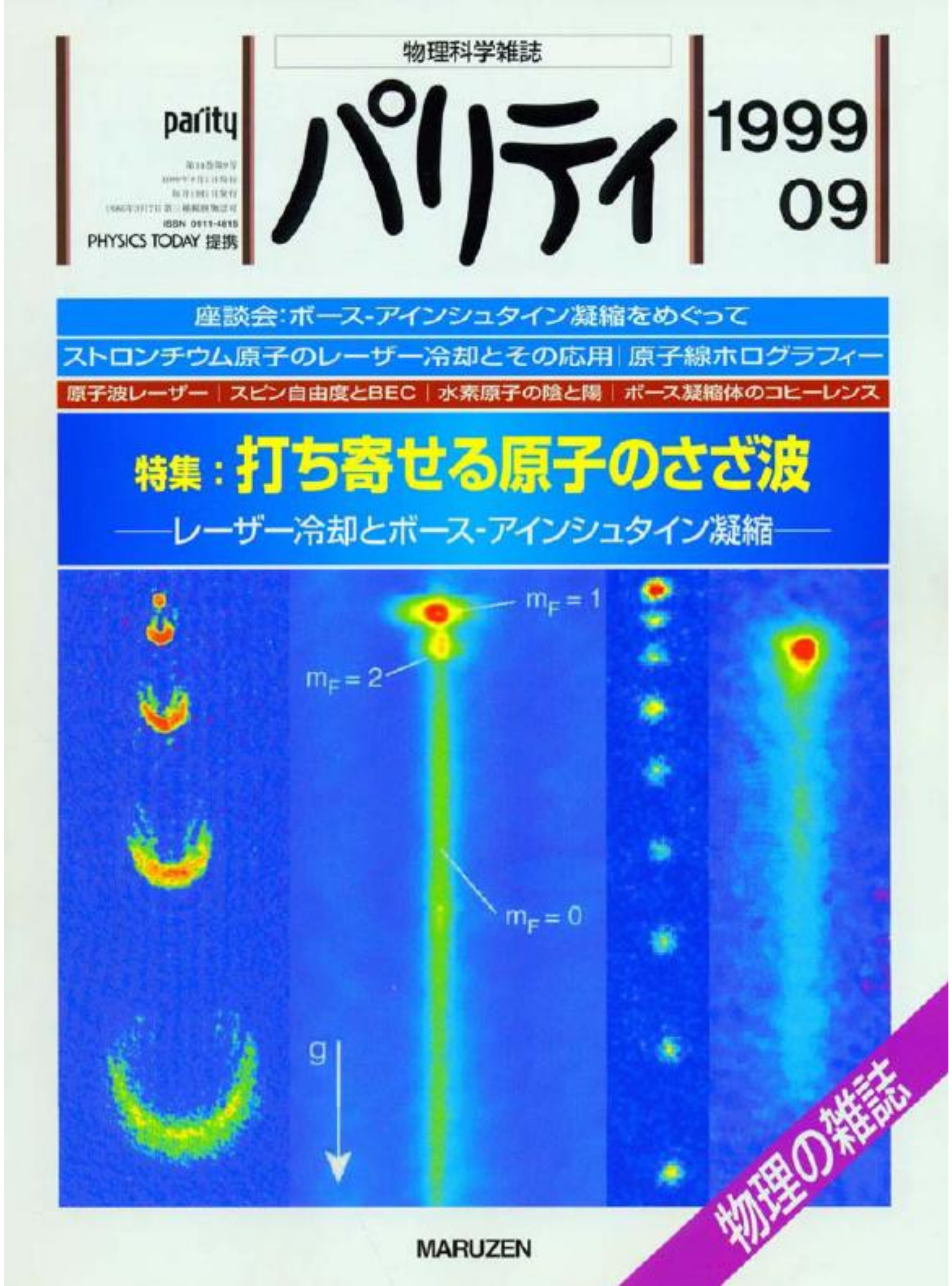
Andrews et al.,
Science 275, 637 (1997)



towards an atom laser



atom lasers



物理科学雑誌
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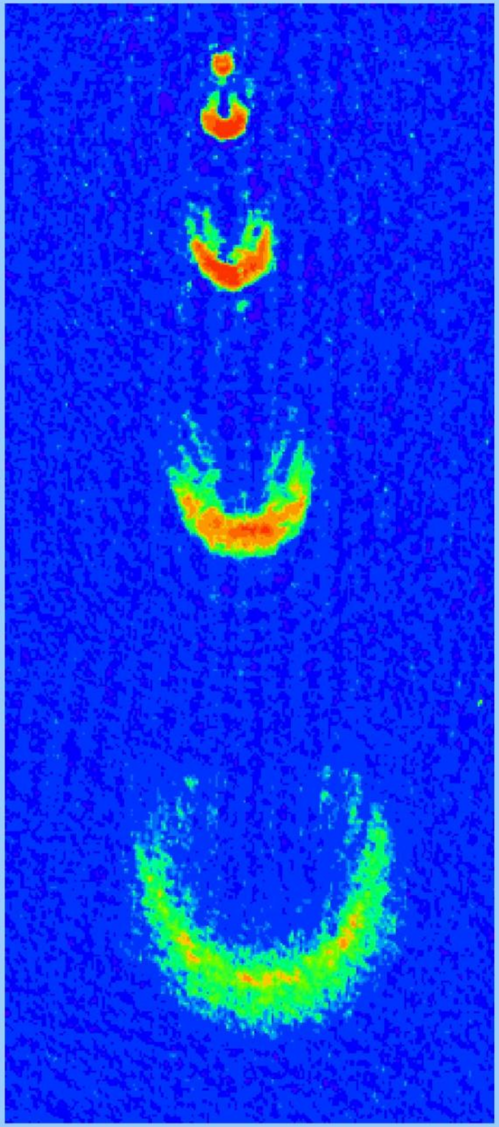
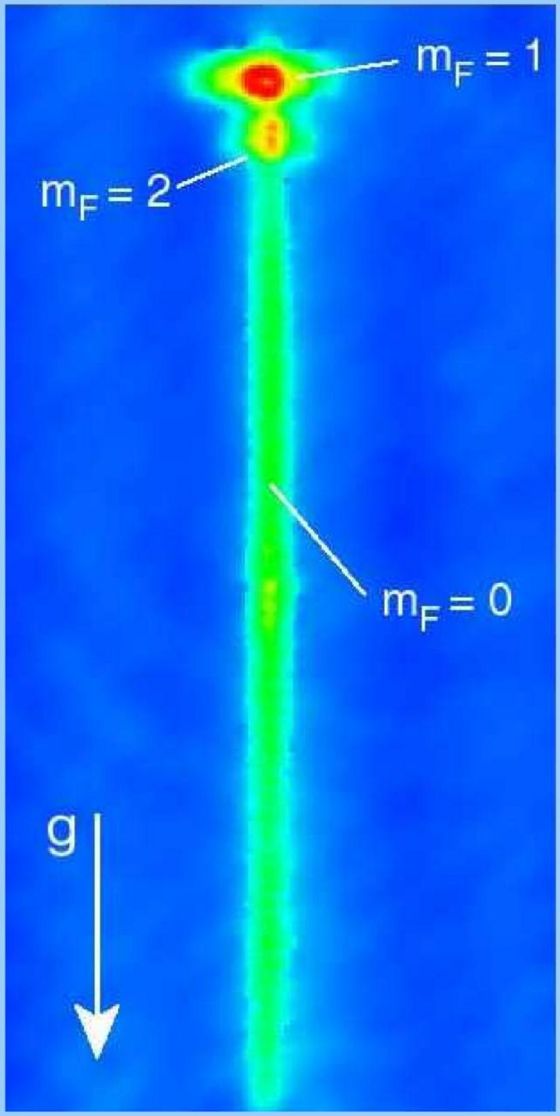
PHYSICS TODAY 提携
座談会:ボース-アインシュタイン凝縮をめぐって
ストロンチウム原子のレーザー冷却とその応用 | 原子線ホログラフィー
原子波レーザー | スピン自由度とBEC | 水素原子の陰と陽 | ボース凝縮体のコヒーレンス
特集:打ち寄せる原子のさざ波
—レーザー冷却とボース-アインシュタイン凝縮—
m_F = 1
m_F = 2
m_F = 0
g
物理の雑誌
MARUZEN

Atom laser gallery

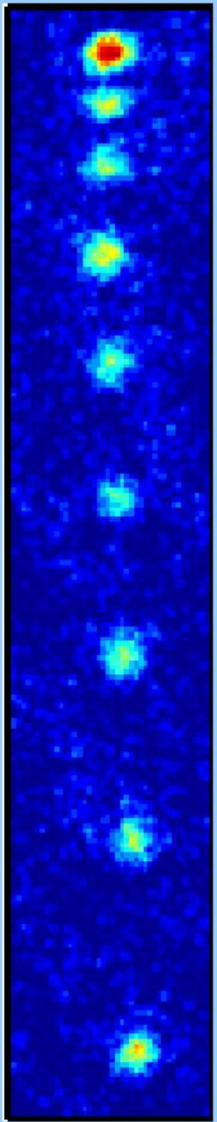
Height:
5, 2, 0.5, 1 mm



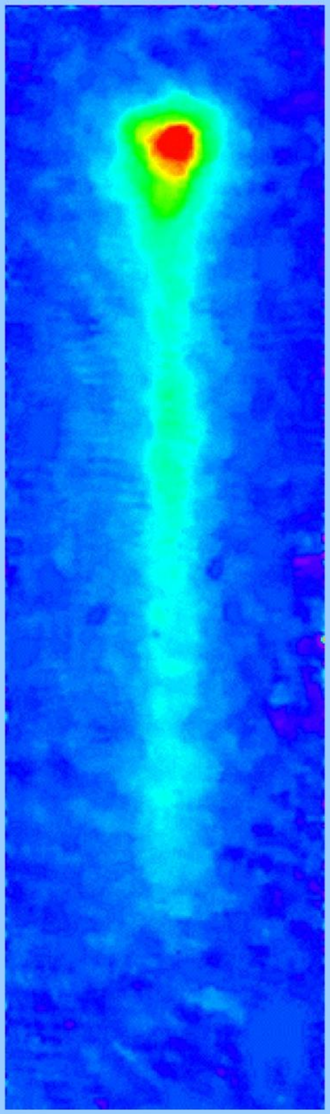
MIT '97



Munich '99



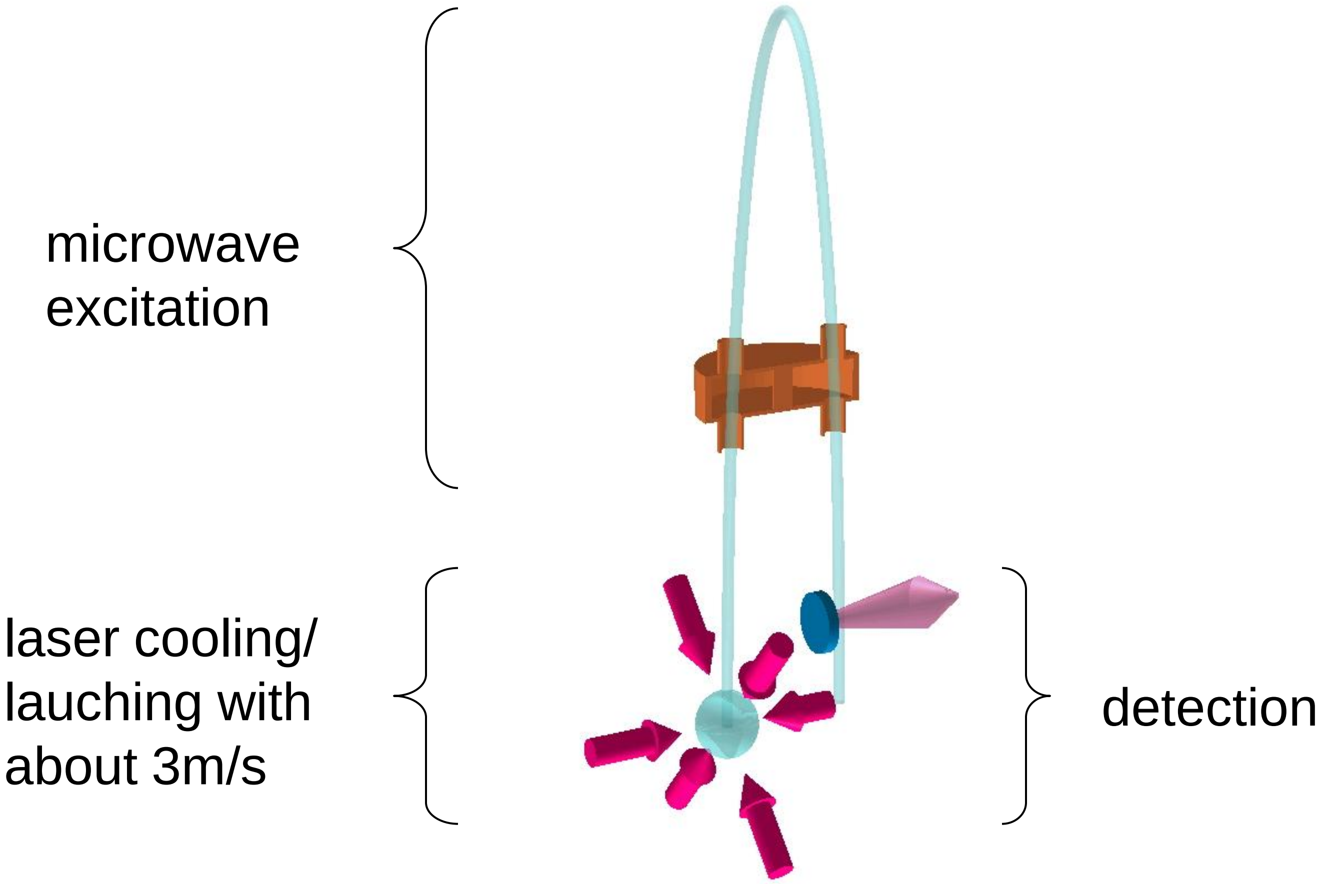
Yale '98



NIST '99

one application: ultra-precise experiments with an atomic fountail

e.g., for frequency standards



atom fountain: realization