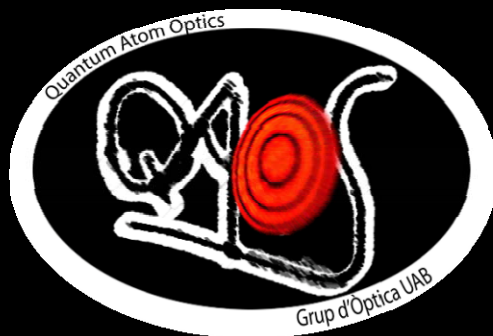


Refredant àtoms amb làser: cap al zero absolut de temperatura

Verònica Ahufinger



UAB

Universitat Autònoma de Barcelona

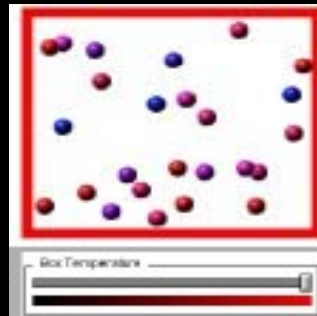
Àtoms ultra-freds

Però que vol dir ultra-fred?

Què és la temperatura?

"La temperatura és una magnitud física descriptiva d'un sistema que caracteritza la transferència d'energia tèrmica o calor entre aquell sistema i altres. Des d'un punt de vista microscòpic, és una mesura de l'energia cinètica associada al moviment aleatori de les partícules que componen el sistema".

**Per baixar la temperatura....
cal frenar els àtoms!**

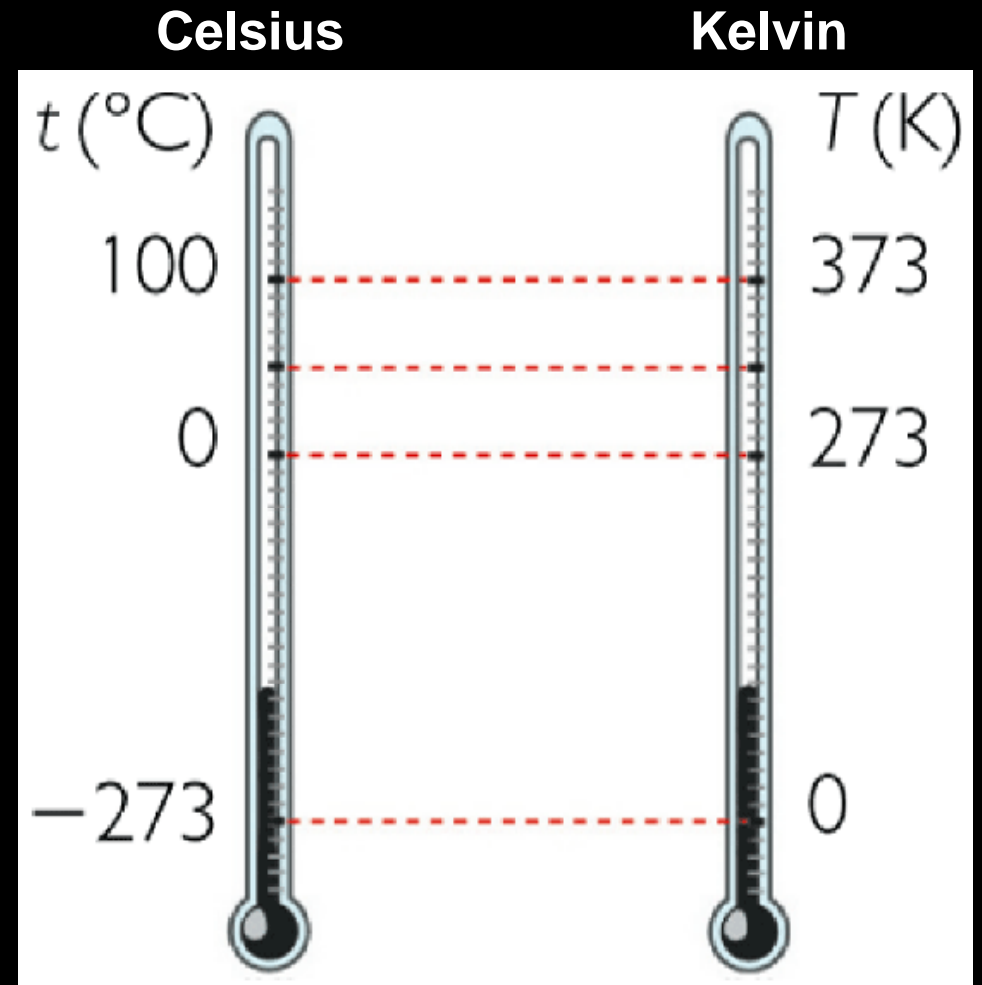
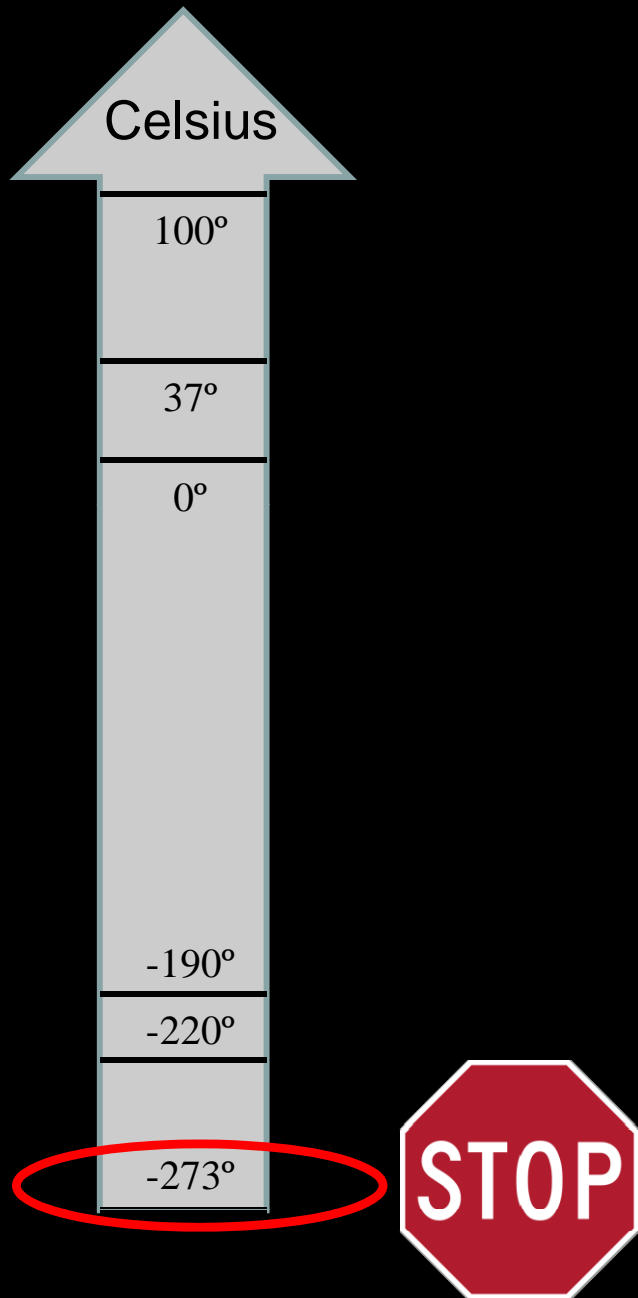


<http://www.colorado.edu/physics/2000/bec>

Velocitat a T ambient (300K) ~ 4000Km/h!!!!

Velocitat a $3 \times 10^{-7} \text{K}$ ~ 0.4Km/h

Escales de temperatura



Quines són les temperatures més fredes que coneixem?

-270,5 °C

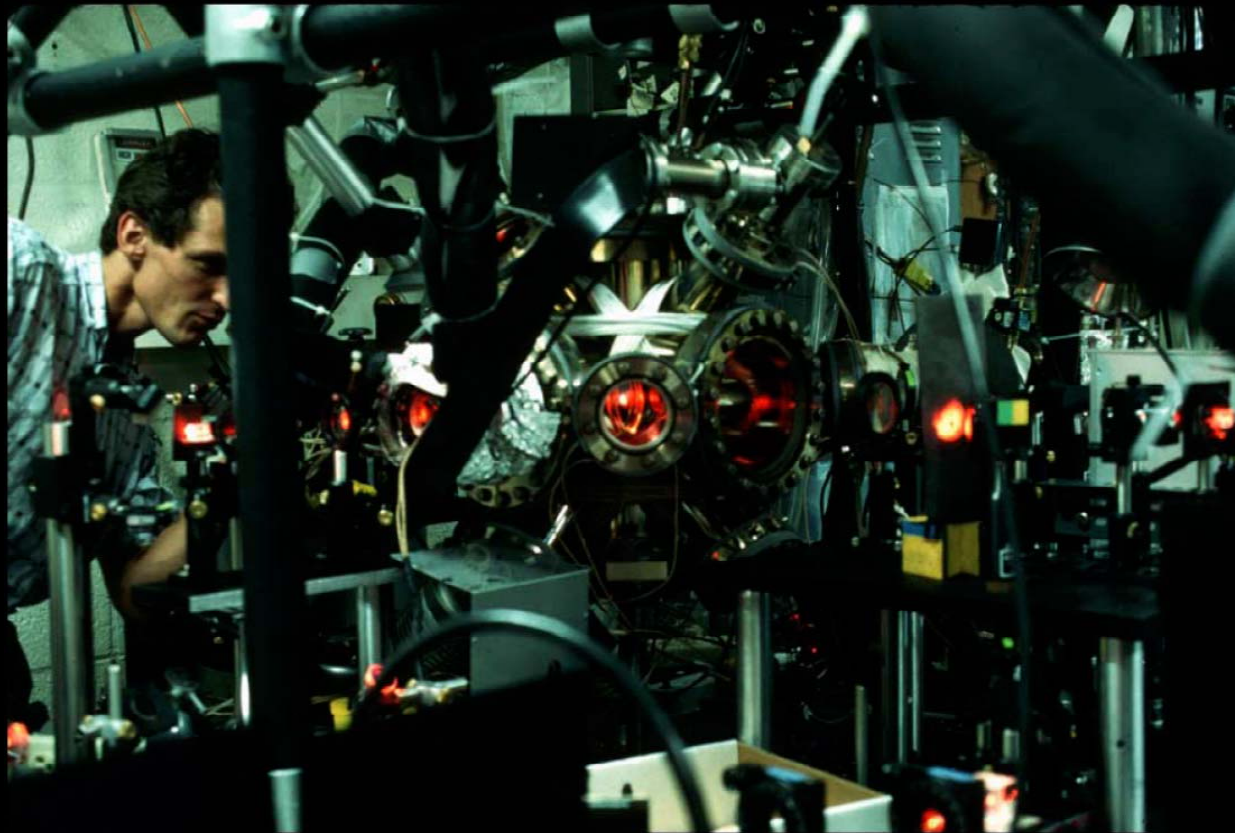
-227,78 °C



I també al laboratori !

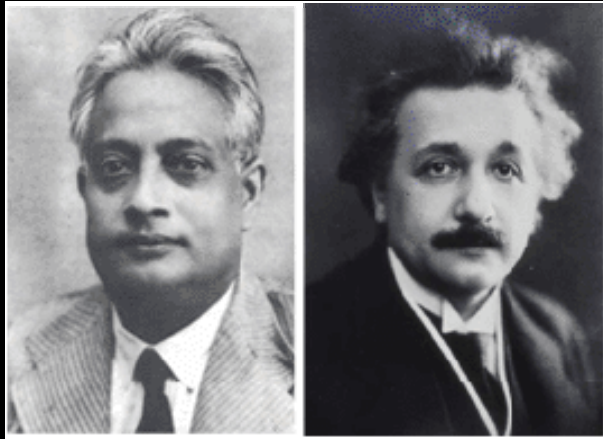
Condensats de Bose Einstein

Només a unes bilionèsimes (0.000000001) de grau per sobre del zero absolut!!!



Fotografia extreta de la presentació en motiu del premi Nobel realitzada pel Prof. W. Ketterle (12-08-2001)

Predit el 1924



**Satyendra
Nath Bose**

**Albert
Einstein**

**Aconseguí
experimentalment
el 1995!!**



The Nobel Prize in Physics 2001

"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates"



Eric A. Cornell

🕒 1/3 of the prize

USA

University of Colorado,
JILA
Boulder, CO, USA



Wolfgang Ketterle

🕒 1/3 of the prize

Federal Republic of
Germany

Massachusetts Institute
of Technology (MIT)
Cambridge, MA, USA



Carl E. Wieman

🕒 1/3 of the prize

USA

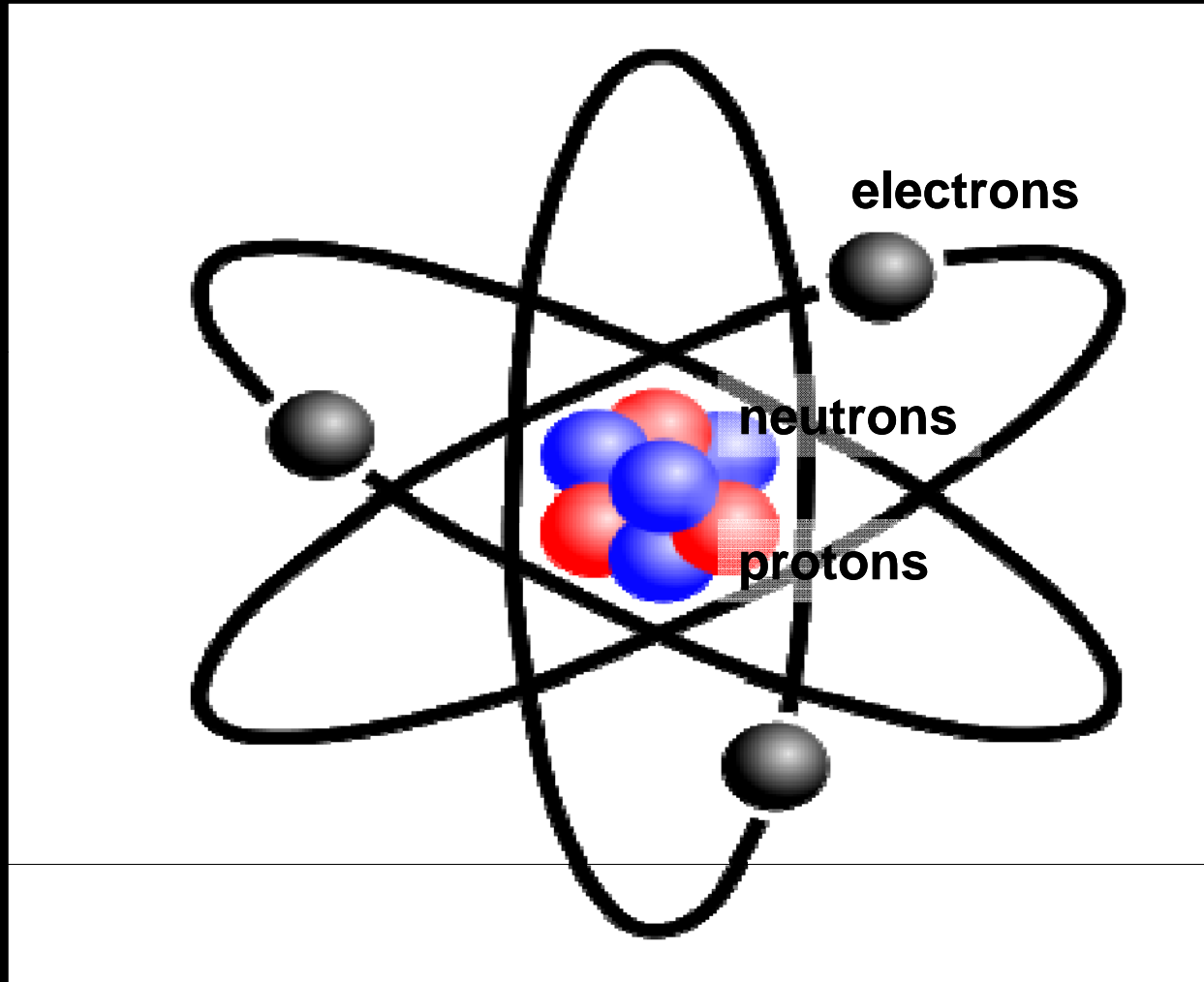
University of Colorado,
JILA
Boulder, CO, USA

**Per baixar la temperatura i crear un condensat de Bose-Einstein....
cal frenar els àtoms!**

Però tots els àtoms poden crear un condensat de Bose-Einstein?

NO

Àtoms



Àtoms



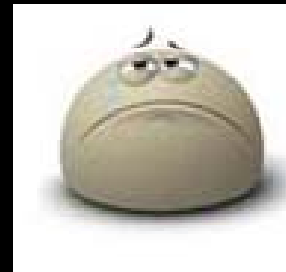
Bosons

Fermions

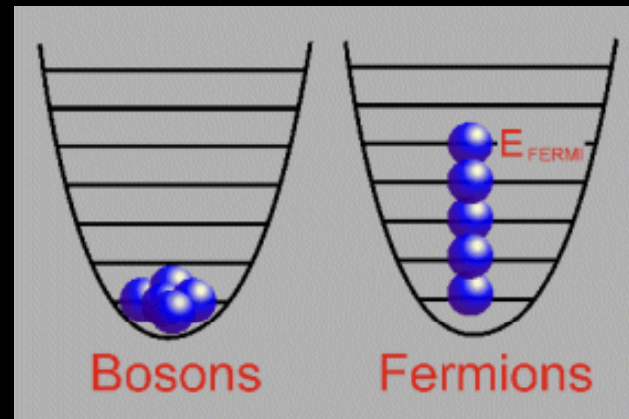
Àtoms
neutres:

n° parell de neutrons

n° imparell de neutrons



Diferent
comportament a
baixa
temperatura...



Taula periòdica dels elements

Alcalins

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

^{87}Rb

37 electrons = 37 protons
 $87 - 37 = 50$ neutrons → BOSÓ



<http://chemistry.about.com/od/elementgroups/ig/Alkali-Metals-Photo-Gallery/Rubidium.-dwt.htm>

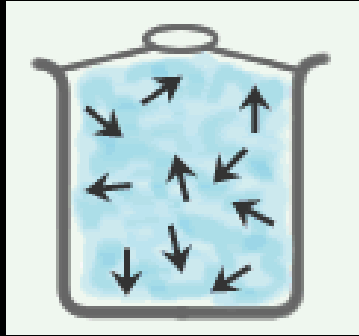
^{23}Na

11 electrons = 11 protons
 $23 - 11 = 12$ neutrons → BOSÓ

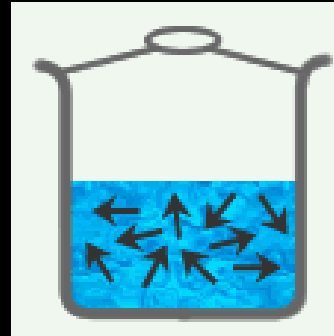
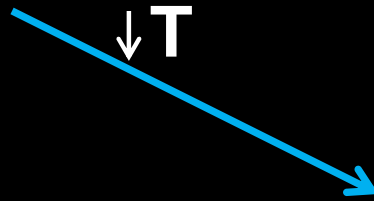


<http://en.wikipedia.org/wiki/Sodium>

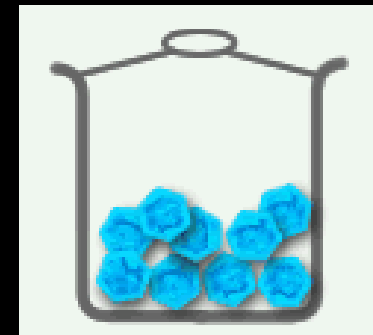
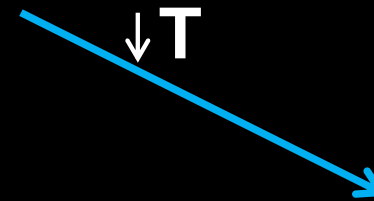
Canvis d'estat



Gas



Líquid



Sòlid

**Però en gasos molt diluïts i si els àtoms són bosons,
a baixa Temperatura...**



<http://www.colorado.edu/physics/2000/bec>

I com podem frenar els àtoms?...



La llum pot transferir moment lineal

Força de pressió de radiació



refredament làser



The Nobel Prize in Physics 1997

"for development of methods to cool and trap atoms with laser light"



Steven Chu

🕒 1/3 of the prize

USA

Stanford University
Stanford, CA, USA



Claude Cohen-Tannoudji

🕒 1/3 of the prize

France

Collège de France; École
Normale Supérieure
Paris, France



William D. Phillips

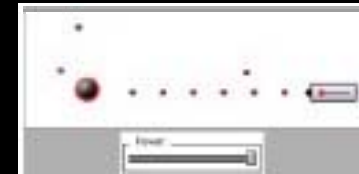
🕒 1/3 of the prize

USA

National Institute of
Standards and
Technology
Gaithersburg, MD, USA

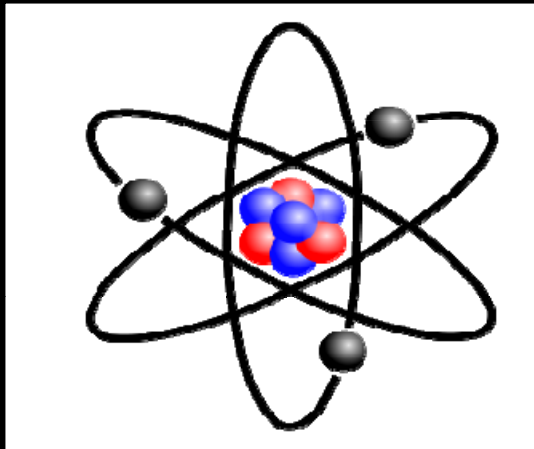
Refredament làser

Absorció

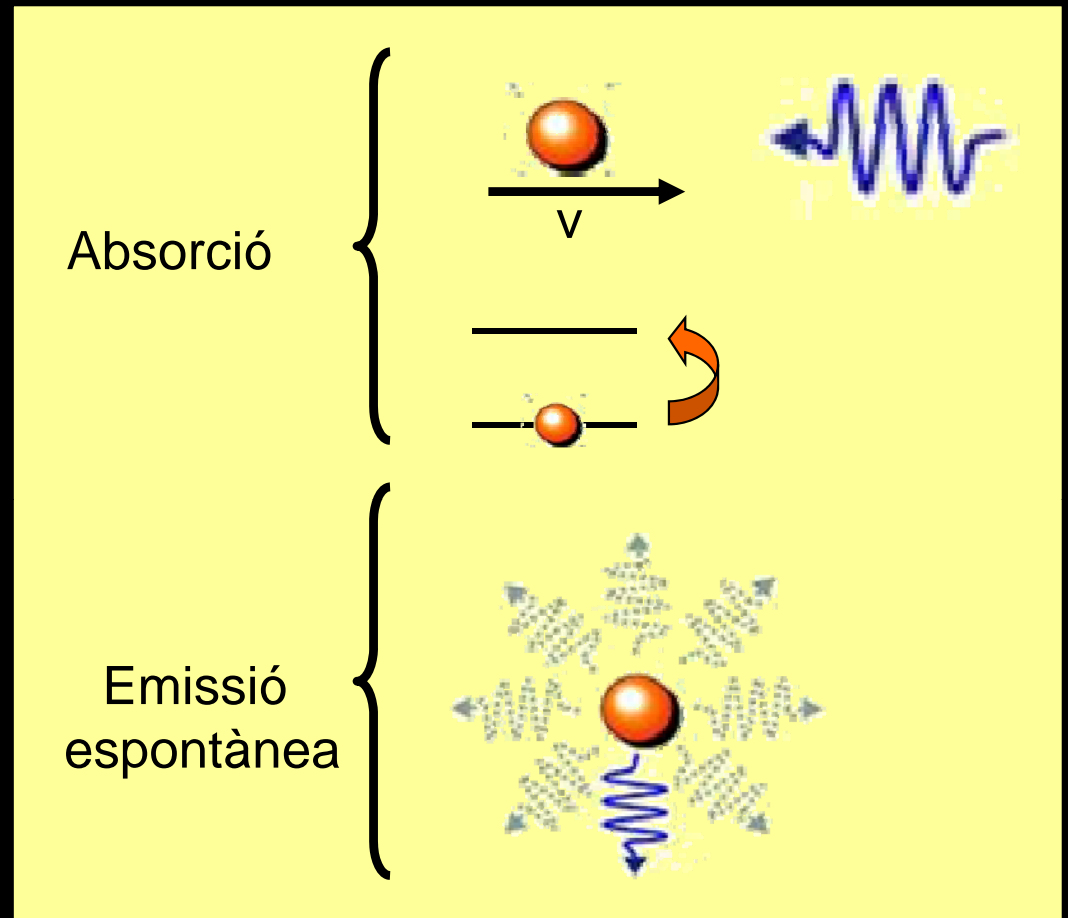


Refredament làser

Model atòmic de Bohr



<http://es.quimica.wikia.com/wiki/%C3%81tomo>

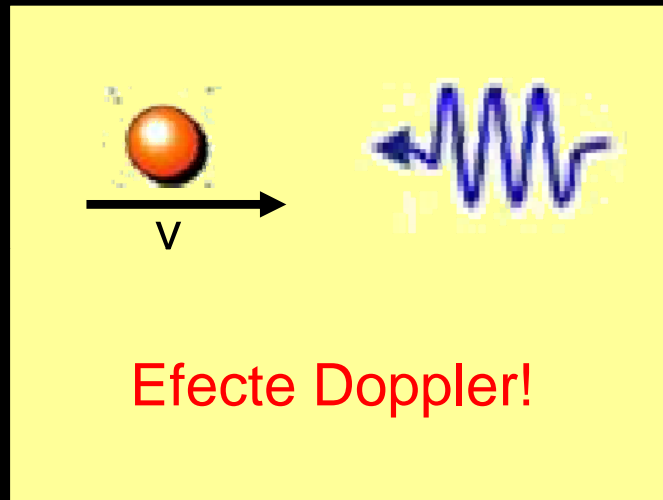


<http://en.wikipedia.org/wiki/Sodium>

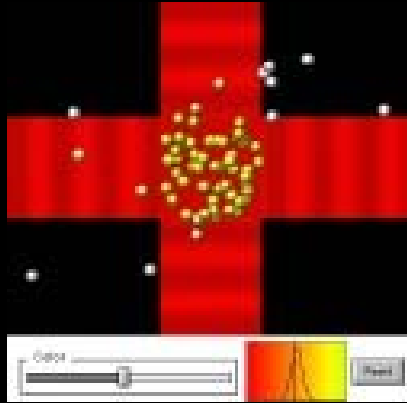


<http://www.colorado.edu/physics/2000/bec>

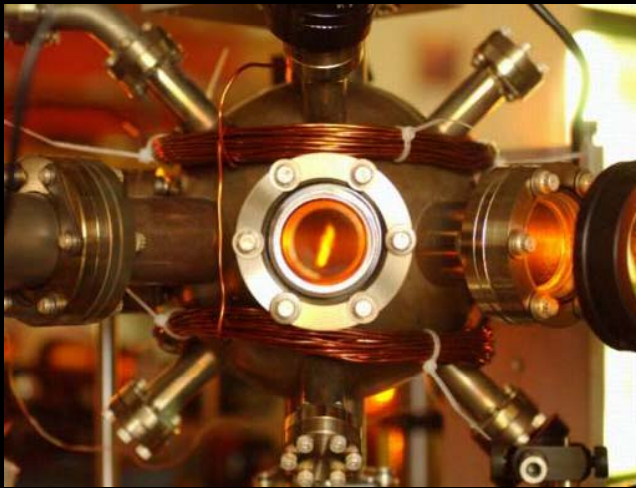
Refredament làser



Melasses optiques



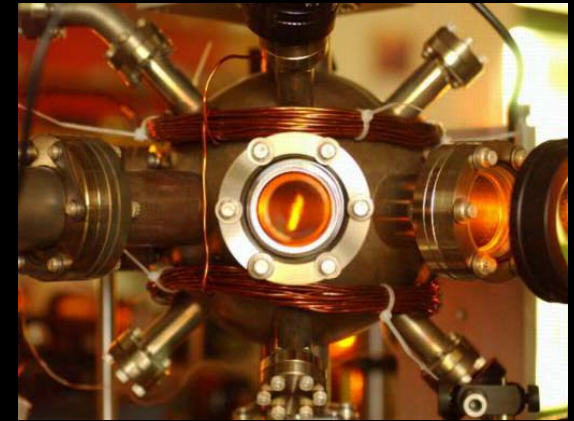
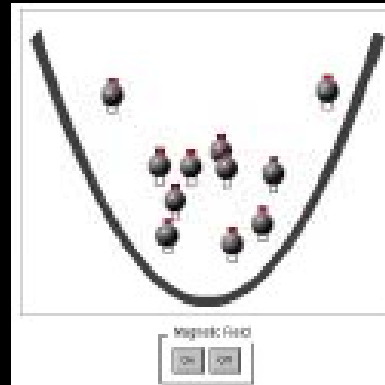
<http://www.colorado.edu/physics/2000/bec>



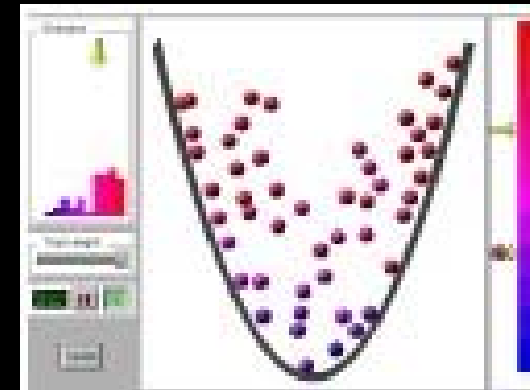
<http://science.williams.edu/files/RS03html/RepSci2003fnl.html>

<http://www.laserfest.org/about/poster-spots.cfm>

Atrapament magnètic

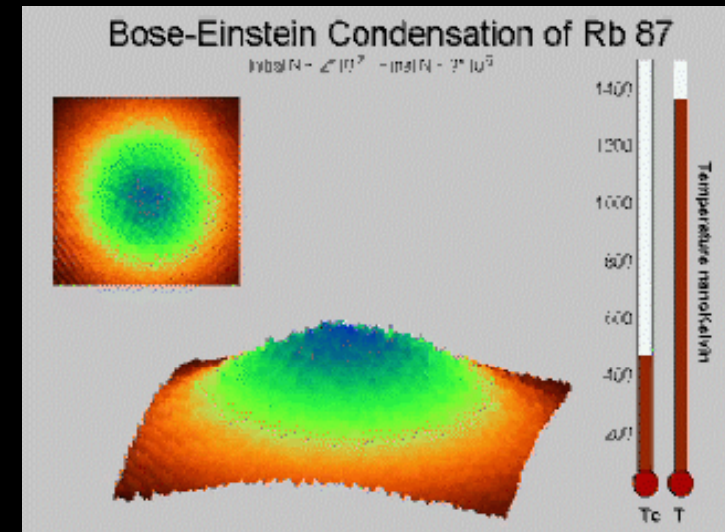
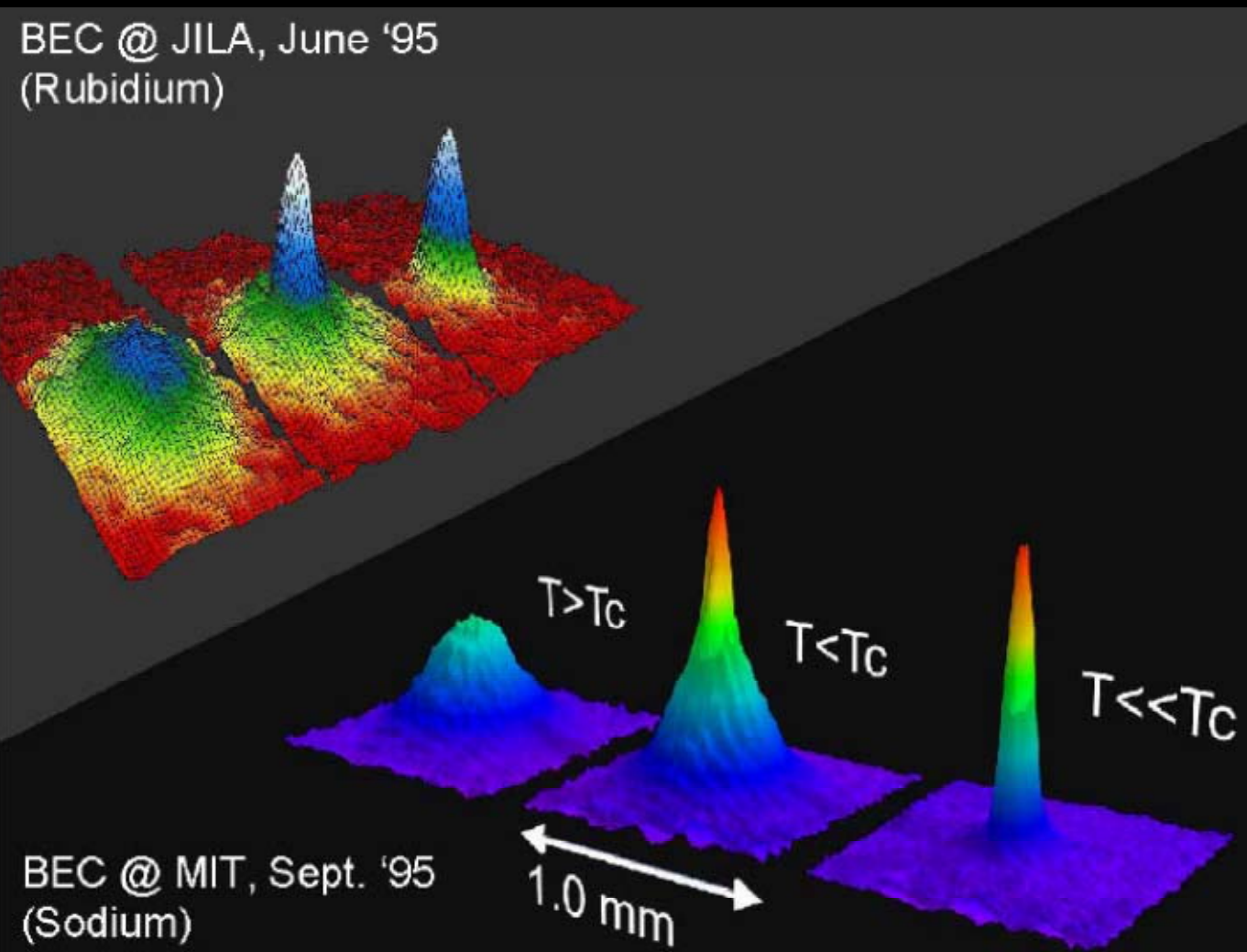


Refredament evaporatiu



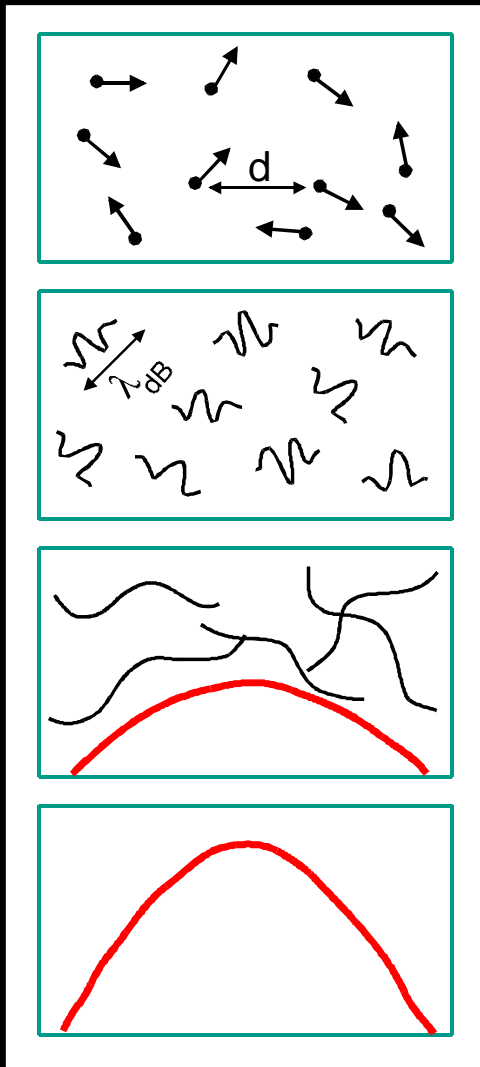
Condensació de Bose-Einstein

<http://www.colorado.edu/physics/2000/bec>



I per a què són interessants els condensats?....

↓ T



The Nobel Prize in Physics 1929
Louis de Broglie

The Nobel Prize in Physics 1929 was awarded to Louis de Broglie "for his discovery of the wave nature of electrons".



1924: Dualitat ona-partícula

http://www.nobelprize.org/nobel_prizes/physics/laureates/

Àtoms amb comportament ondulatori macroscòpic!

Com els podem interpretar?....

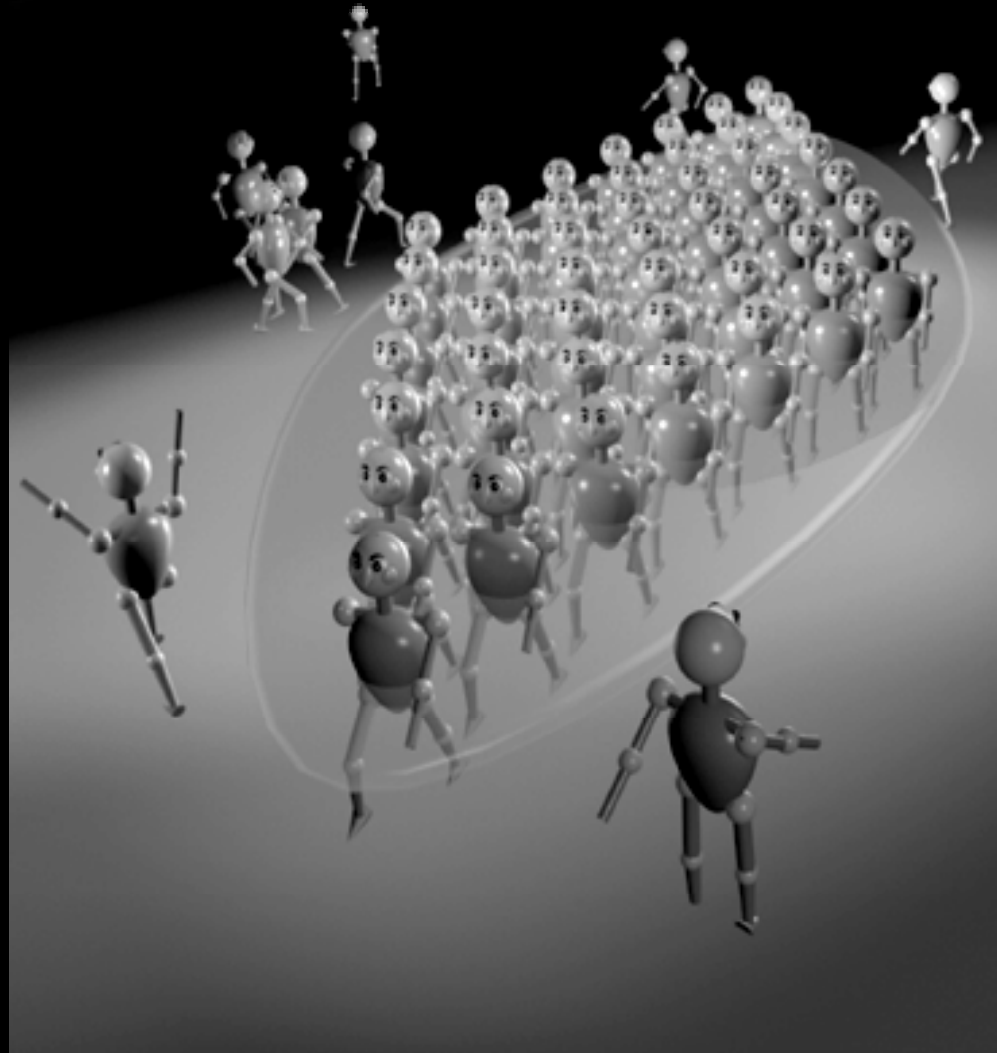
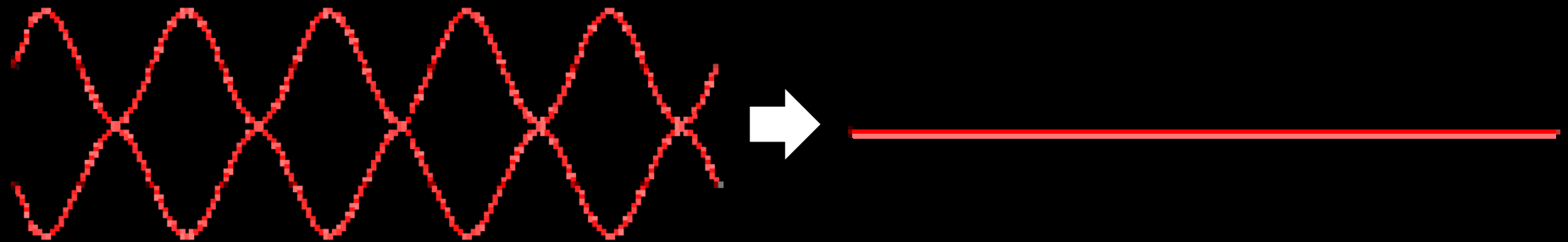
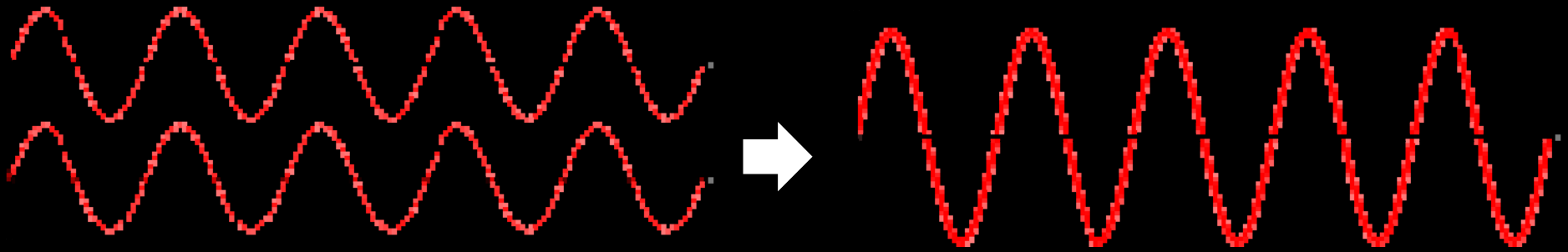


Figura adaptada per Dave Cantrell de la original "Molecule of the Year" portada de Science (December 22, 1995) per Steve Keller.

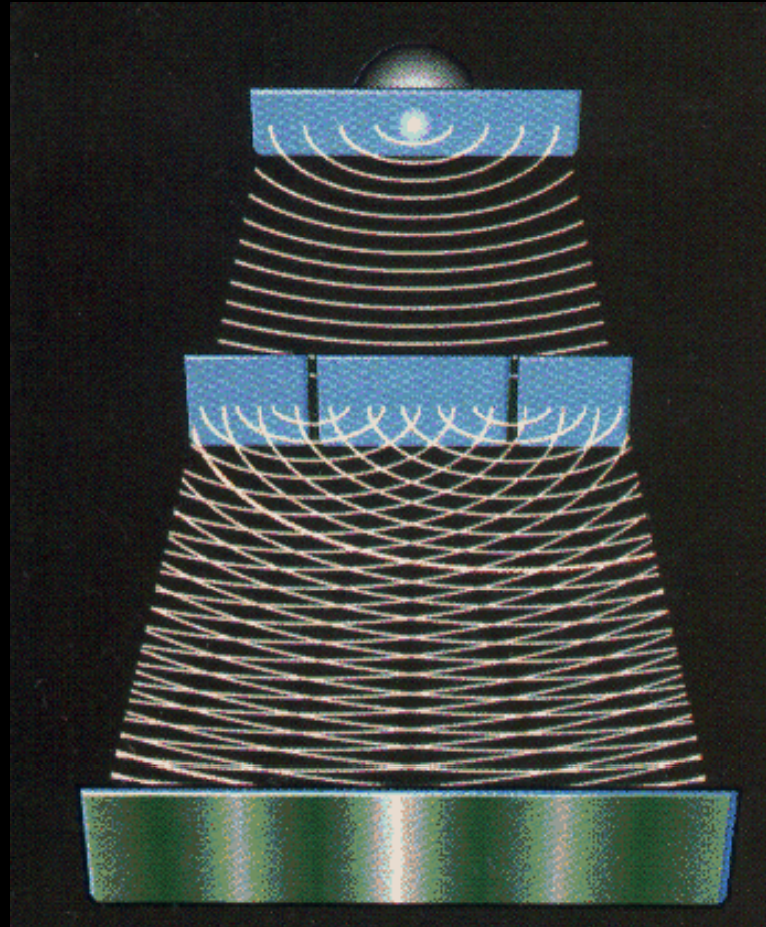
Interferències constructives i destructives



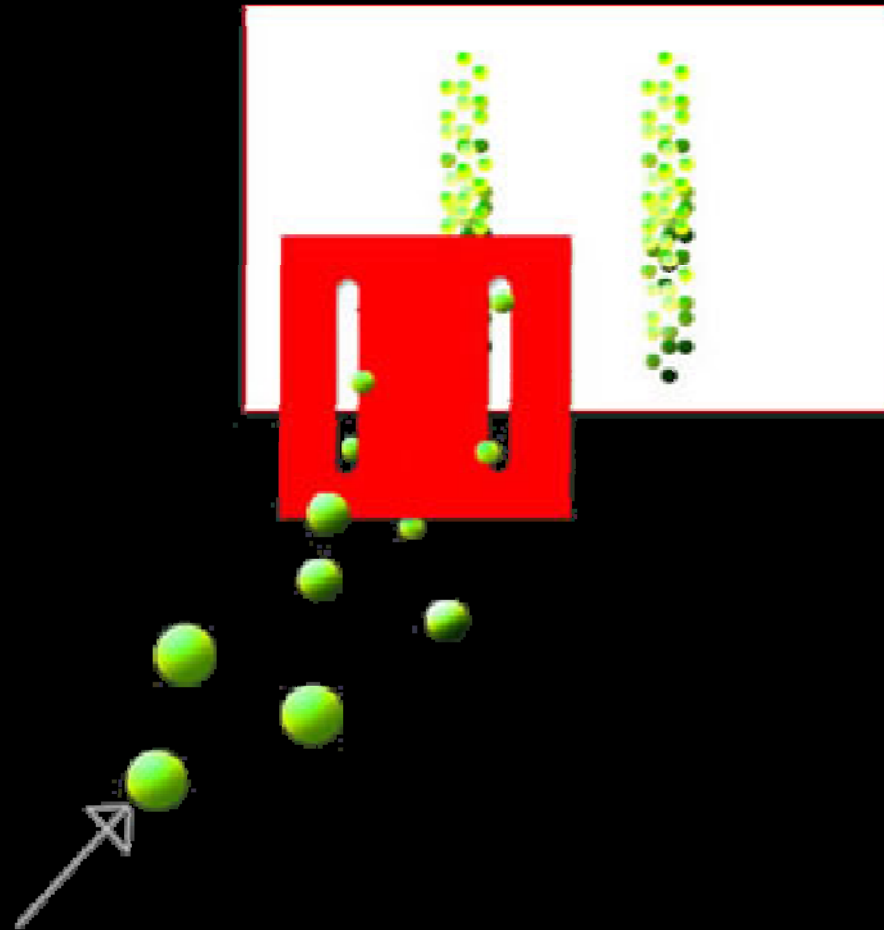
Interferències a la natura



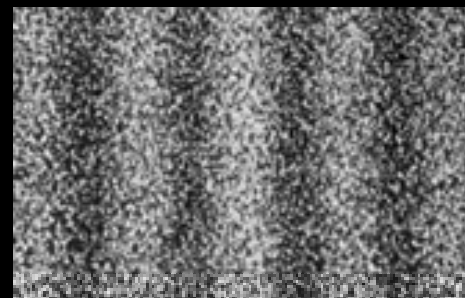
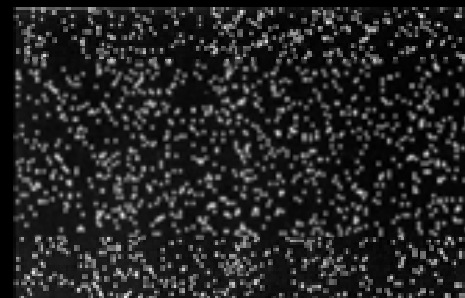
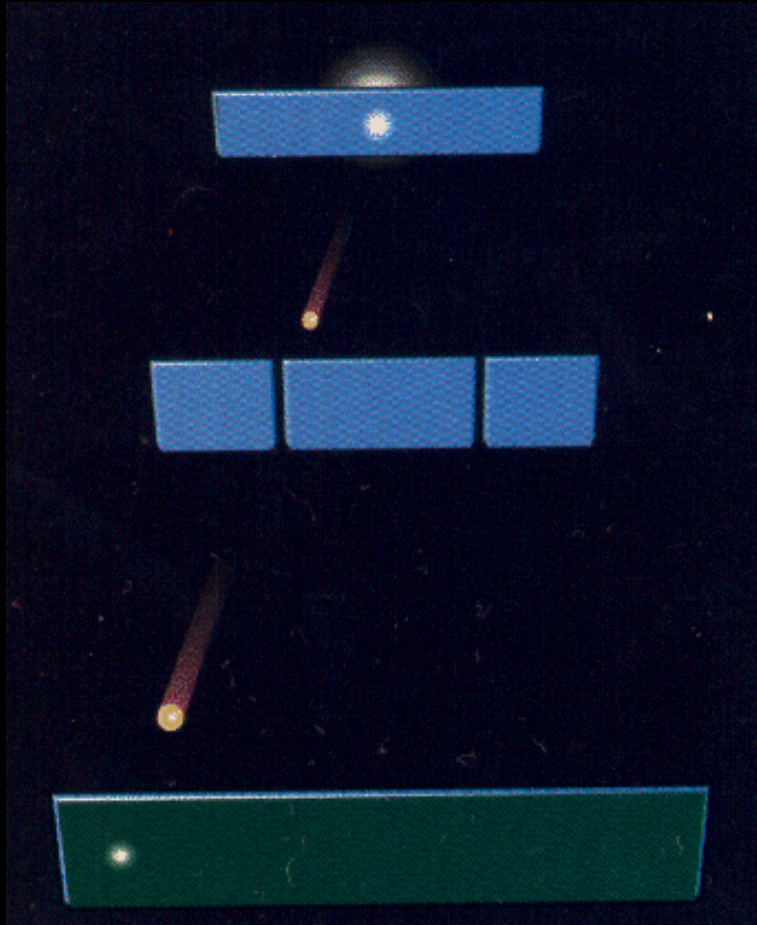
Experiment de la doble escletxa amb llum



Experiment de la doble escletxa amb partícules macroscòpiques



Experiment de la doble esclatxa amb electrons

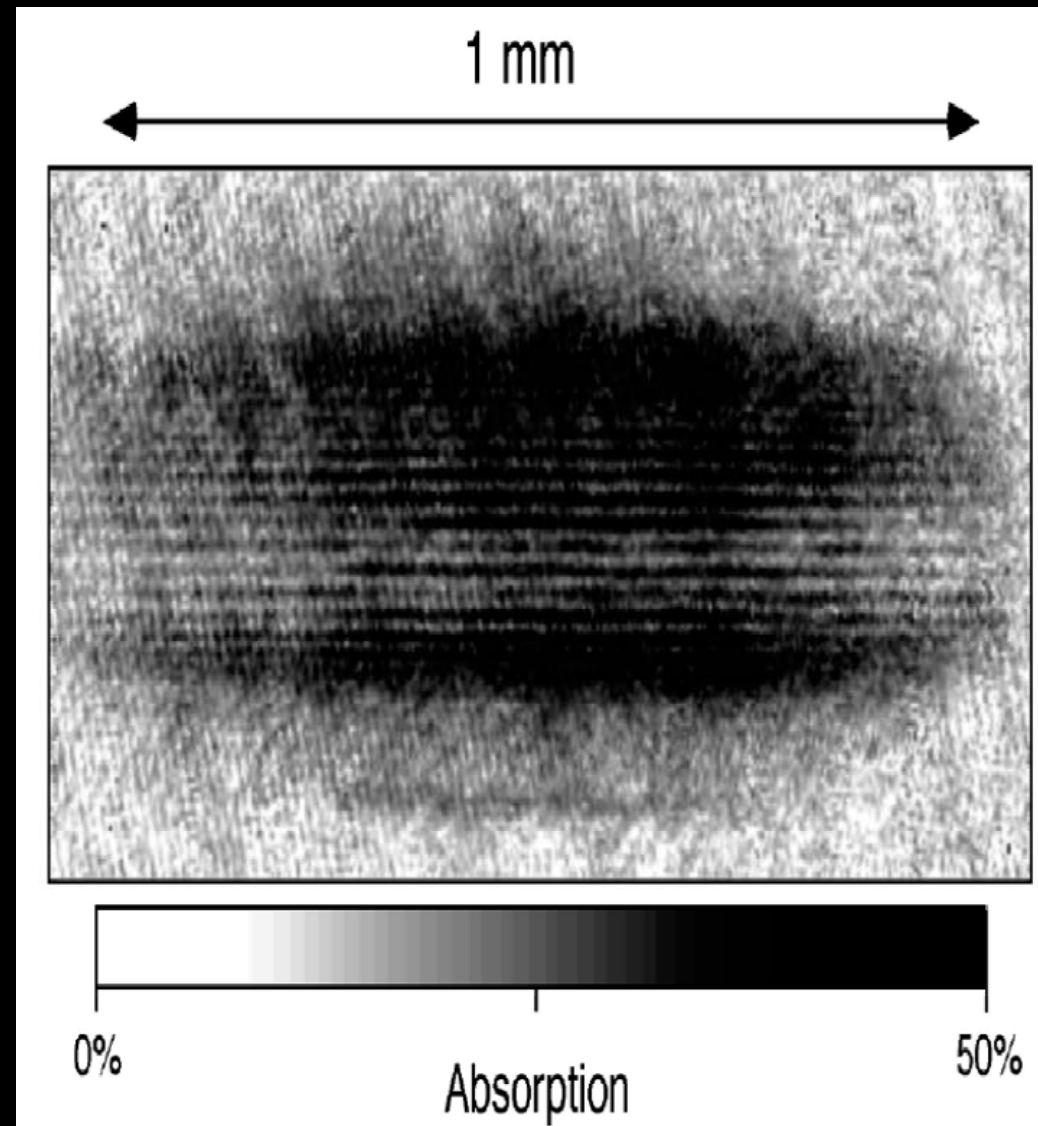
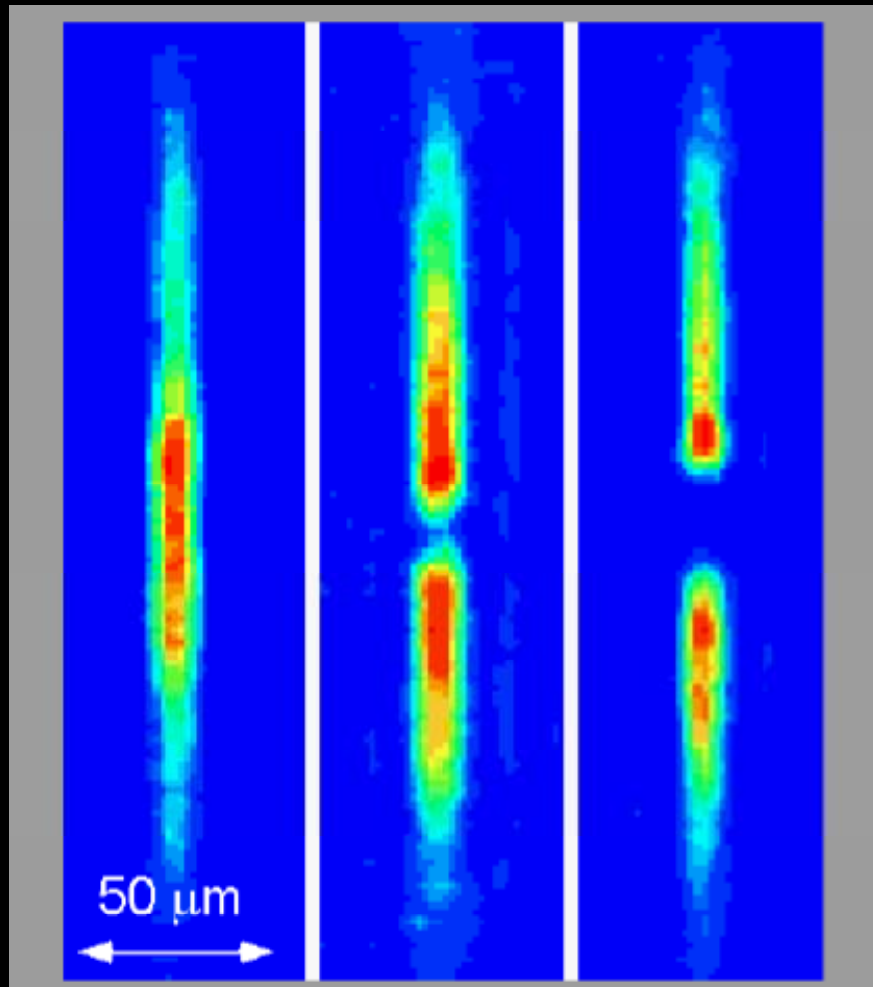
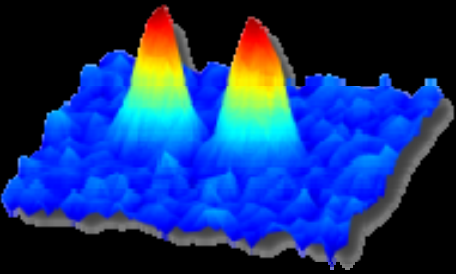


http://abyss.uoregon.edu/~js/21st_century_science/lectures/lec13.html

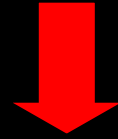
<http://www.hitachi.com/rd/research/em/doubleslit.html>

Experiment de la doble escletxa amb un condensat de Bose-Einstein

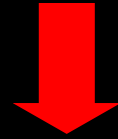
M. R. Andrews et al., Science 275, 637 (1997)



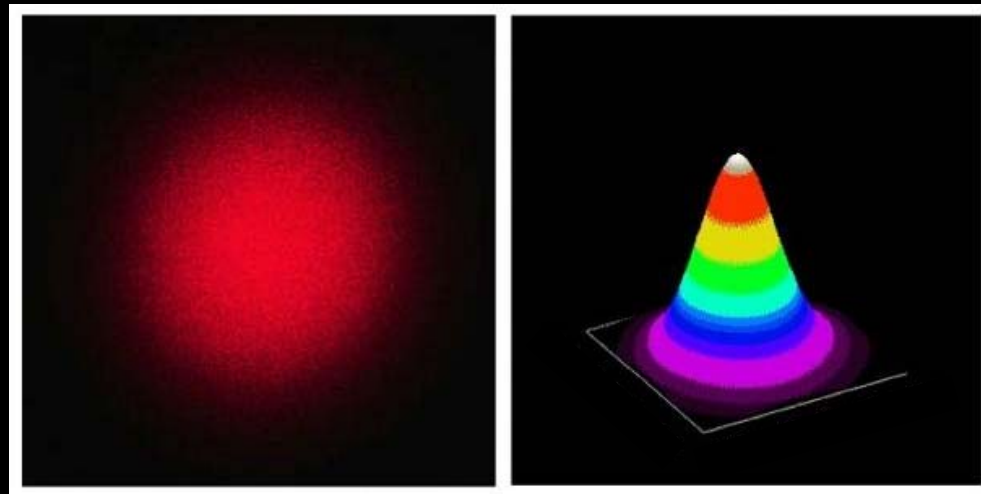
La llum pot atrapar els àtoms



Força dipolar



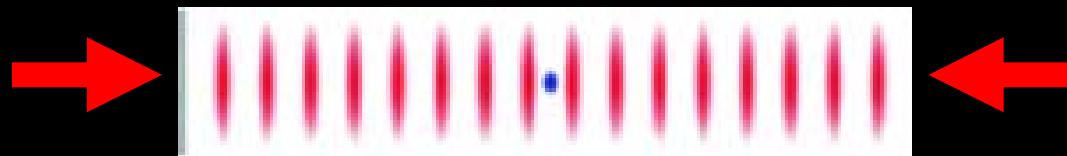
**quan la intensitat és
inhomogènia**



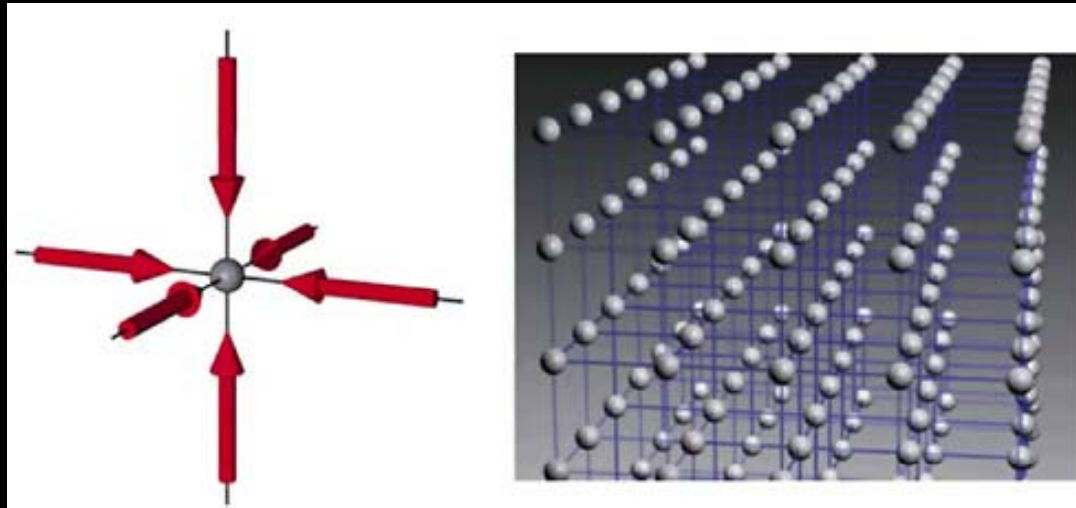
ona estacionària



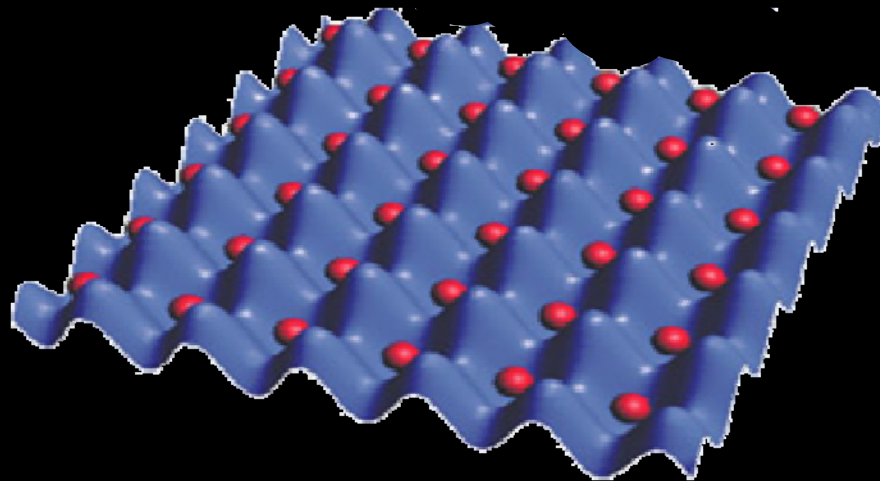
Amb llum



Cristalls perfectes d'àtoms

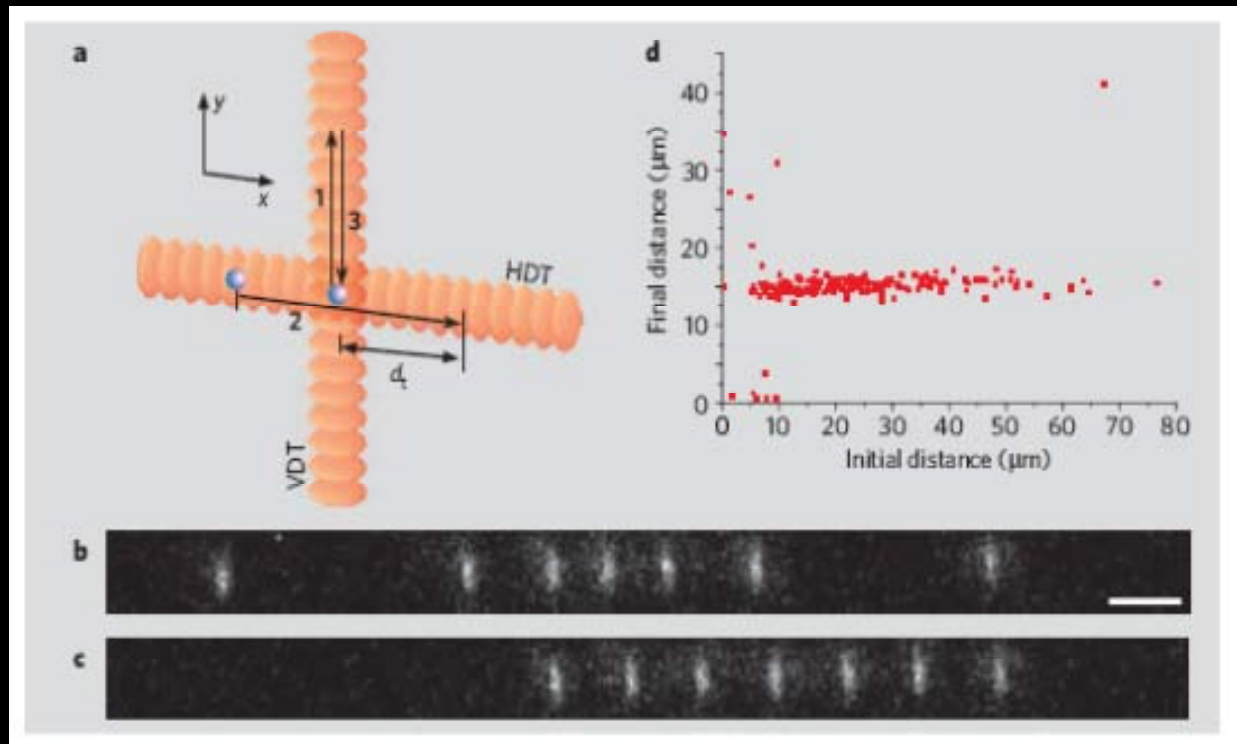


M. Greiner et al., Nature 415, 39 (2002)



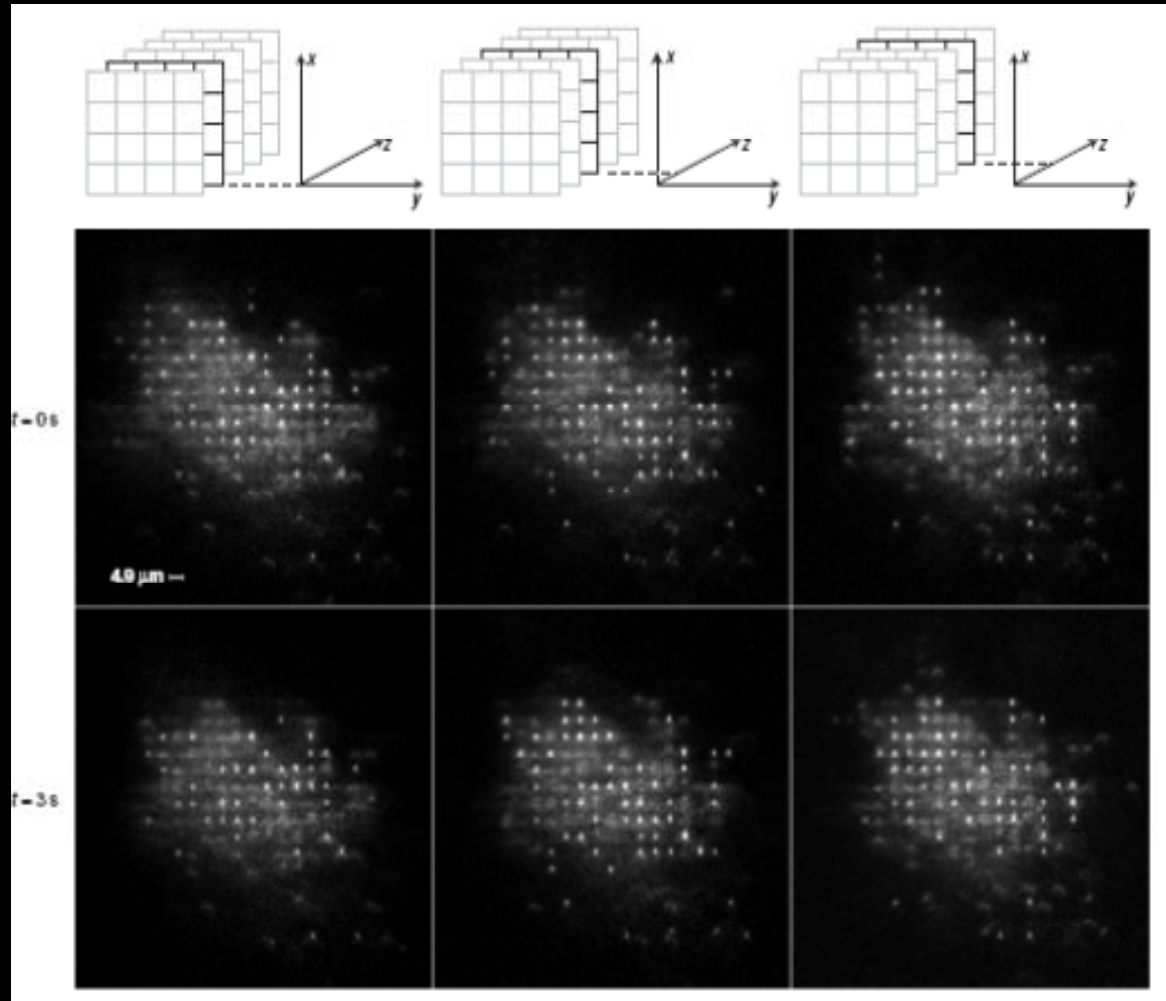
Manipulació d'àtoms individuals

Yevhen Miroshnychenko et al., Nature 442, 151 (2006)



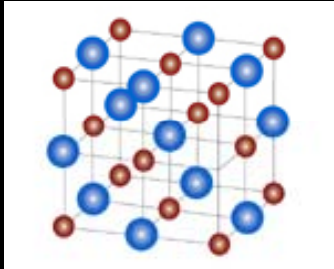
Images d'atomes individuels

K. D. Nelson et al., Nat. Physics 3, 556 (2007)

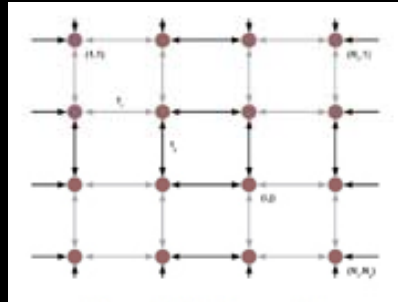


Simuladors quàntics?

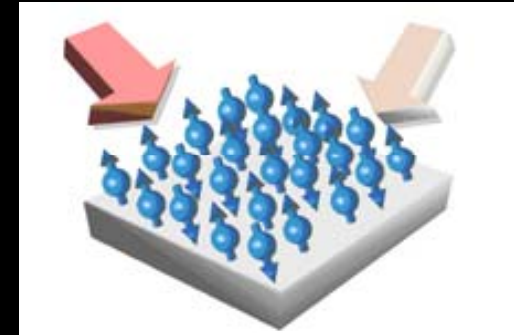
Sistema quàntic



Model



Sistema físic controlable
Simulador quàntic



Ordinadors quàntics?

