The Abdus Salam
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Exploring an ultracold Fermi-Fermi mixture of 6Li and 40K

SCHRECK Florian Eberhard

Institut fur Quantenoptik & Quanteninformation der
Osterreichischen Akademie der Wissenschaften
Universitaet Innsbruck, ICT Building
Technikerstrasse 21a, A-6020 Innsbruck
AUSTRIA

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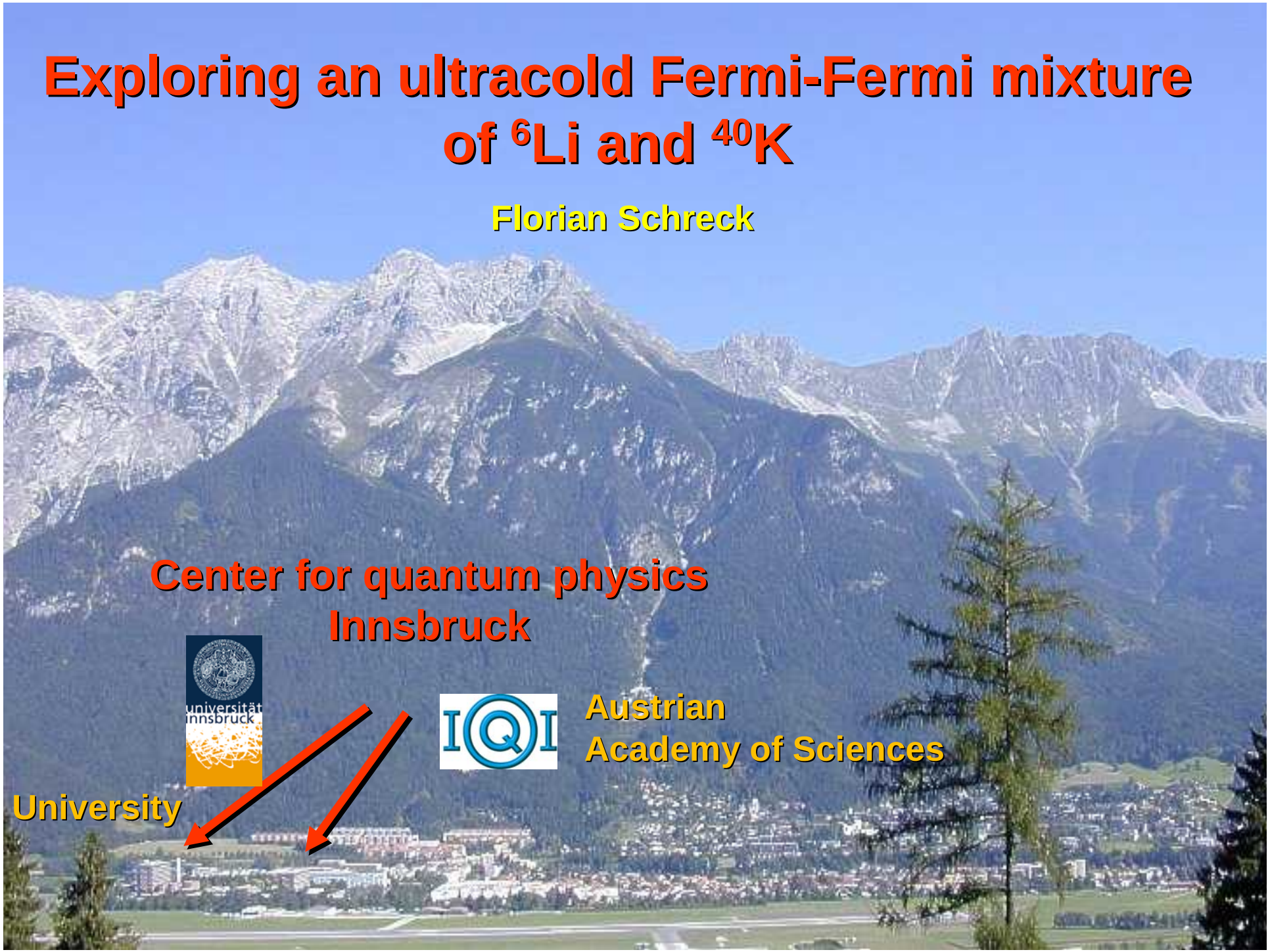
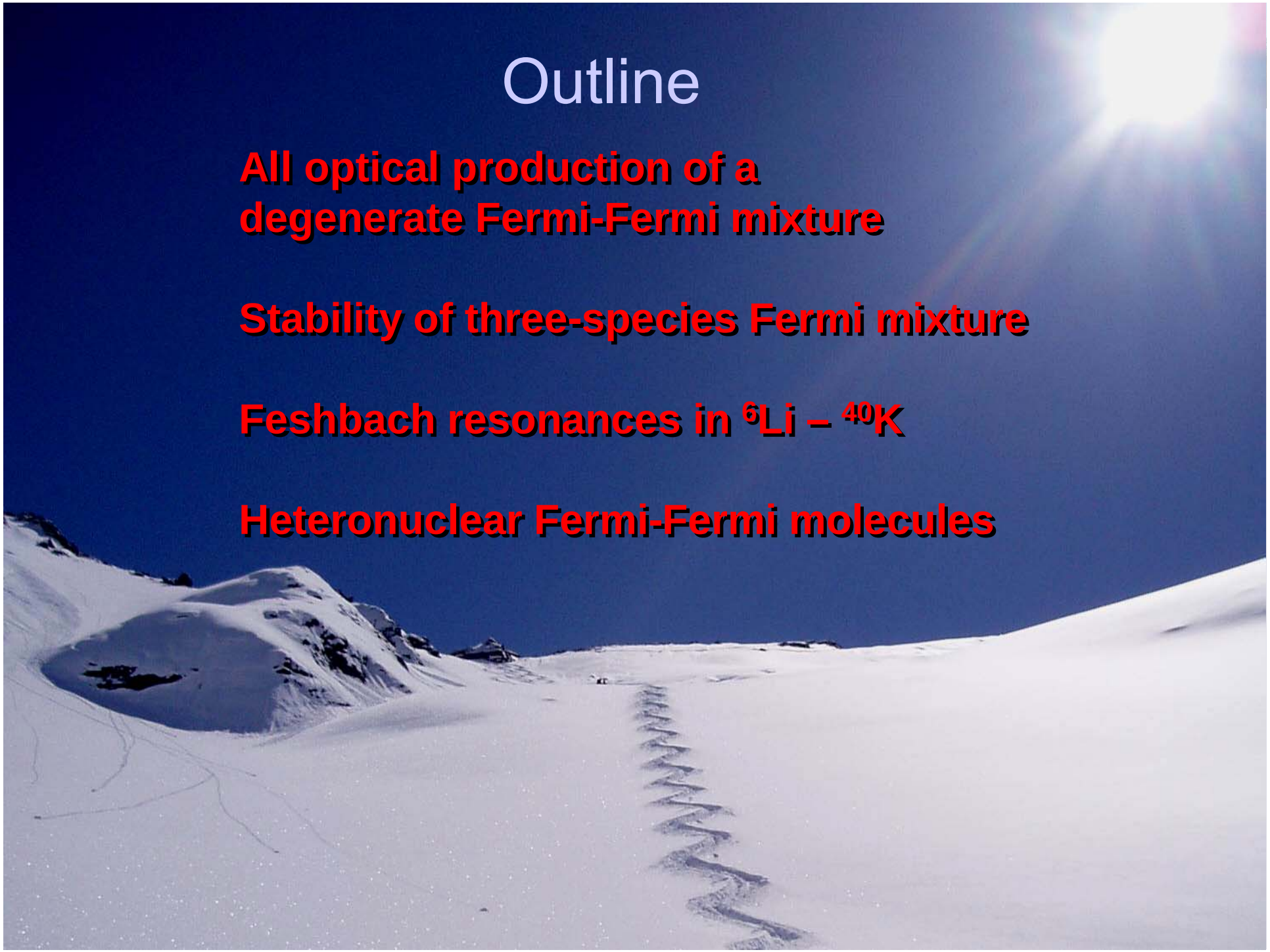
Florian Schreck





Outline

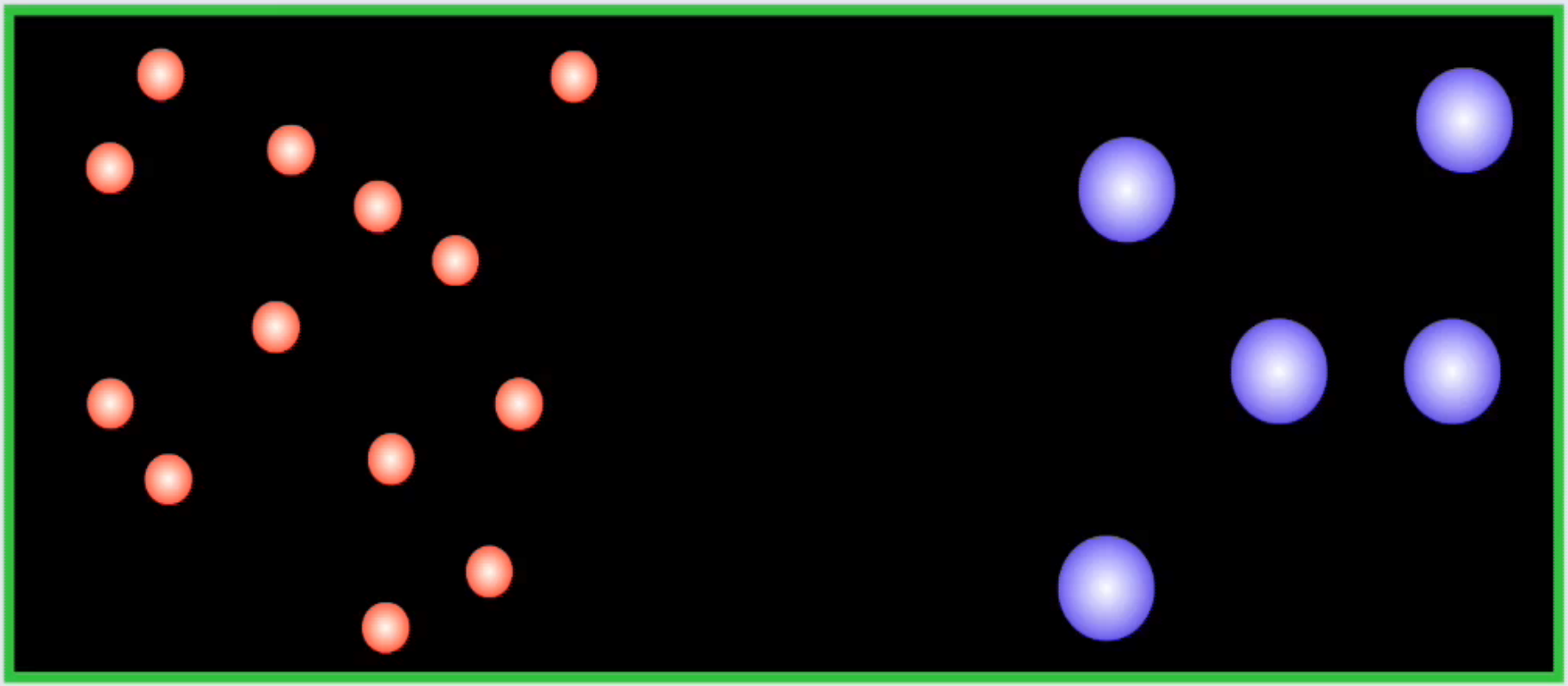
All optical production of a degenerate Fermi-Fermi mixture

Stability of three-species Fermi mixture

Feshbach resonances in ^{6}Li – ^{40}K

Heteronuclear Fermi-Fermi molecules

Ultracold alkali fermions

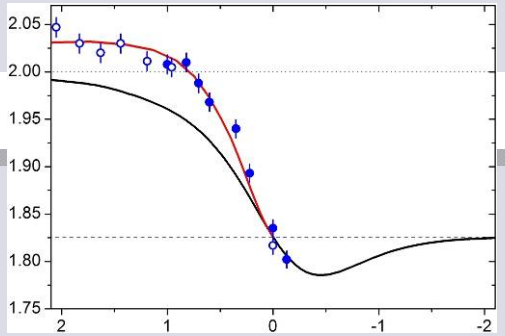


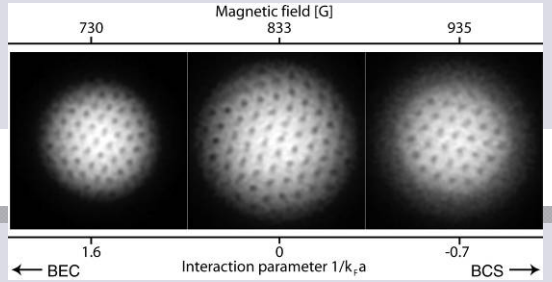
movie

control knobs (single species)

BEC-BCS crossover physics

interaction strength





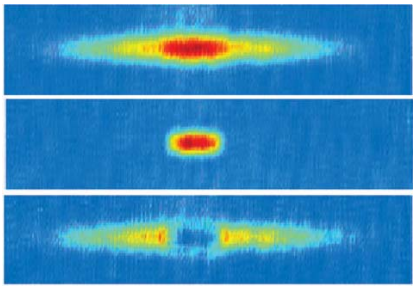
Innsbruck, JILA, MIT, Duke, ENS, Rice

. . .

trap parameters:
anisotropy, ellipticity etc. (very flexible!)

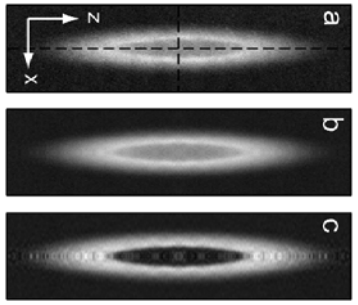
spin imbalance

physics of polarized Fermi gases



Rice

MIT



new possibilities in FF mixtures

87/40 = 2.2

40/6 = 6.7

87/6 = 14.5

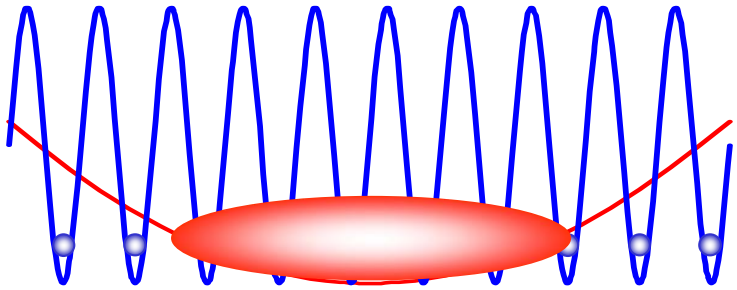
control of mass ratio

fermion pairing with unequal masses,
stable heteronuclear molecules,
novel quantum phases …

independent control of optical potentials

pairing with unequal Fermi surfaces

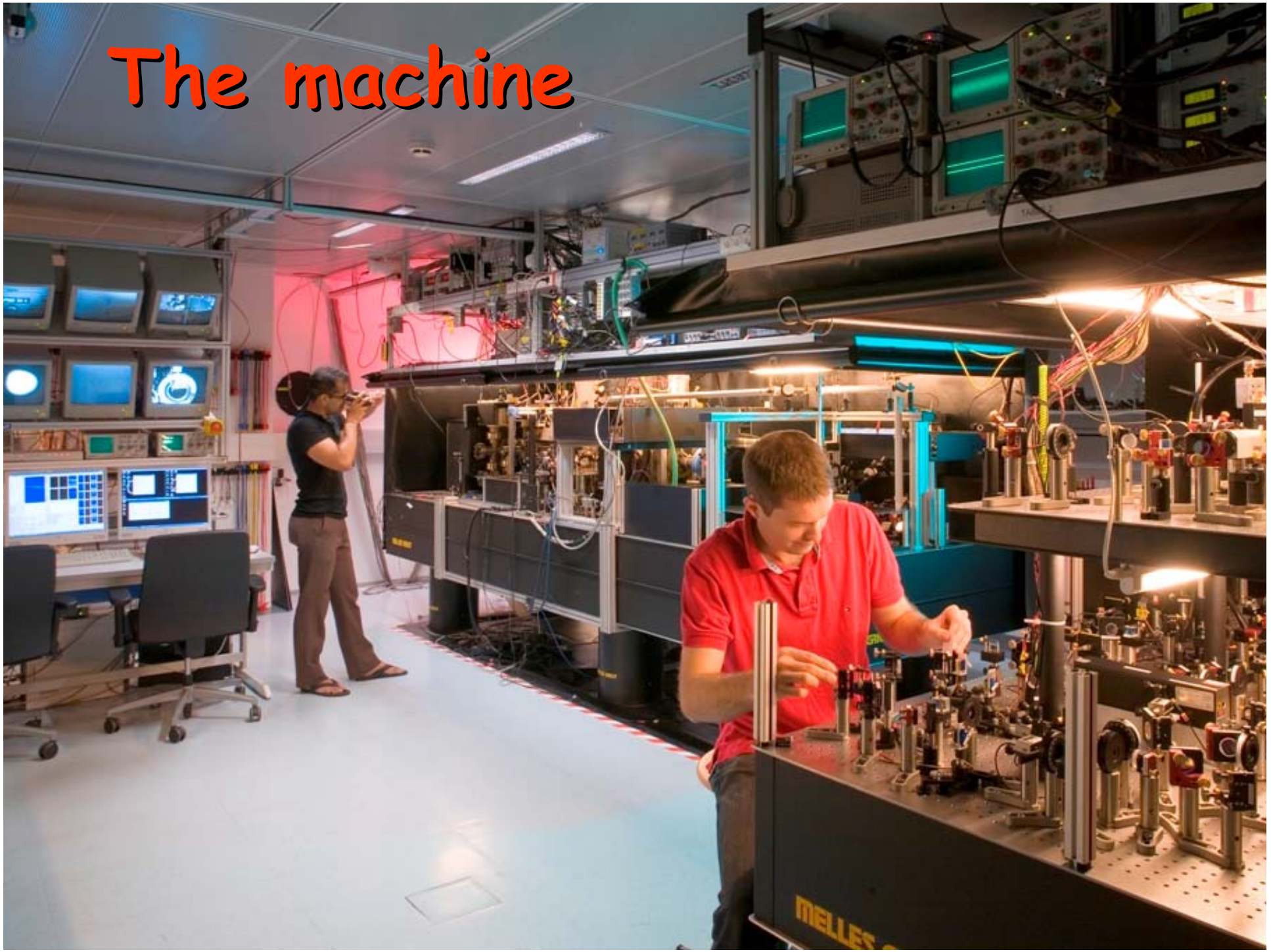
e.g., small trap of ^{40}K in a large trap of ^{6}Li
or optical lattice for ^{87}Sr in a bath of ^{6}Li …



movie


All optical production of
a degenerate Fermi-Fermi
mixture

The machine



Lithium-Potassium-Strontium Machine

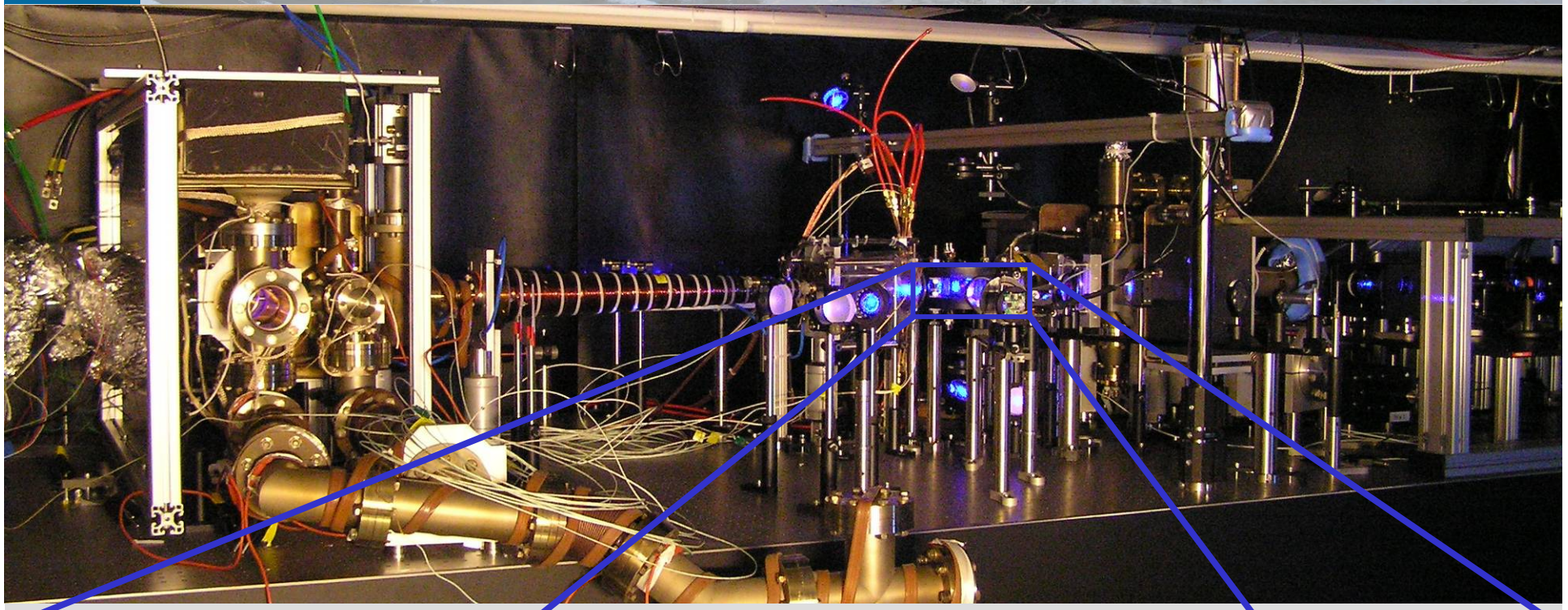


Fig. 1

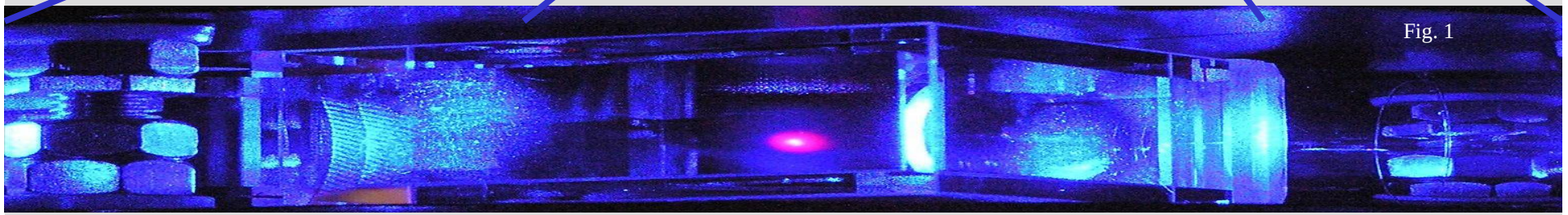
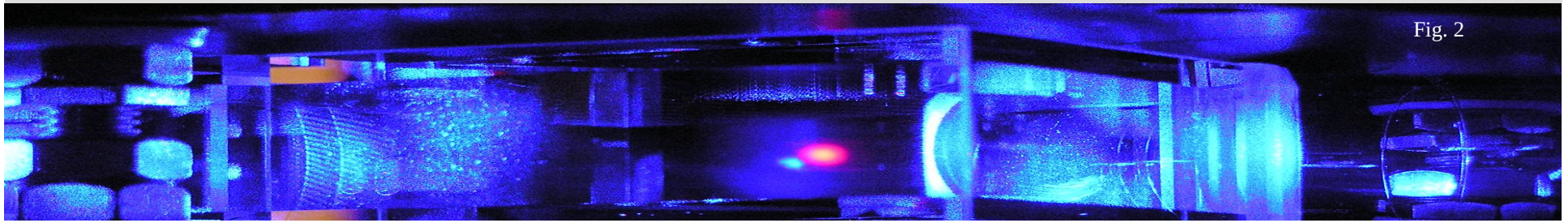
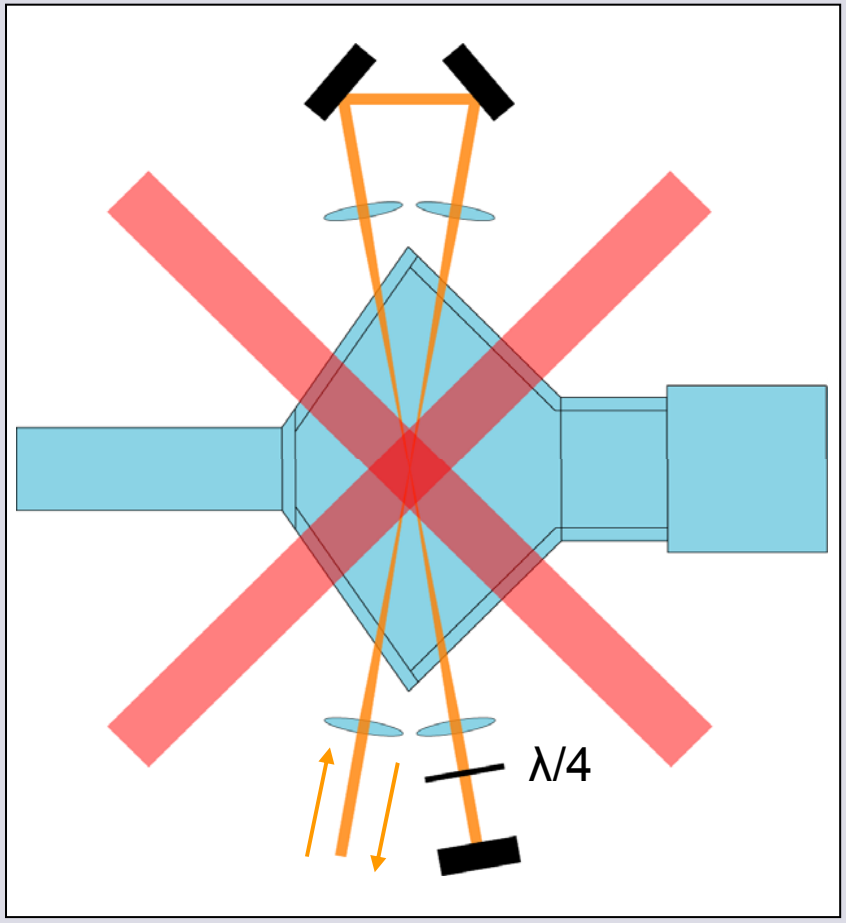


Fig. 2

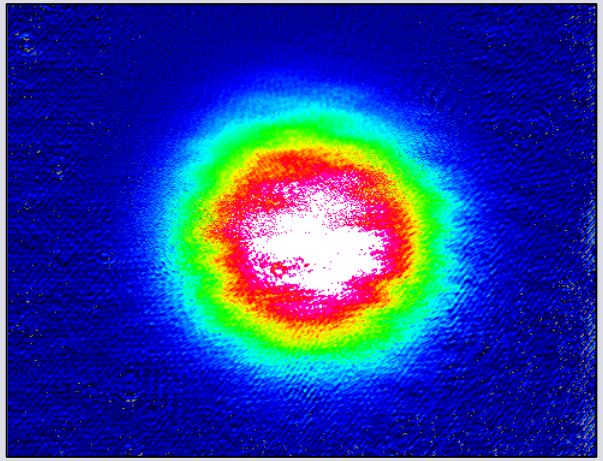


The all-optical way

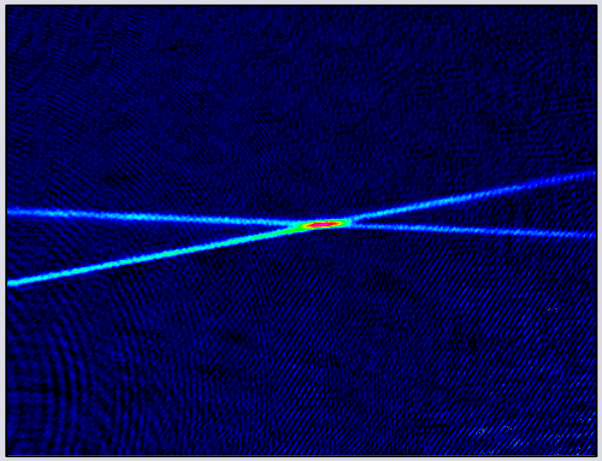


dipole trap (200W 1075nm laser):
U ~ k_B 1 mK
w ~ 30 µm

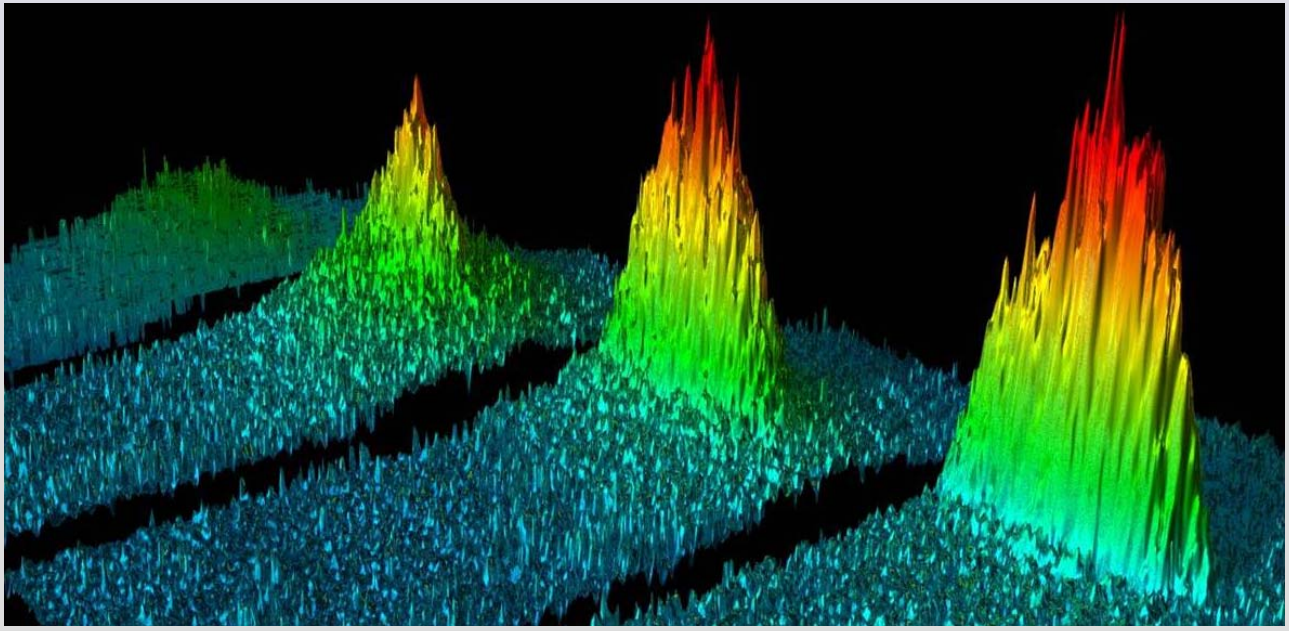
^{6}Li MOT: N ~ 10^9 T ~ 300µK



dipole trap: N > 10^6



$^6Li_2$ molecular Bose condensation

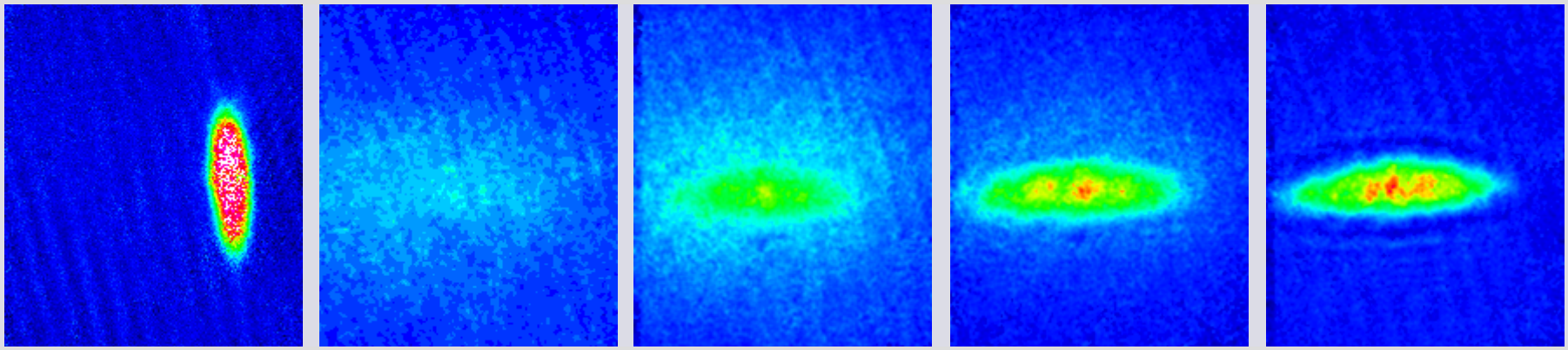


in dipole trap

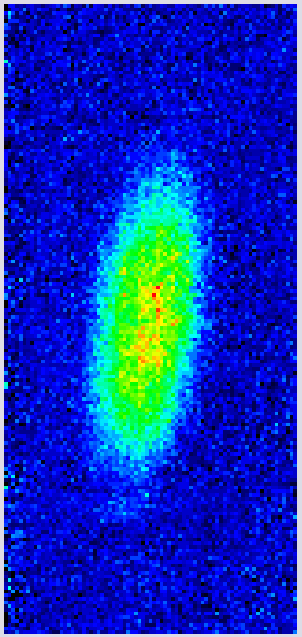
After 10ms time of flight:

PURE BEC!

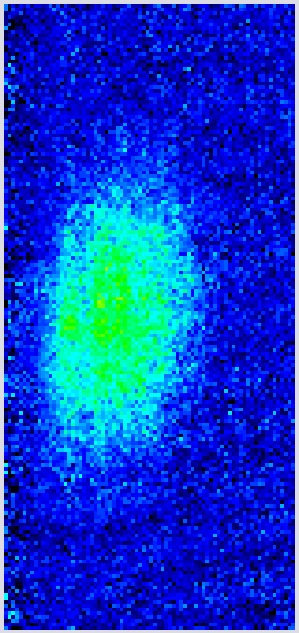
4.3 sec evap **4.7 sec evap** **4.8 sec evap** **5.1 sec evap**



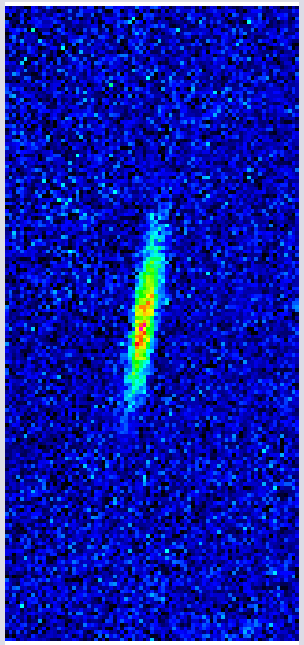
heteronuclear FF mixture



Li|1>



Li|2>



K|1>

$N = 4.5\ 10^4$
$T = 70nK$
$T/T_F = 0.2$

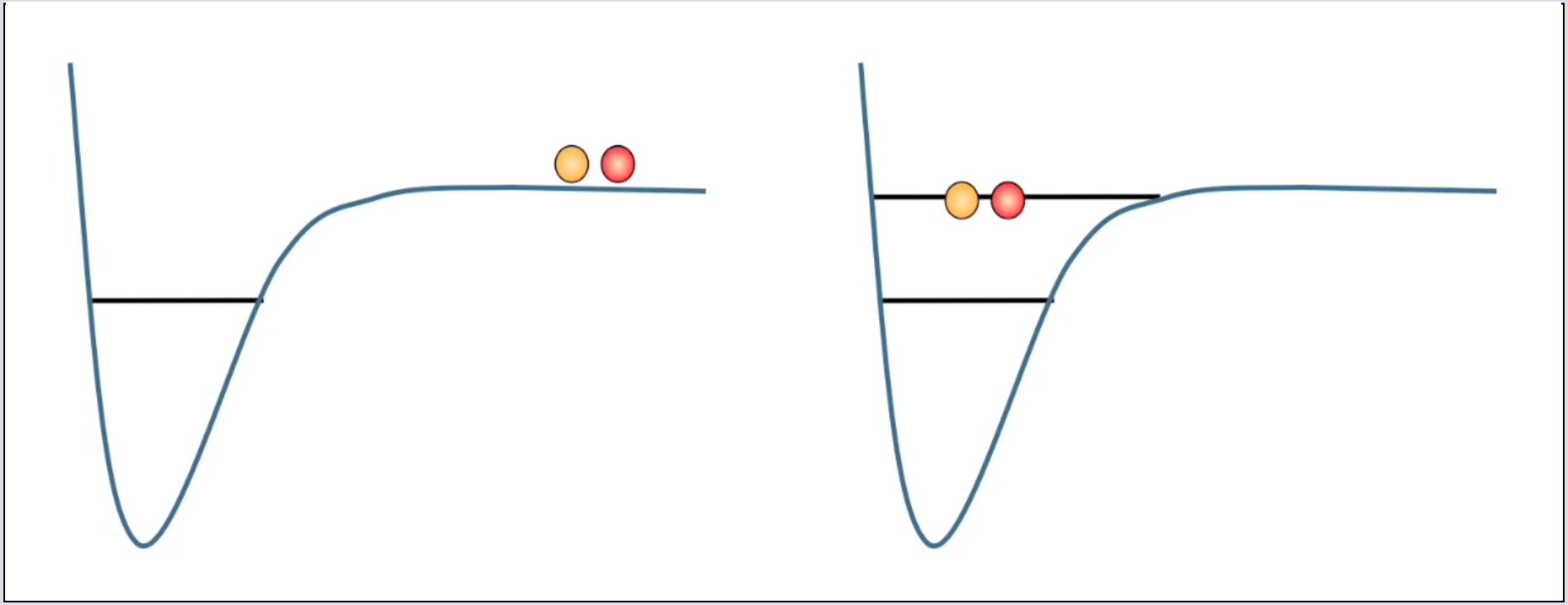
$N = 3.7\ 10^3$
$T = 76nK$
$T/T_F = 0.7$

Degenerate heteronuclear Fermi-Fermi mixture

in the Lithium BCS regime (B = 1200G)

Stability of three-component Fermi mixture

Stability



movie

What happens in
3-Fermion mixture?

Formation of deeply bound molecules leads to loss

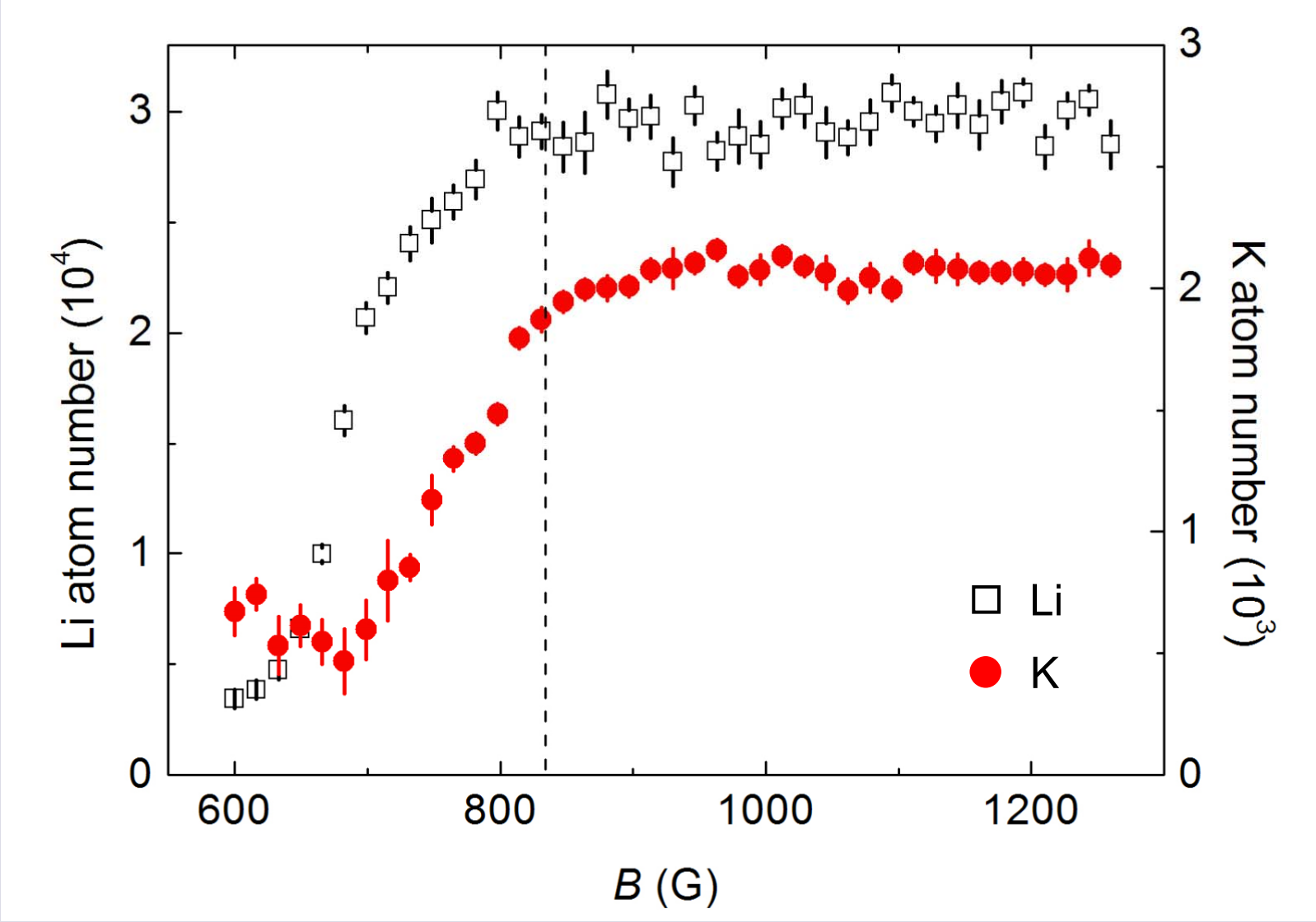
Energy & momentum conservation:
3 atom need to come closer than size of endstate

2 fermion mixture:
Pauli principle inhibits two of the three atoms to get close

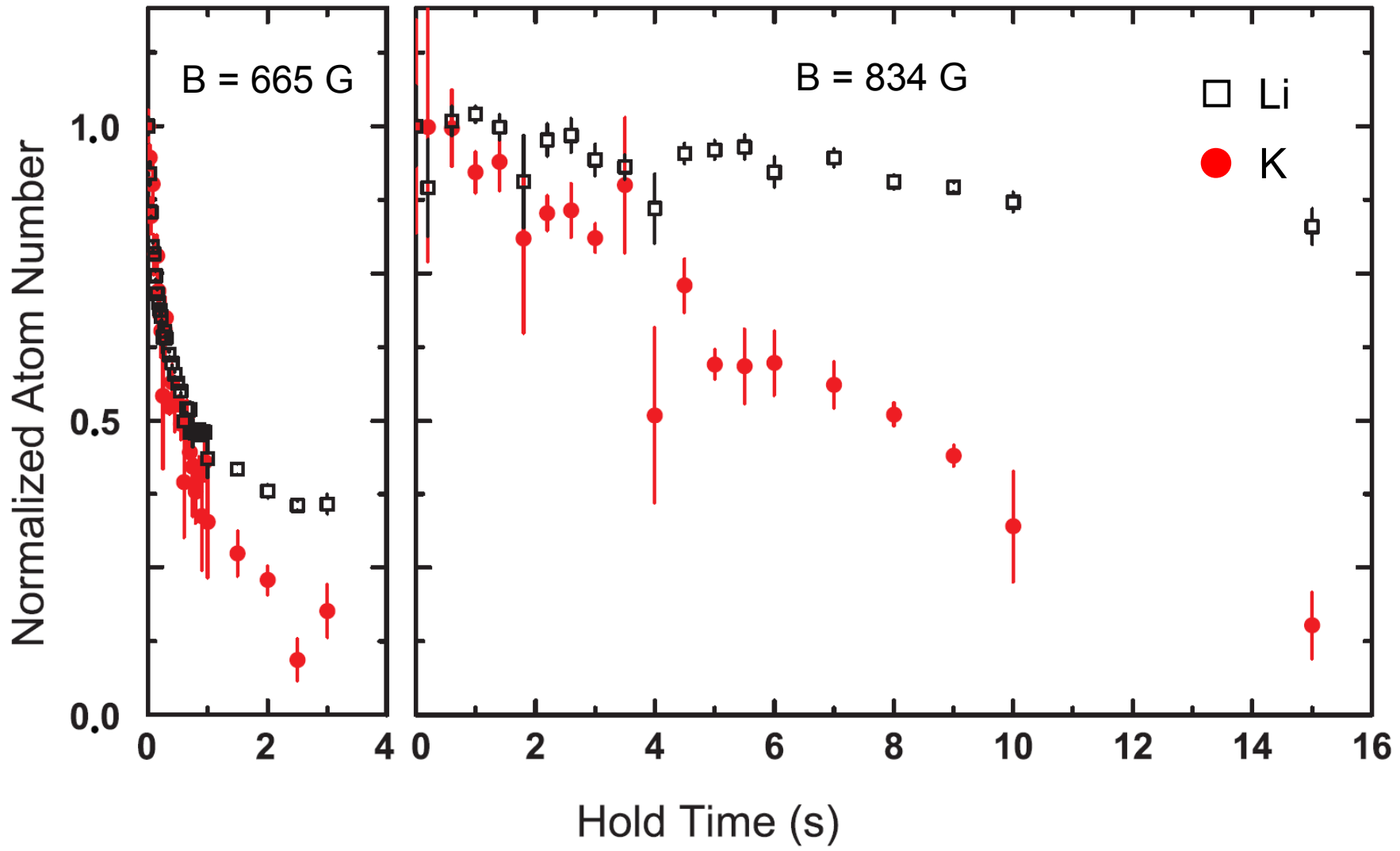
PRL, **93**, 090404

Loss from 3-fermion mixture

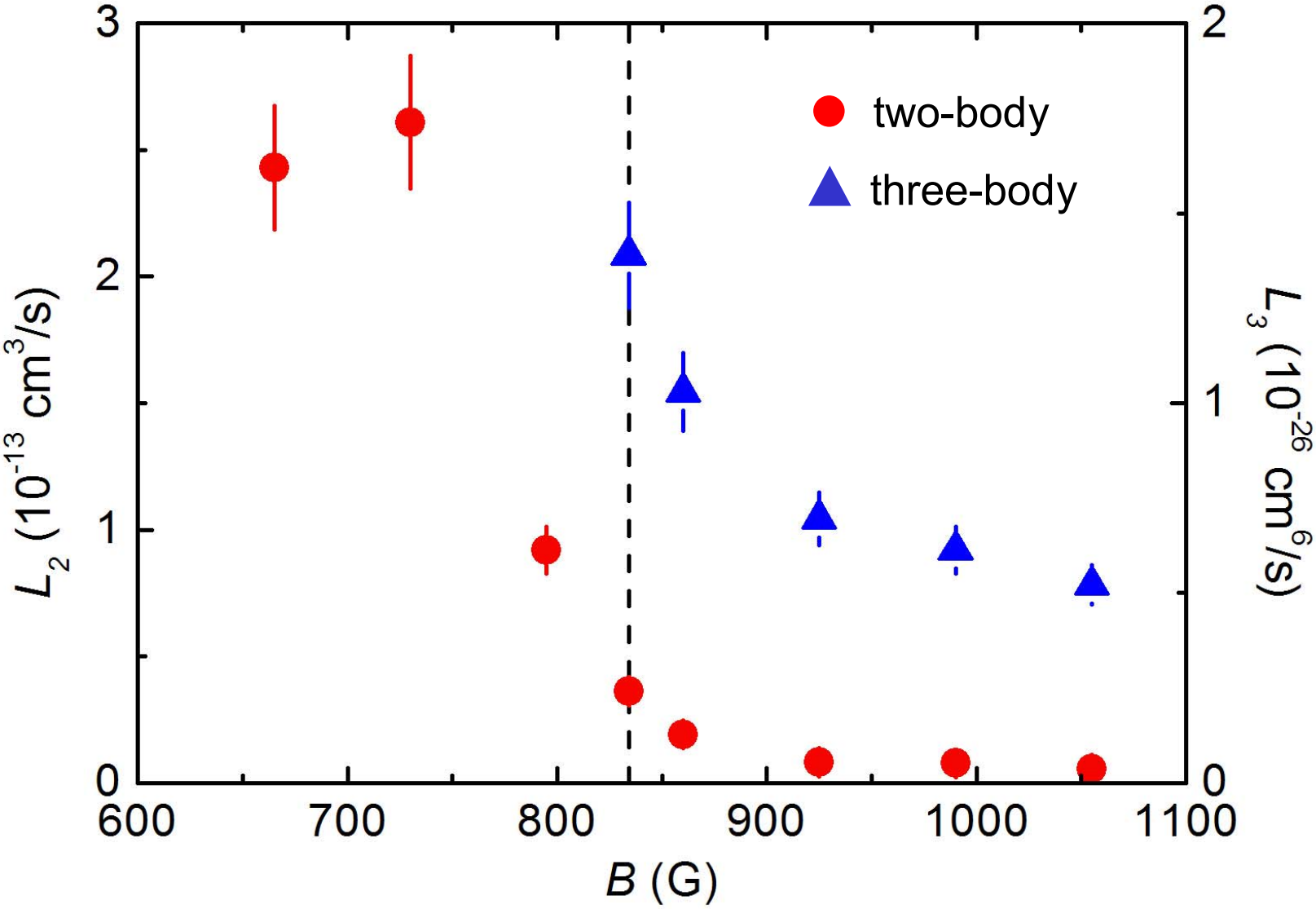
Atomnumbers after 2 seconds of hold



Sample decay data

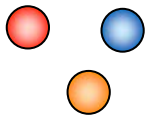


Loss rate coefficients

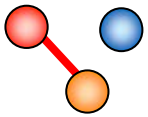


Why is that?

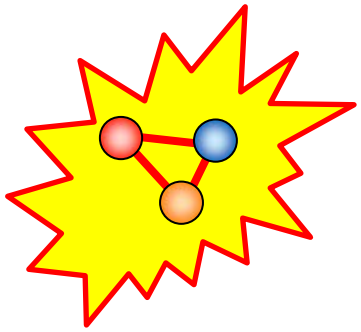
Yet another suppresion mechanism:



3 atoms close to each other:
increased kinetic energy due to Heisenberg uncertainty principle



Only 1 resonant interaction:
Kinetic energy wins: system stable

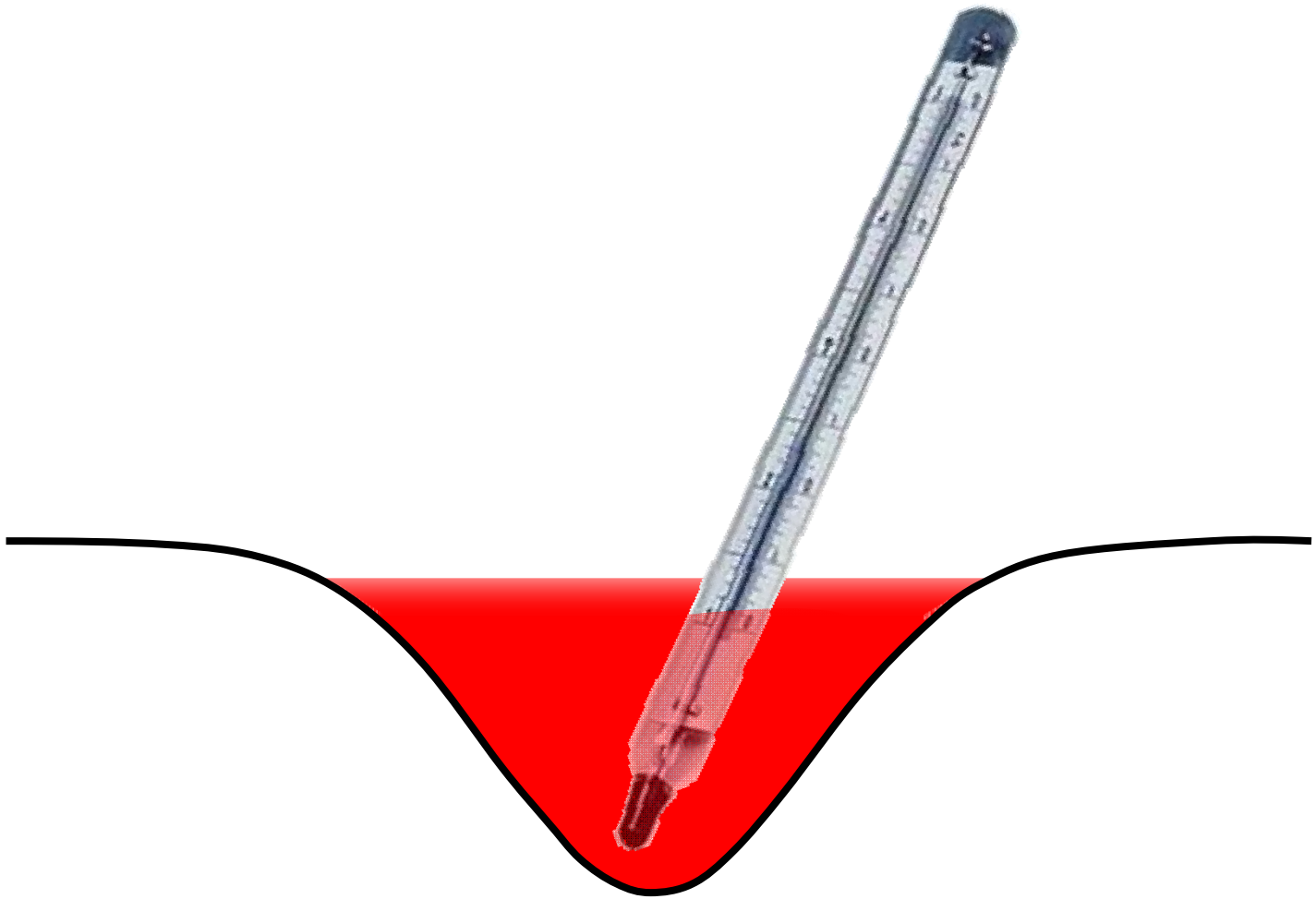


2 or 3 resonant interactions:
Interaction wins, system unstable
Seen in Li|1>Li|2>Li|3> mixture:
PRL **101**, 203202 and PRL **102**, 165302

J. P. D'Incao and B. D. Esry: PRL **100**, 163201 (2008)

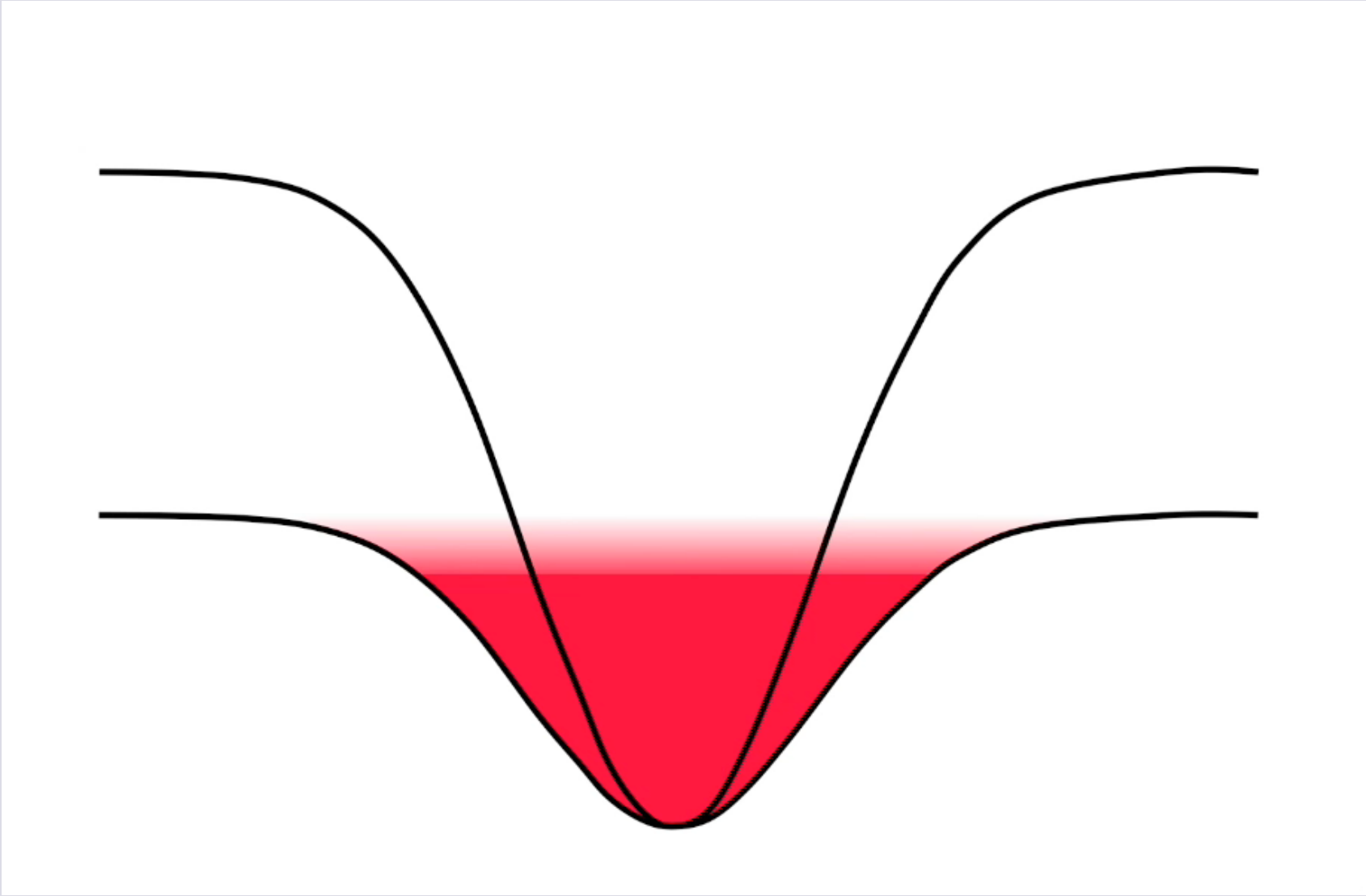
Seen in RbK|1> + K|2> mixture: PRL **100**, 143201 (2008)

Temperature measurement



PRL **95**, 260405

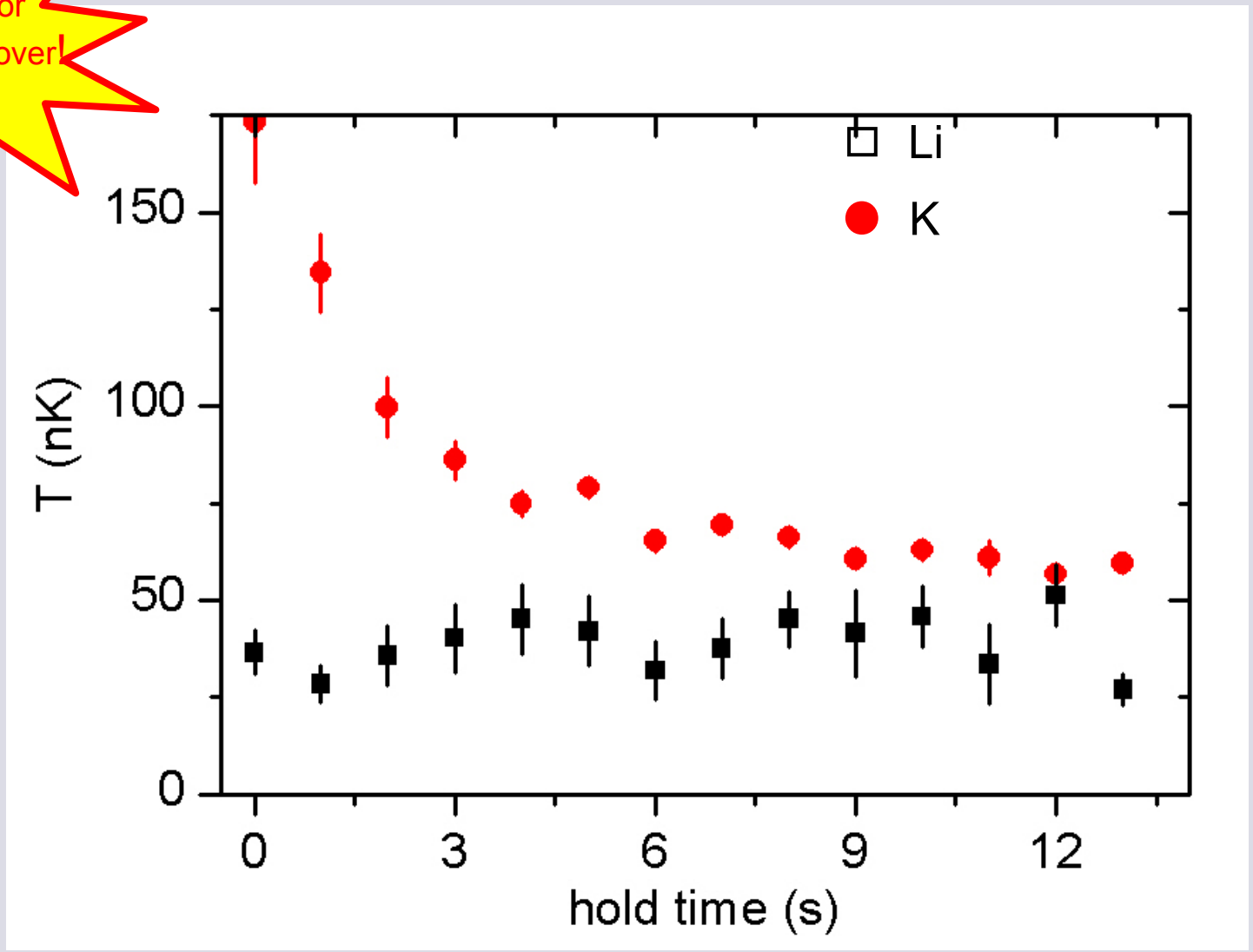
A thermometer!



movie

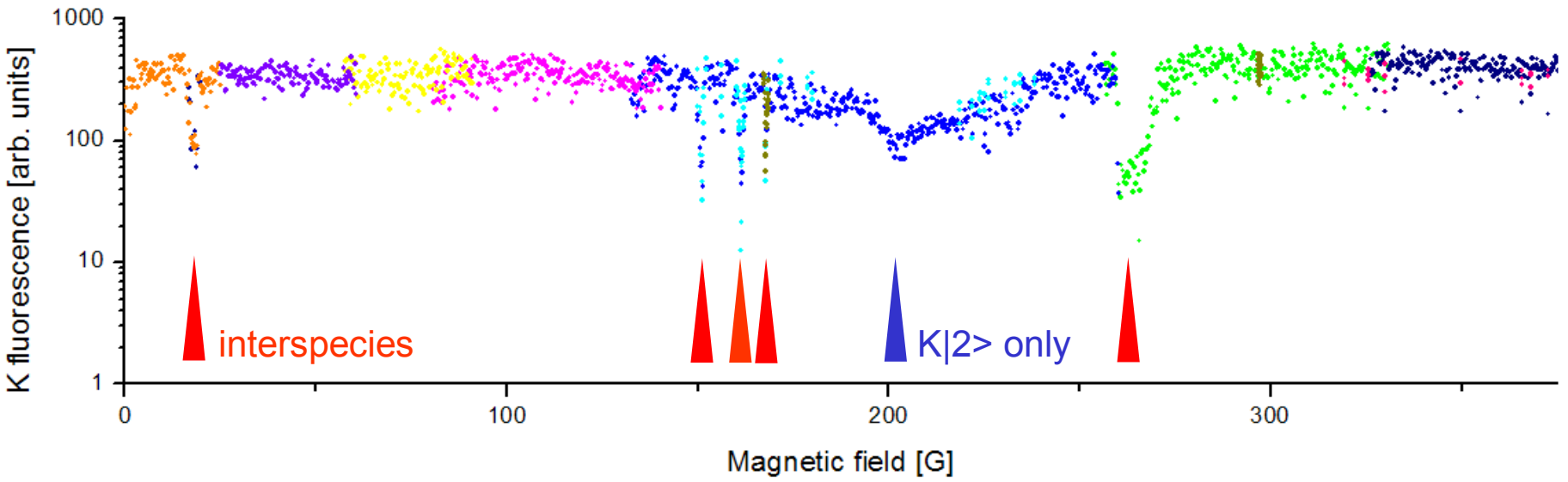
Thermalisation of K by Li

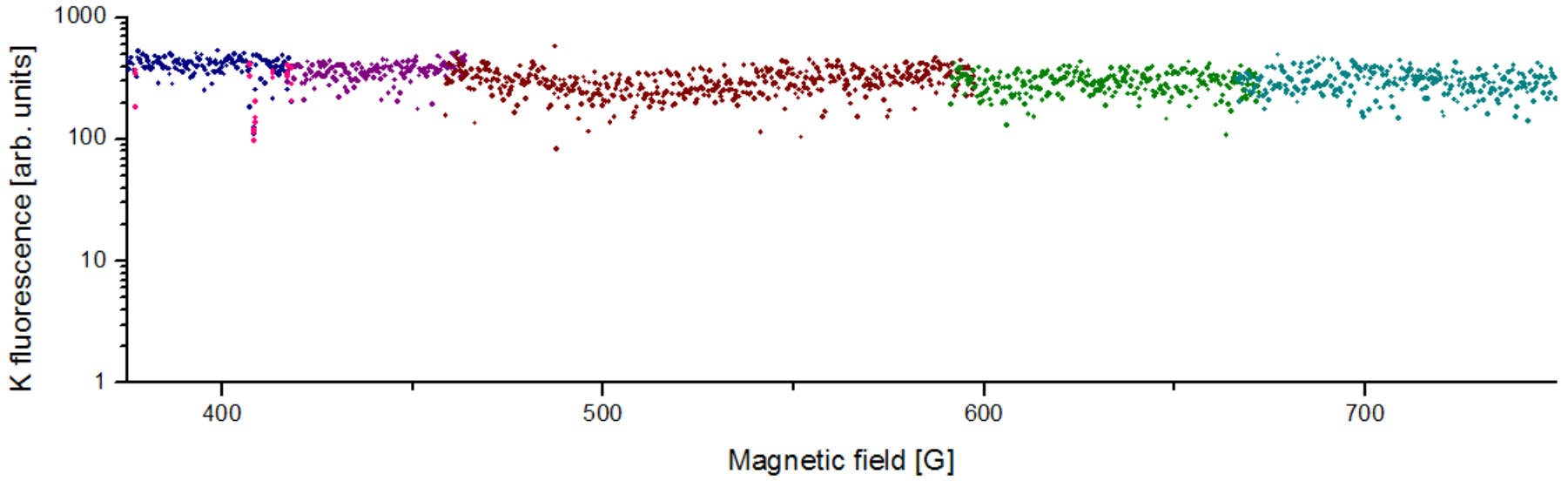
^{40}K good probe for Li BEC-BCS crossover!



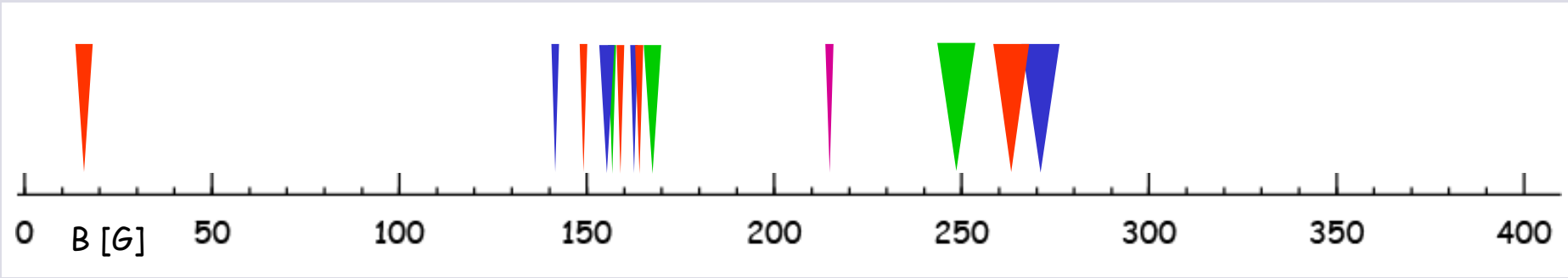

Interspecies
Feshbach resonances

Li|1> K|2> scan


1000
100
10
1
K fluorescence [arb. units]
interspecies
K|2> only
0
100
200
300
Magnetic field [G]


1000
100
10
1
K fluorescence [arb. units]
400
500
600
700
Magnetic field [G]

Interspecies Feshbach resonances

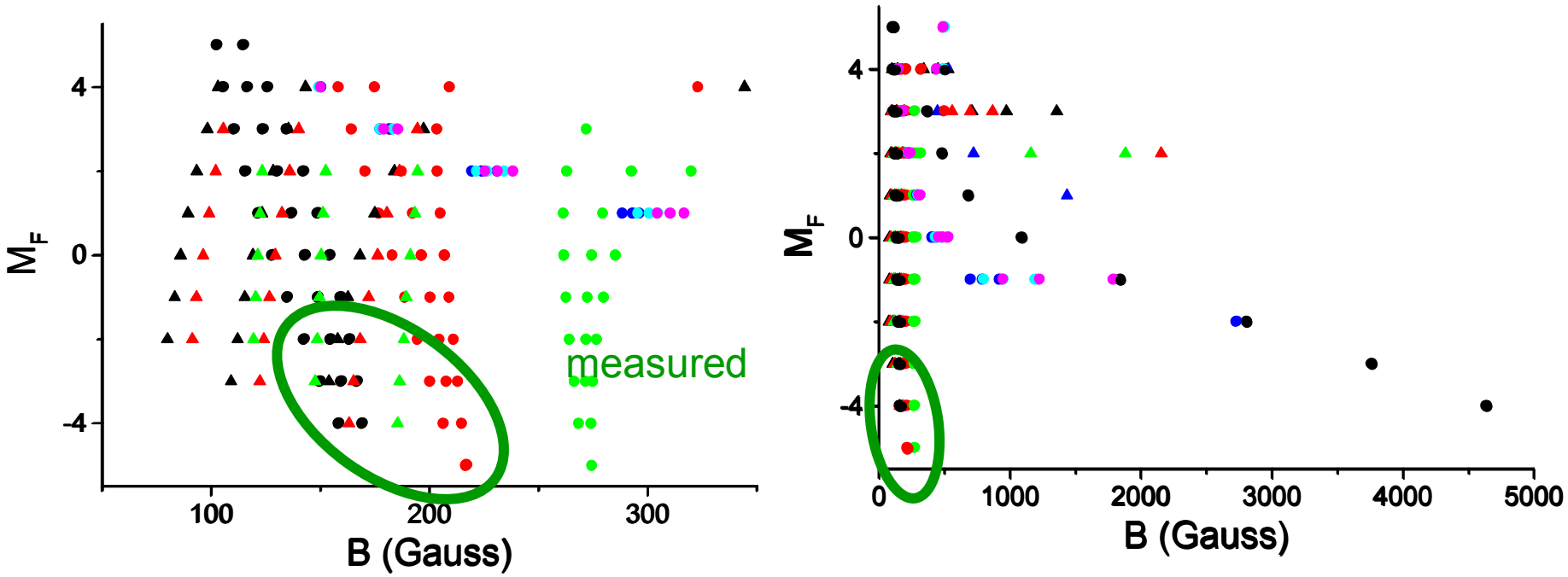


channel	position [G]	width [G]
Li|2> + K|1>	215.6	1.7
Li|1> + K|1>	157.6	1.7
Li|1> + K|1>	168.2	1.2
Li|1> + K|1>	249	11
Li|1> + K|2>	16.1	3.8
Li|1> + K|2>	149.2	1.2
Li|1> + K|2>	159.5	1.7
Li|1> + K|2>	165.9	0.6
Li|1> + K|2>	263	11
Li|1> + K|3>	141.7	1.4
Li|1> + K|3>	154.9	2.0
Li|1> + K|3>	162.7	1.7
Li|1> + K|3>	271	14

- „asymptotic bound state“ model by S. Kokkelmans, T. Tiecke and J. Walraven
- coupled channels calculation by P. Julienne, E. Tiesinga
- coupled channels calculation by E. Tiemann

Predicted s-wave resonances

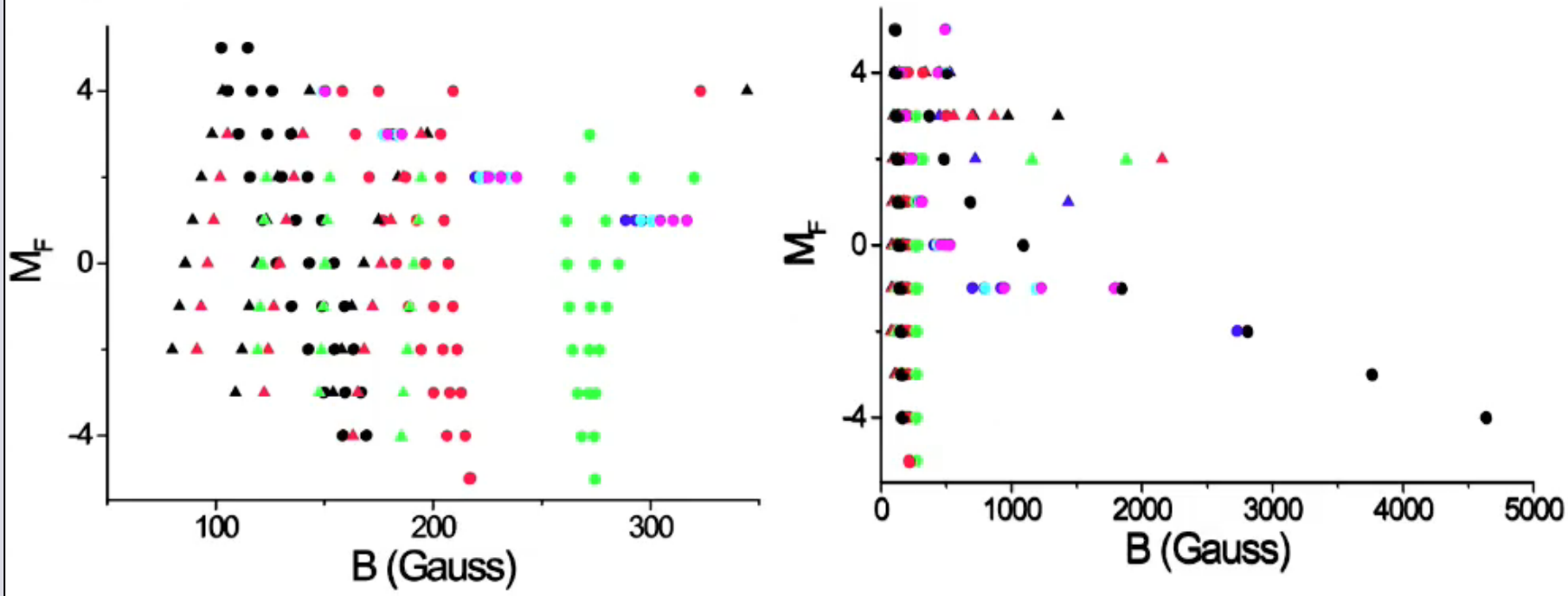
All-wave Feshbach resonances for ^{6}Li in lowest HF state:



Results from simple „asymptotic bound state“ model
by S. Kokkelmans, T. Tiecke and J. Walraven

Predicted s-wave resonances

All predicted *s*-wave Feshbach resonances:



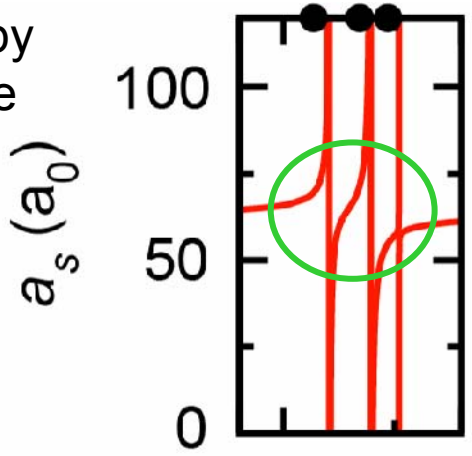
Results from simple „asymptotic bound state“ model
by S. Kokkelmans, T. Tiecke and J. Walraven

movie

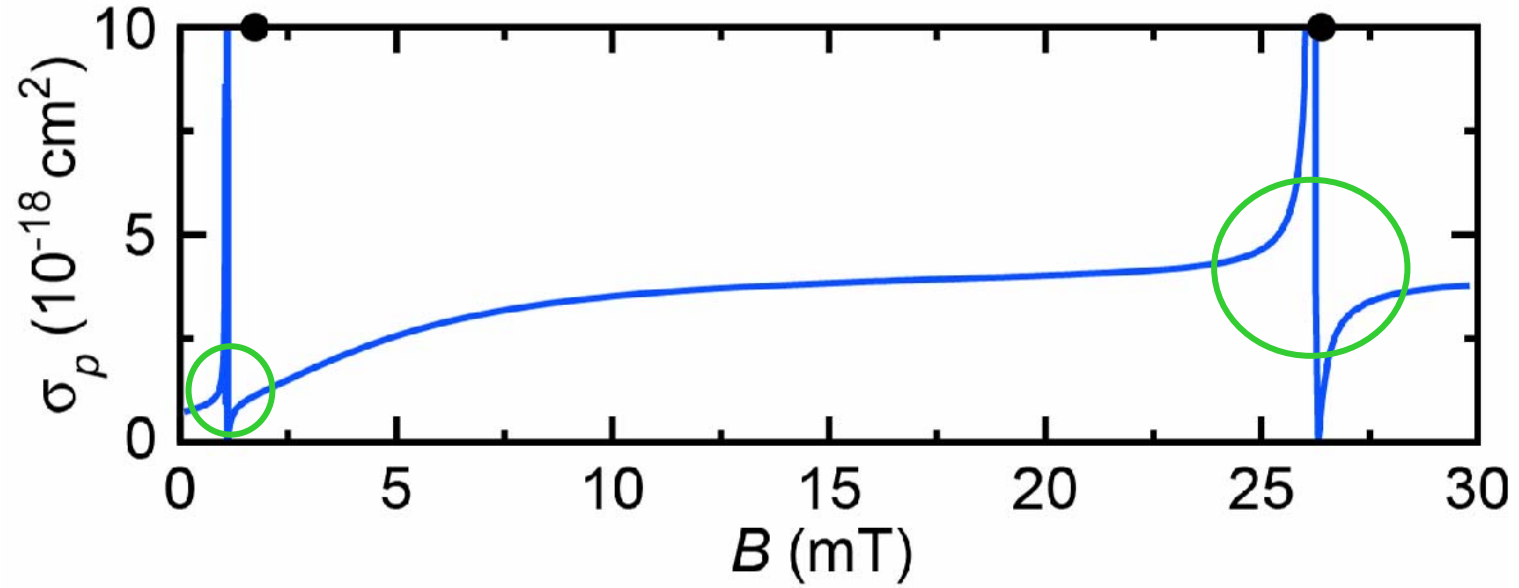
Li|1> K|2> scattering length

Coupled channels calculation by
Eite Tiesinga and Paul Julienne

interaction tuning !

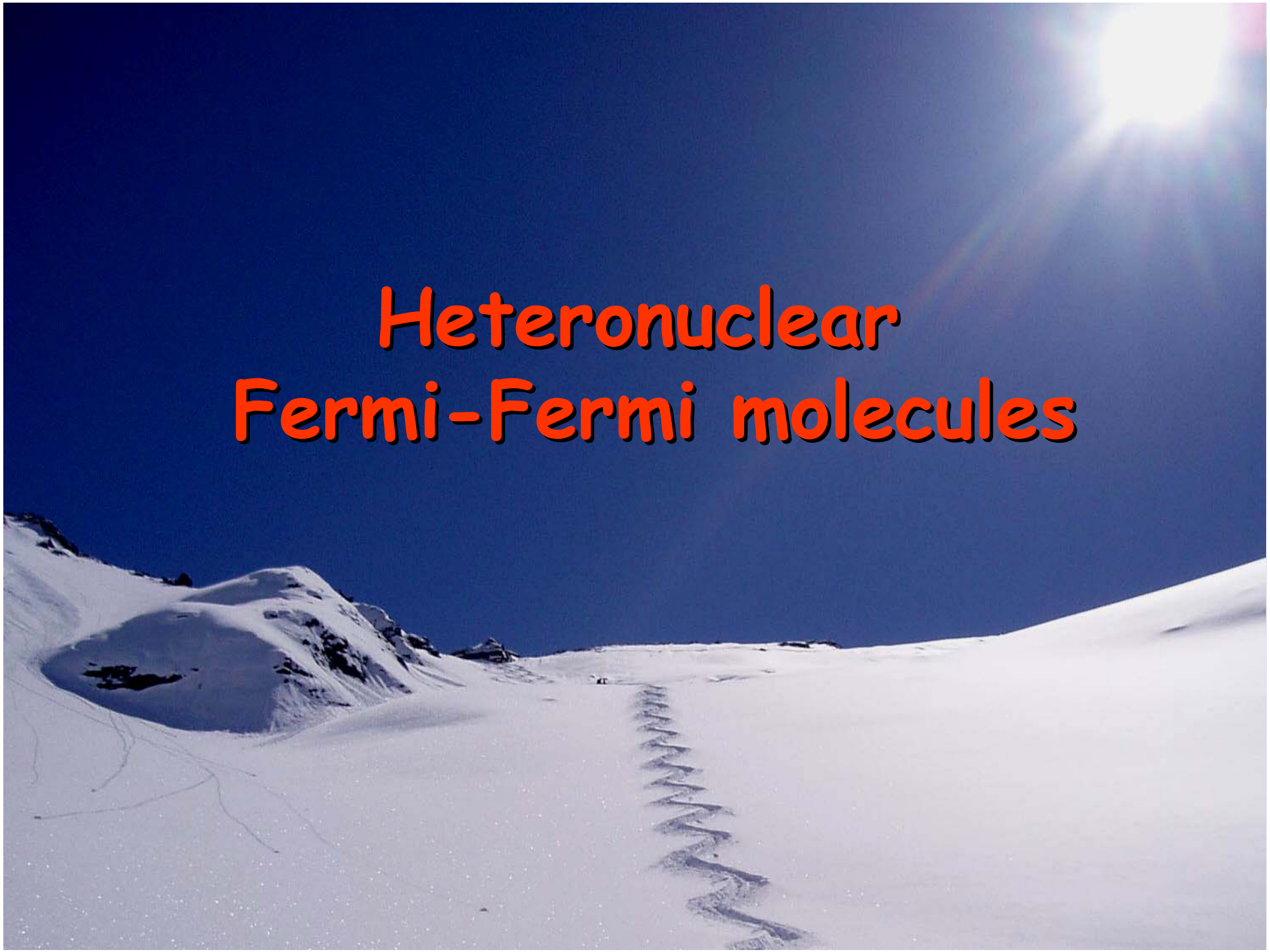


heteronuclear molecules!
Kai Dieckmanns group

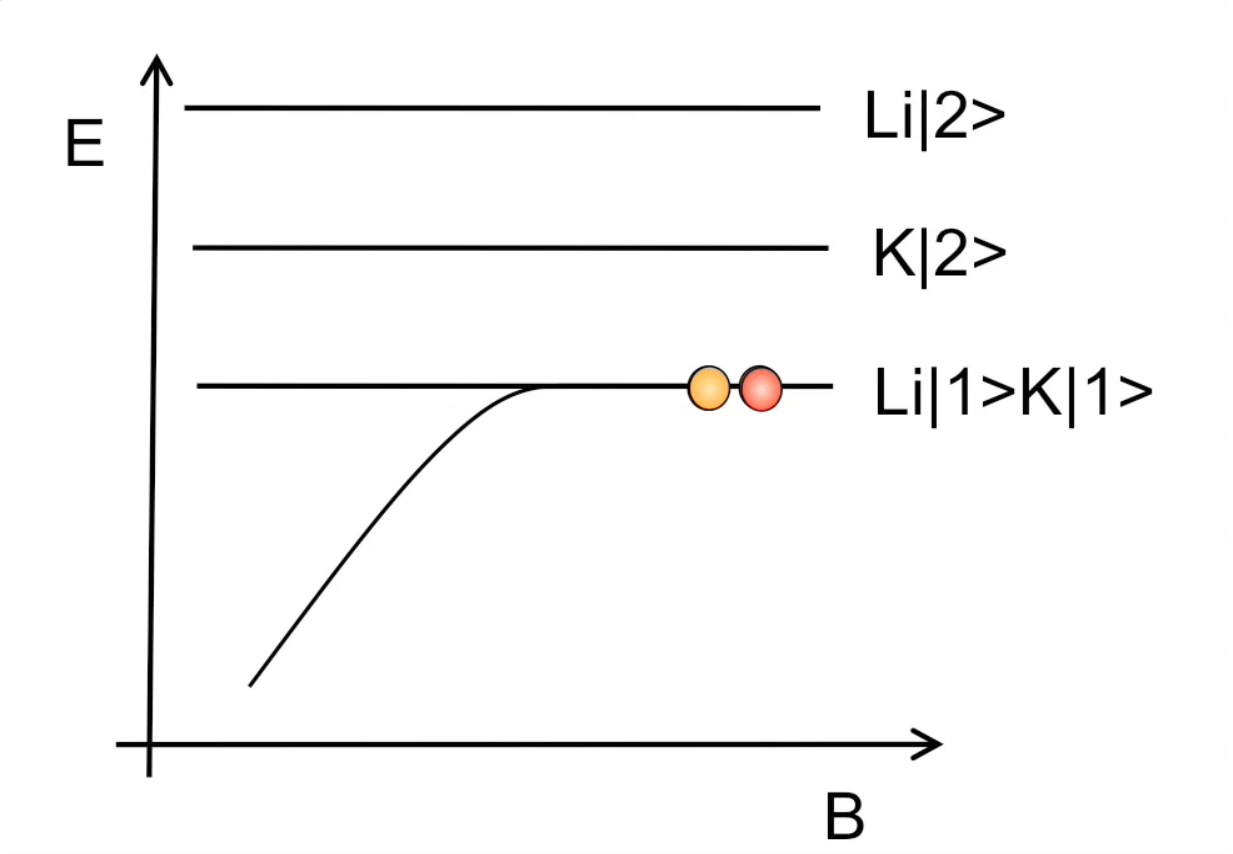


singlet scattering length a_s = 52.1 a_0

triplet scattering length a_t = 63.5 a_0


Heteronuclear
Fermi-Fermi molecules

LiK Molecules



movie

Produce molecules by adiabatic magnetic field ramp (see K. Dieckmann)

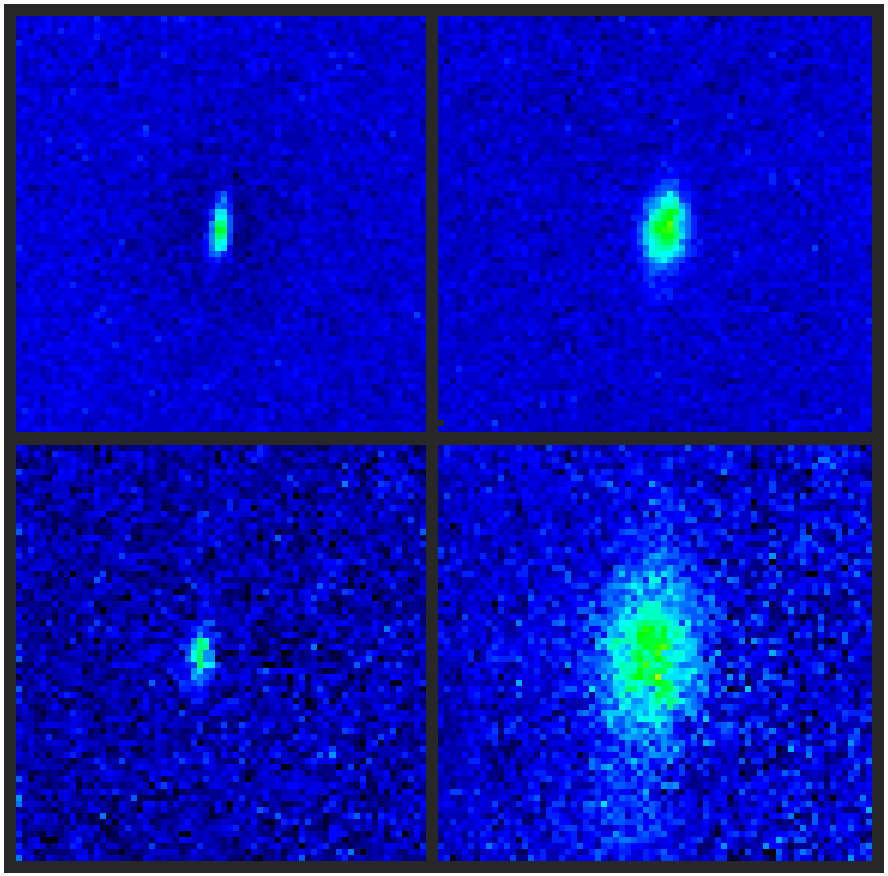
Transfer remaining free atoms to different m_F state by π-pulse

Image molecules and free atoms using m_F state selective absorption imaging

LiK Molecules

Potassium images

Lithium images



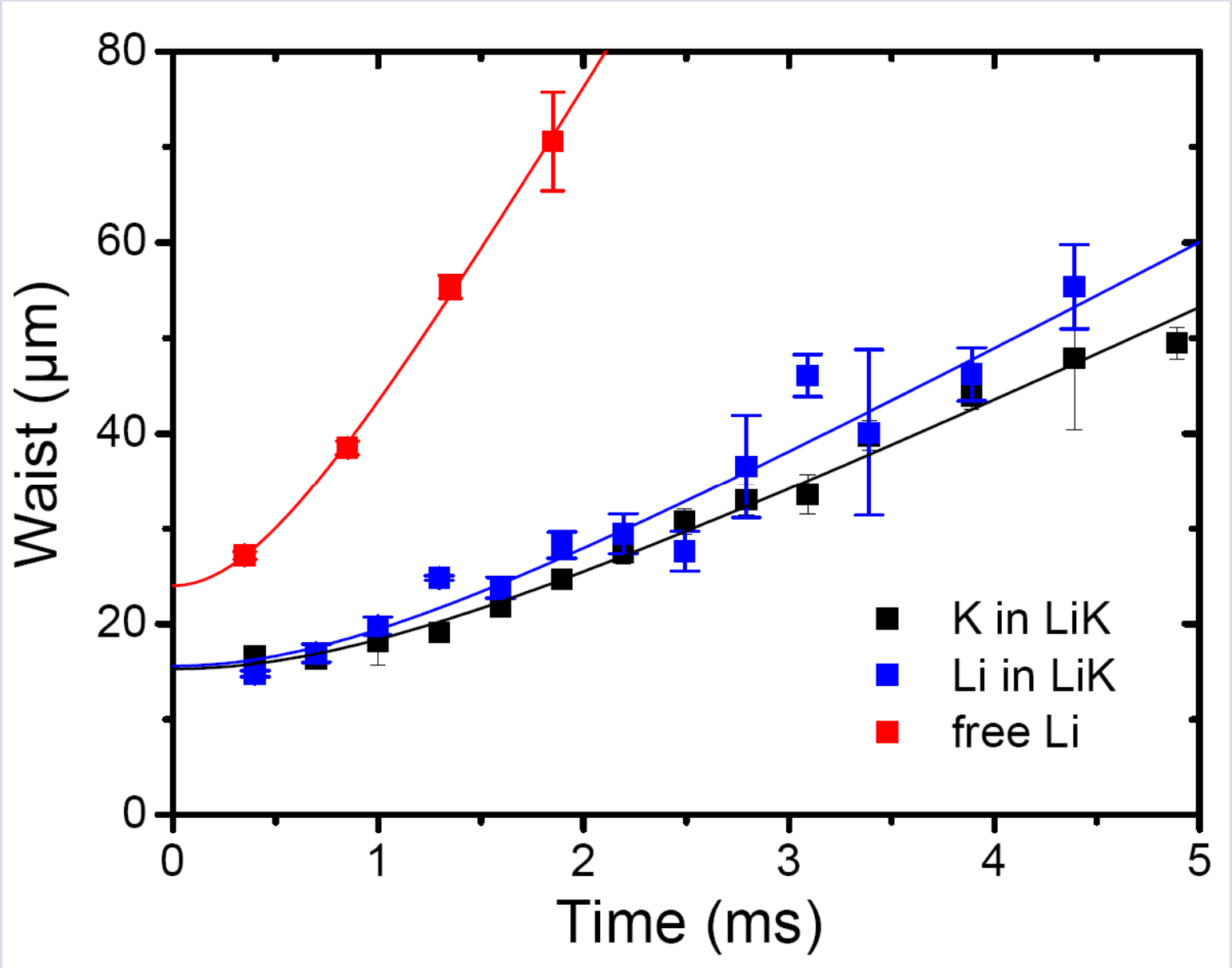
LiK molecules
N~1500

free atoms

$N_{Li} = 5\ 10^4$
$N_K = 5\ 10^3$

168 G Li|1>K|1>
Feshbach resonance

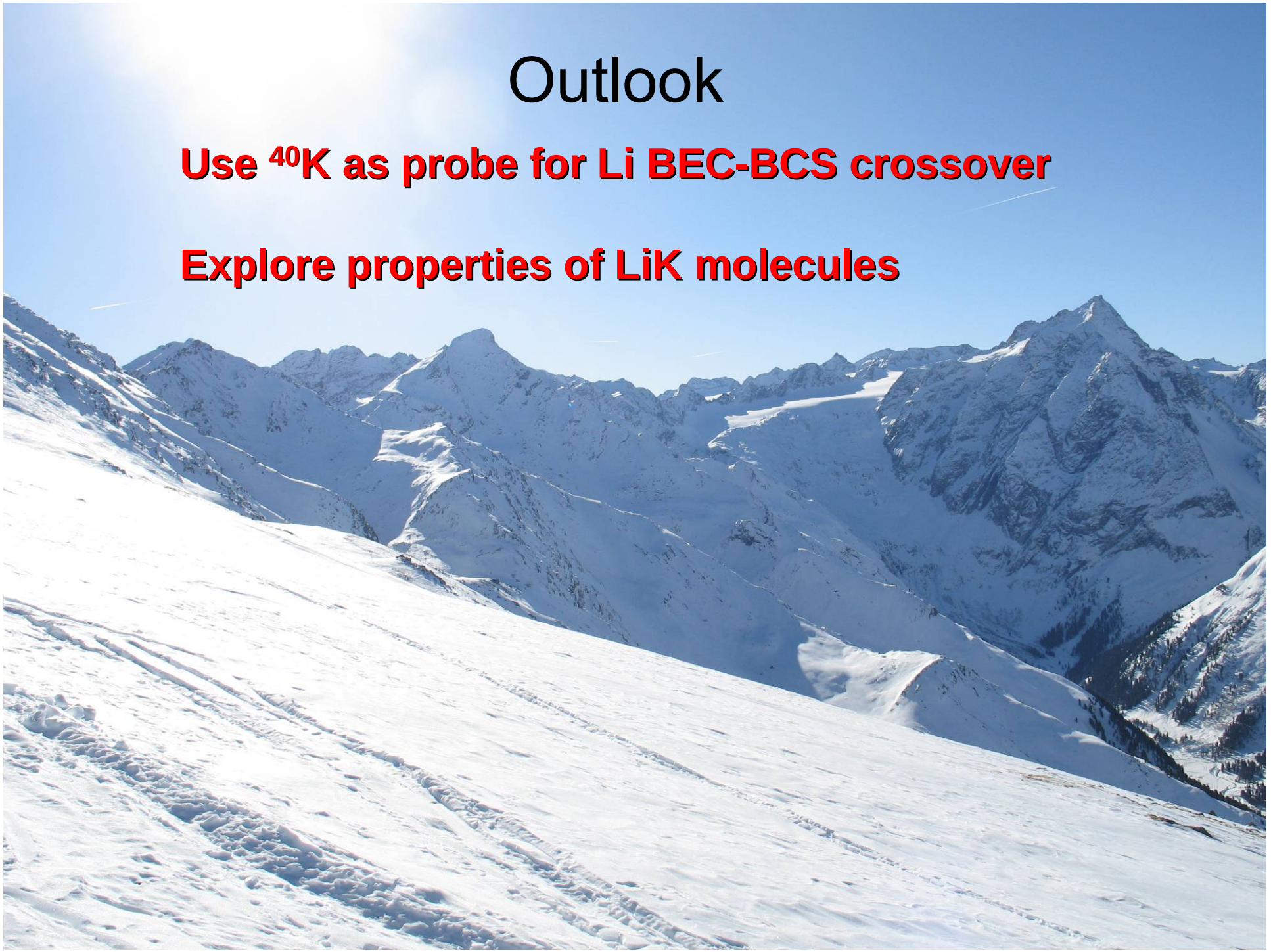
LiK Molecules



Outlook

Use ^{40}K as probe for Li BEC-BCS crossover

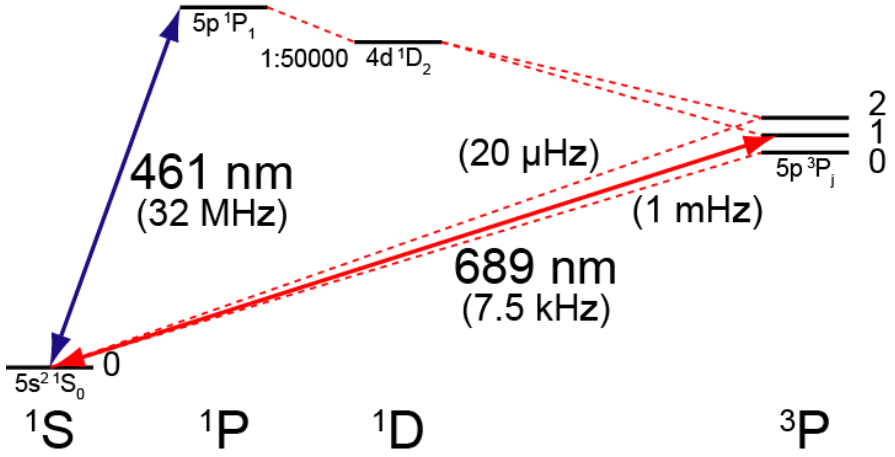
Explore properties of LiK molecules




Towards a BEC of Strontium

Towards a BEC of Sr

Strontium



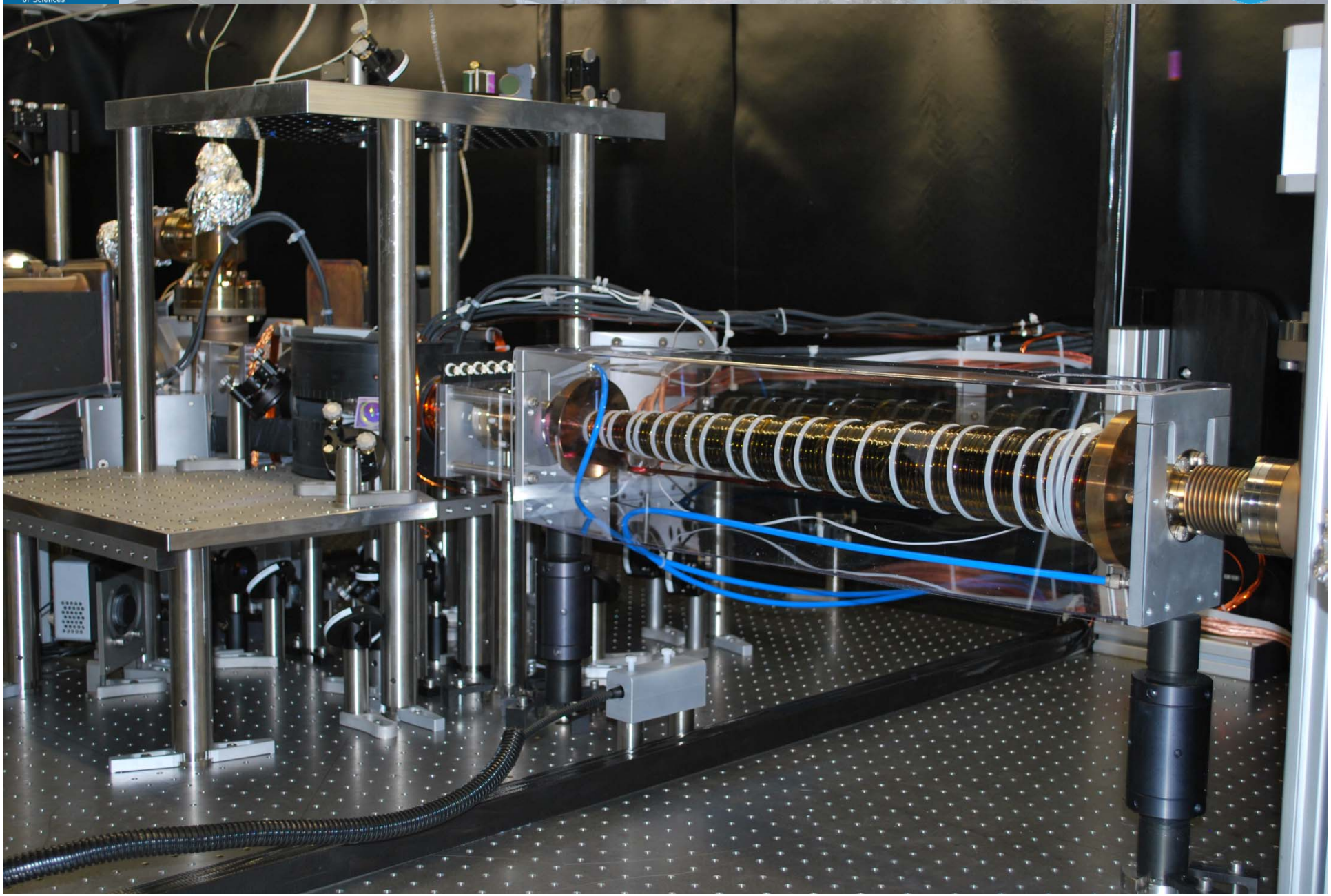
- metastable state
- intercombination line
- weak magnetic moment

Possibilities:

- Optical Feshbach resonances
- Subwavelength optical lattices (proposals by Zoller group)
- State specific optical potential
- Storage of quantum information in nuclear spin

→ possibilities for quantum simulation and computation

Towards a BEC of Sr



The ultracold group