ARC COE FOR QUANTUM-ATOM OPTICS

SWINBURNE UNIVERSITY OF TECHNOLOGY

ACQAO Molecular BEC

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Melbourne, Australia

Kioloa, December 2004

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Aims

- Demonstrate a coherent ensemble of ultracold molecules.
- Investigate novel quantum properties of a molecular BEC (MBEC), especially regarding bose/fermi statistics.

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MBEC development

- $^{85}Rb_2$ at JILA (*Wieman*) - *bosenova*
- $^{133}Cs_2$ at Innsbruck (*Grimm*)
- $^{23}Na_2$ at MIT (Ketterle)

bosons → boson
(quantum degenerate molecules)

- $^{6}Li_2$ at Innsbruck (*Grimm*)
- $^{40}K_2$ at JILA (*Jin*)
- $^{6}Li_2$ at MIT (*Ketterle*)
- $^{6}Li_2$ at ENS (*Salomon*)
- $^{6}Li_2$ at Rice (*Hulet*)

fermions → boson
(BEC of molecules)

? $^{87}Rb_2$ at Texas (*Heinzen*)
$^{6}Li_2$ at Duke (*Thomas*)

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Background

- $^6Li_2$ molecules formed by 3-body recombination in tightly confining optical trap
- Fermion → composite boson gives long MBEC lifetimes (> 10 s)
- New physics with degenerate fermionic systems - important for ACQAO

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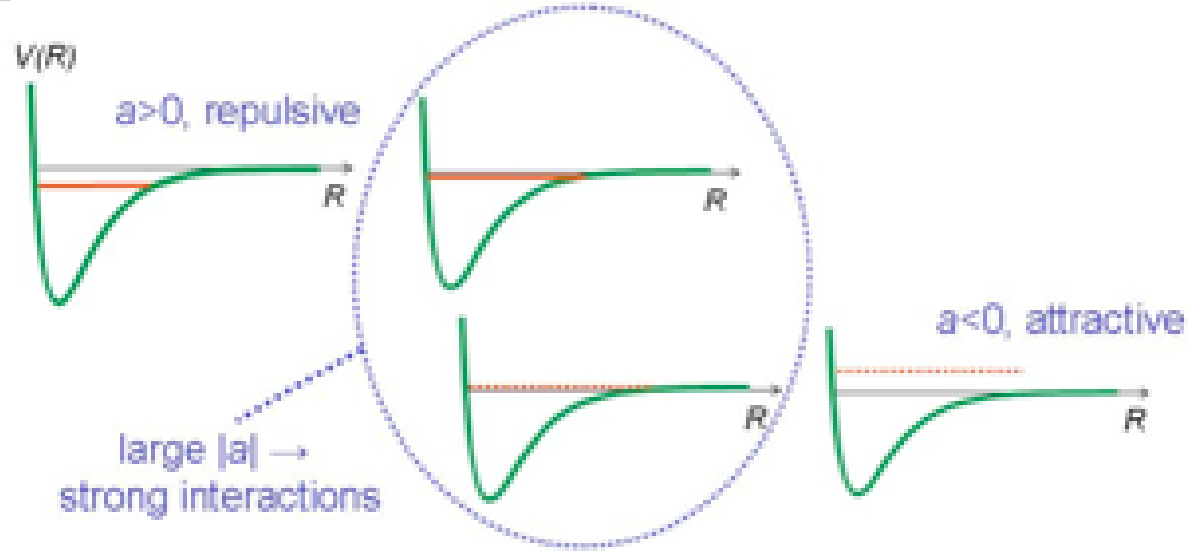
Making molecules

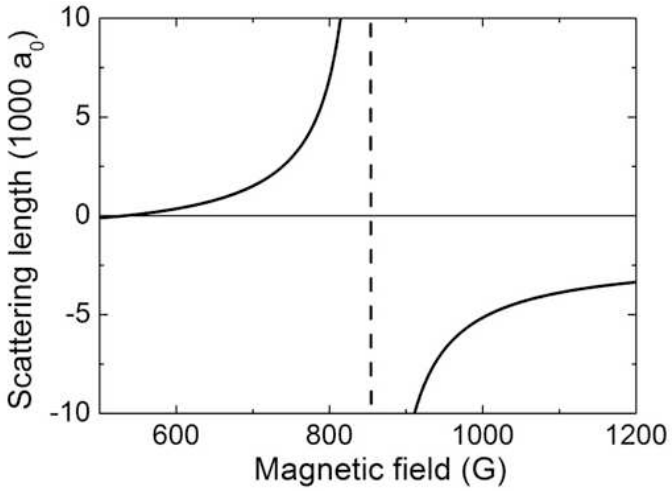
- Feshbach resonance

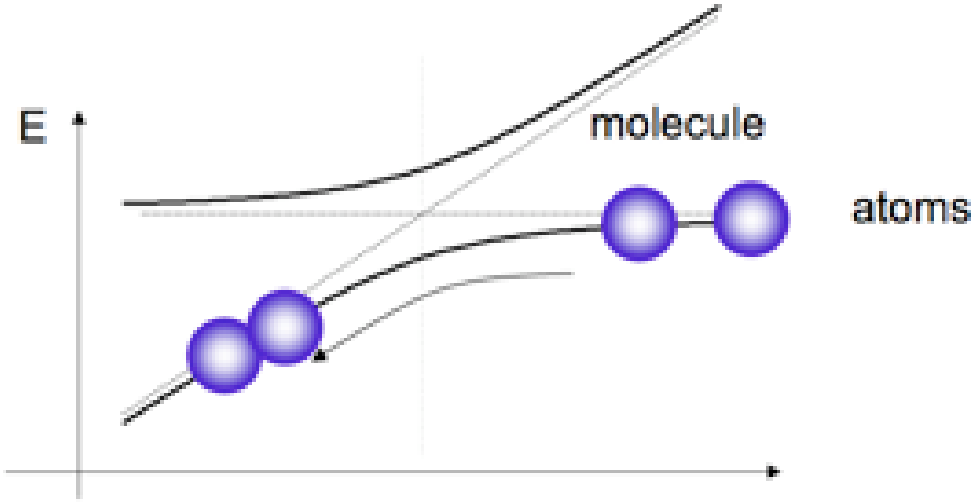
A Feshbach resonance occurs when a bound state for one spin combination has identical energy with the unbound state of another spin combination



Making molecules

- Magnetically tuned Feshbach resonance





^{6}Li spin mixture

$|F, m_F\rangle = |^1/_2, +^1/_2\rangle, |^1/_2, -^1/_2\rangle$

K.M. O'Hara et al.,
Phys Rev A B, 041401 (2002)

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General approach

- Load ^{6}Li atoms into a MOT from a slowed atomic beam
- Transfer atoms to a far-off-resonant optical dipole trap (FORT, *Yb:YAG, 20 W*)
- Evaporatively cool by reducing FORT depth
- Evaporation is performed at a magnetic field strength that enhances 3-body recombination (molecules) - *Feshbach resonance at ~830 G*
- Continue evaporation to remove atoms, and condense remaining molecules

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Current/Recent Work

- Lasers set up & locked for MOT/slowing
- UHV system being assembled *(glass cell early 2005)*
- Zeeman slower ready to wind
- Feshbach coils ready to wind

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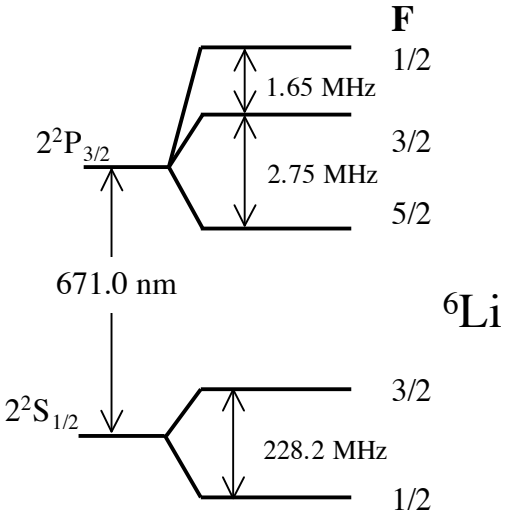
671 nm sources



- Laser diodes
  - 15/30 mW @ 671 nm (Toptica)
  - 80 mW @ 658 nm (Hitachi)
    [40 mW @ 671 nm (65° C)]
- Dye laser
  - 200 mW @ 671 nm
- Tapered amplifier
  (hopefully!)
  - 400 mW (?) @ 671 nm

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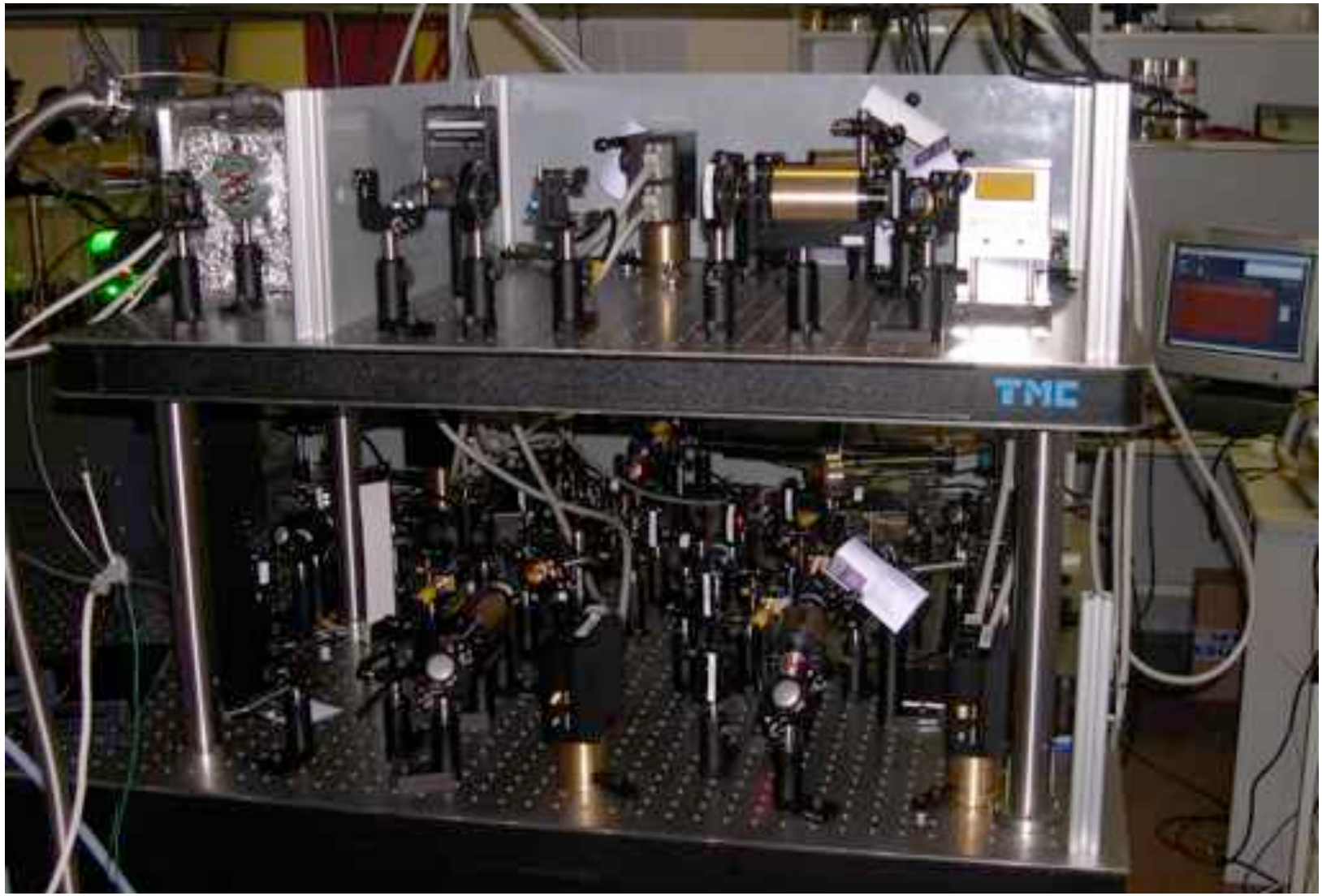

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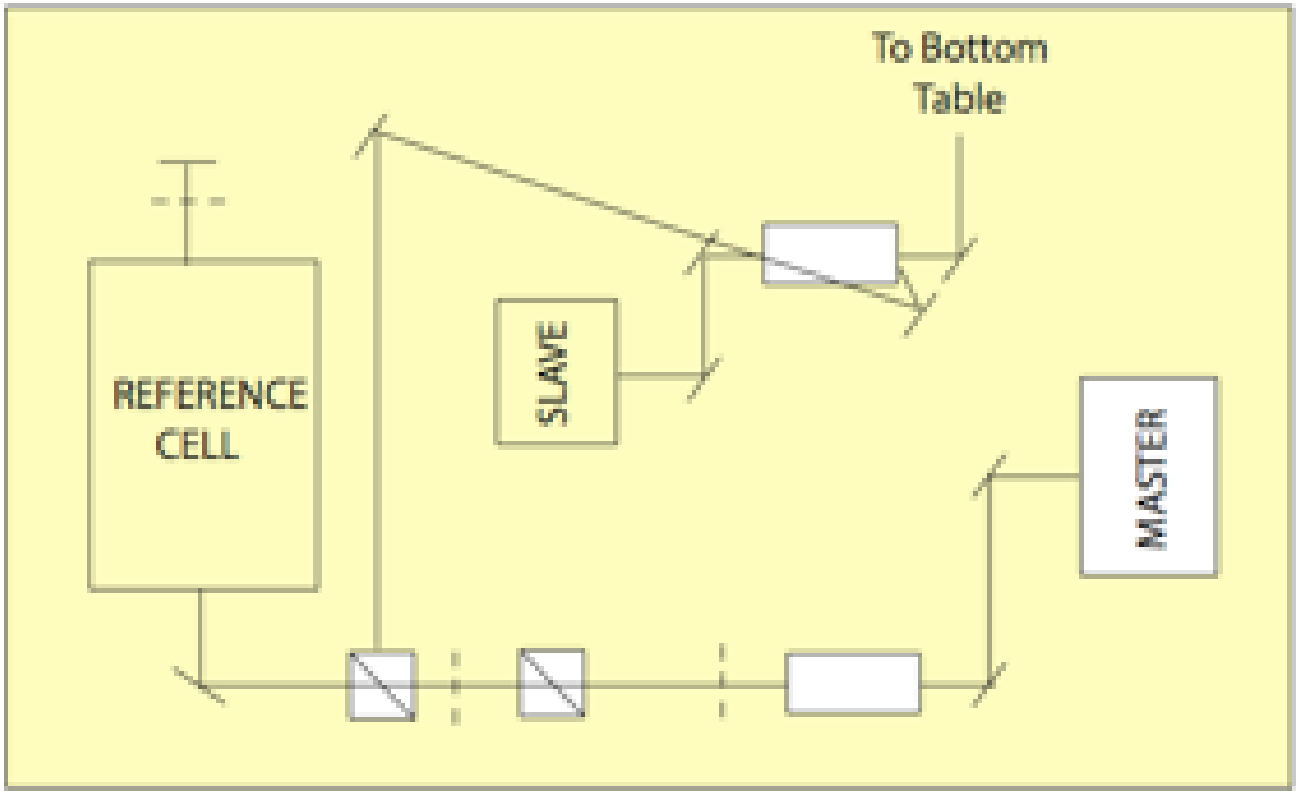
Experimental layout



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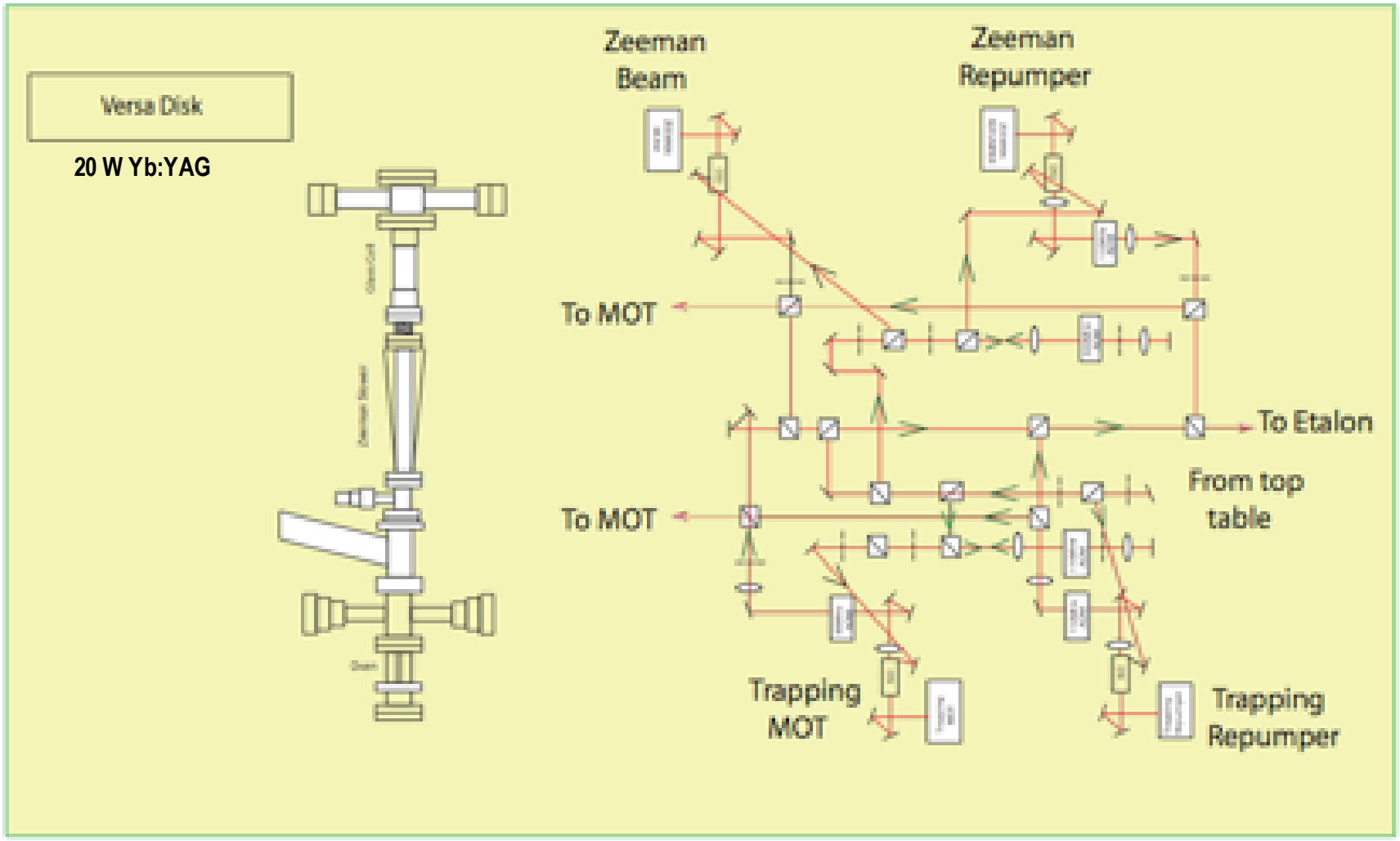
Experimental layout



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Immediate future

- Slowed lithium beam - *Jan 2005*
- ^{6}Li MOT - *March 2005*
- Atoms loaded in FORT - *June 2005*
- Feshbach creation of molecules - *Sep 2005*
- Evaporative cooling - *Nov 2005*
- Molecular BEC - *early 2006*

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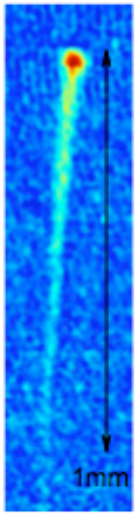
Using a MBEC

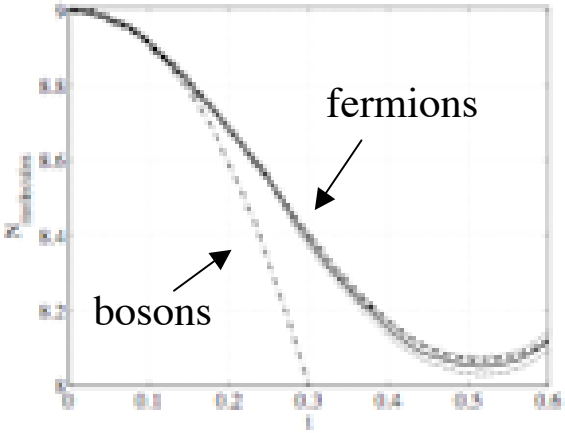
- Collective excitations
- BEC-BCS crossover
- Superfluidity
- "Molecule laser"
- Atom-molecule coherent behaviour ("superchemistry")
- Dissociation of MBEC
  - Pauli blocking
  - Atom entanglement



$^6Li_2$ (Innsbruck)

Dissociated MBEC

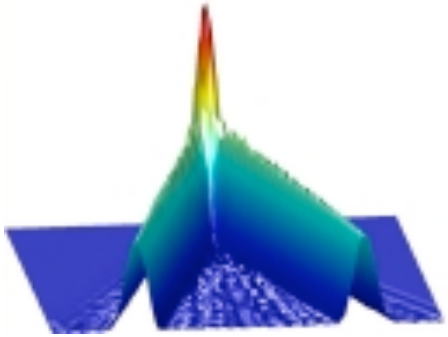
- Pauli blocking of dissociation
- Requires limited number of available atomic states (fermions)
  - Load MBEC into an optical lattice
  - Dissociate using ramp across Feshbach resonance



Single mode trap
Corney & Drummond, quant-ph-0404052

Dissociated MBEC

- MBEC created from bosonic atoms Drummond et. al.
  - Photodissociation of MBEC
  - Quantum-entangled atom beams



Kheruntsyan & Drummond Phys. Rev. A, 66, 031602

- Can we generate similar correlated beams from fermionic atoms?
  - Use photodissociation/RF transition
  - Absence of bosonic enhancement/gain

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Detection

- Measurement of entanglement requires sensitive (single-atom) detection
- Proposed schemes (ionisation, strongly-coupled cavity) require larger experimental space
  - Transport MBEC into a “science chamber”?

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Conclusion

- Presently at the peak of “build-up” phase
- Rapid progress expected in 2005
- Additional research student
- Will benefit from recent theoretical developments at UQ node