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COLLEGE ON

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Strongly interacting mixtures of heavy and light fermions

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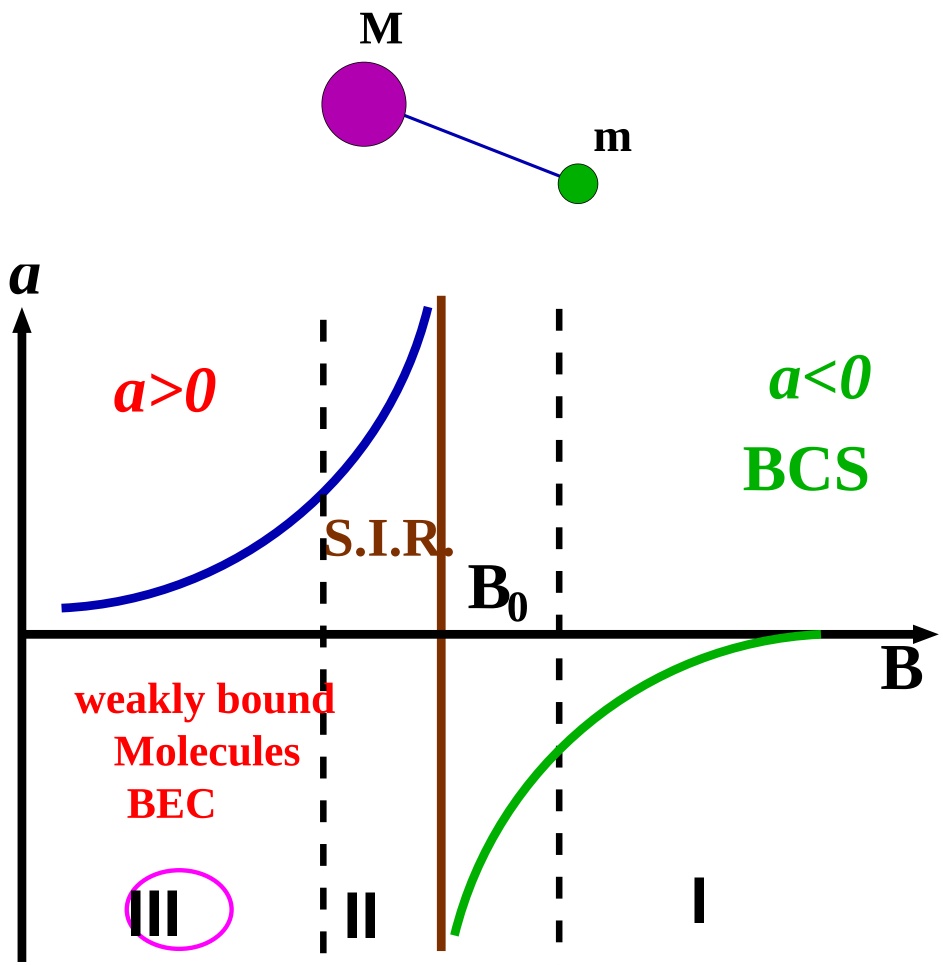
Outline

- Introduction.
- Molecular regime. Interaction between molecules
- Collisional relaxation
- Pauli principle and effect of the mass ratio
- Bose-Fermi molecules
- Ideas for future

Collaborations: D.S. Petrov, C. Salomon (ENS)

Mixtures of Fermi gases

Molecules of different fermionic atoms $^6\mathrm{Li}^{40}\mathrm{K}$ $^6\mathrm{Li}^{87}\mathrm{Sr}$

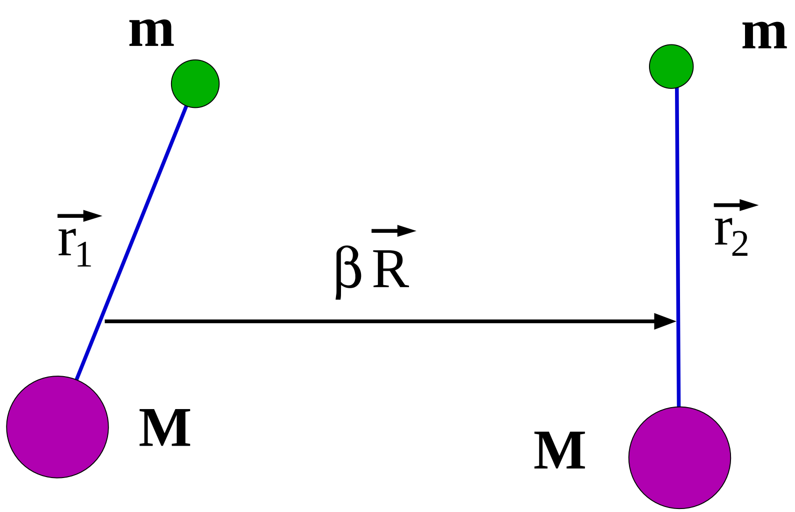


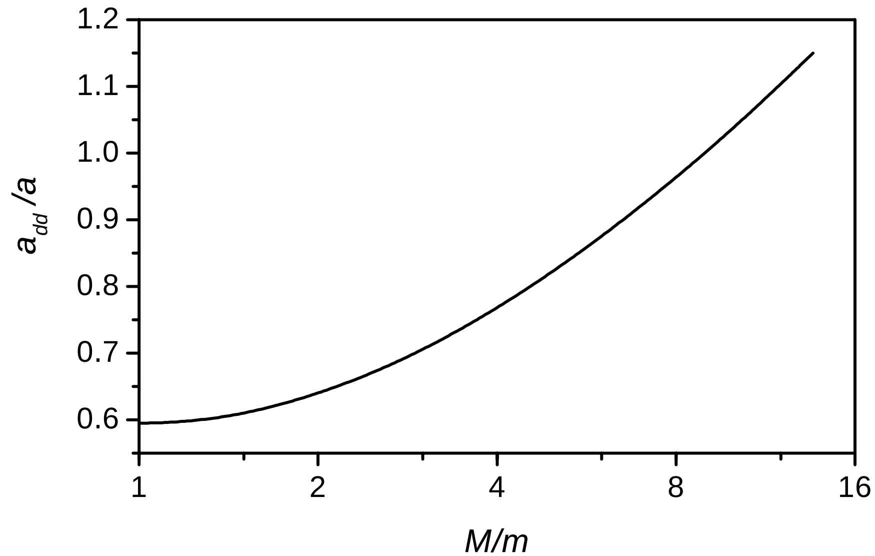
What happens with collisional stability and molecular BEC?

Is there something else interesting ?

Molecule-molecule interaction

Interaction between the molecules (a_{dd}) Petrov et al 2005





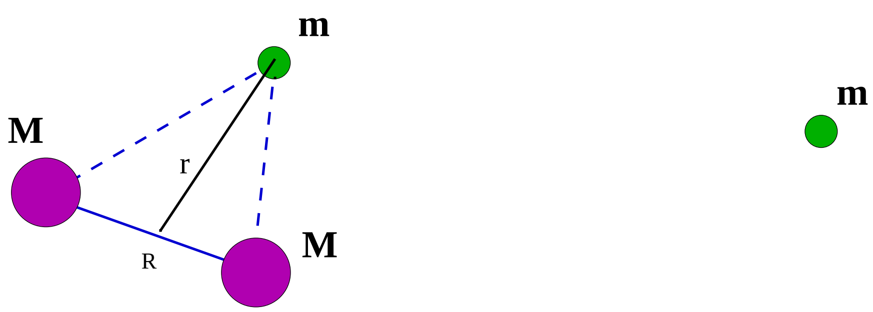
$$\beta = \sqrt{2Mm}/(M+m)$$

Nothing dramatic happens, but why I stop at $M/m = 13.6$?

Collisional relaxation. Effective potential

Exact solution for the dependence on a and M/m

$M \gg m \quad \rightarrow \quad$ Born-Oppenheimer picture



$r \ll a \rightarrow$ One bound state of a light atom with two fixed heavy ones

$$\psi(\vec{r}) \propto \left(\frac{\exp(-\lambda|\vec{r}-\vec{R}/2|/R)}{|\vec{r}-\vec{R}/2|} + \frac{\exp(-\lambda|\vec{r}+\vec{R}/2|/R)}{|\vec{r}+\vec{R}/2|} \right)$$

Bethe-Peierls boundary condition

$|\vec{r} \pm \vec{R}/2| \rightarrow 0 \quad \psi \propto (1 - a/|\vec{r} \pm \vec{R}/2|)$

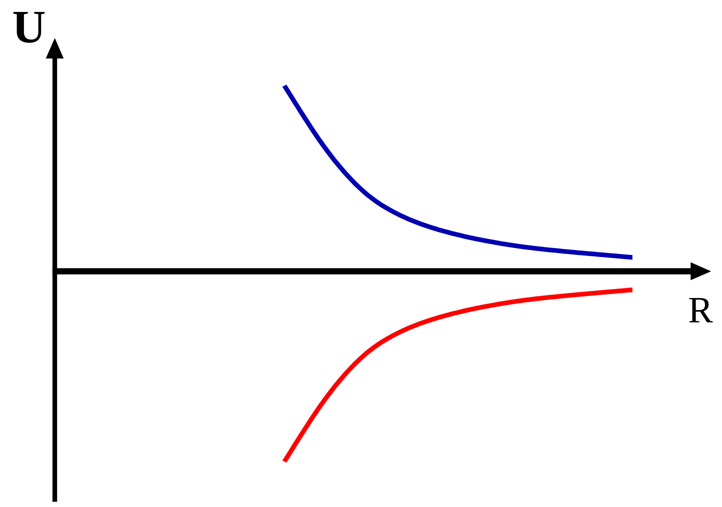
$\lambda \approx 0.567 \quad \varepsilon(R) = U_{eff}(R) = -\hbar^2\lambda^2/2mR^2$

Mediated attractive potential $\quad U_{eff} \approx -0.16\hbar^2/mR^2$

Collisional relaxation. Role of the Pauli principle

Pauli principle $\Rightarrow$ Centrifugal potential $U_c = 2\hbar^2/MR^2$

Mediated attraction competes with Pauli principle

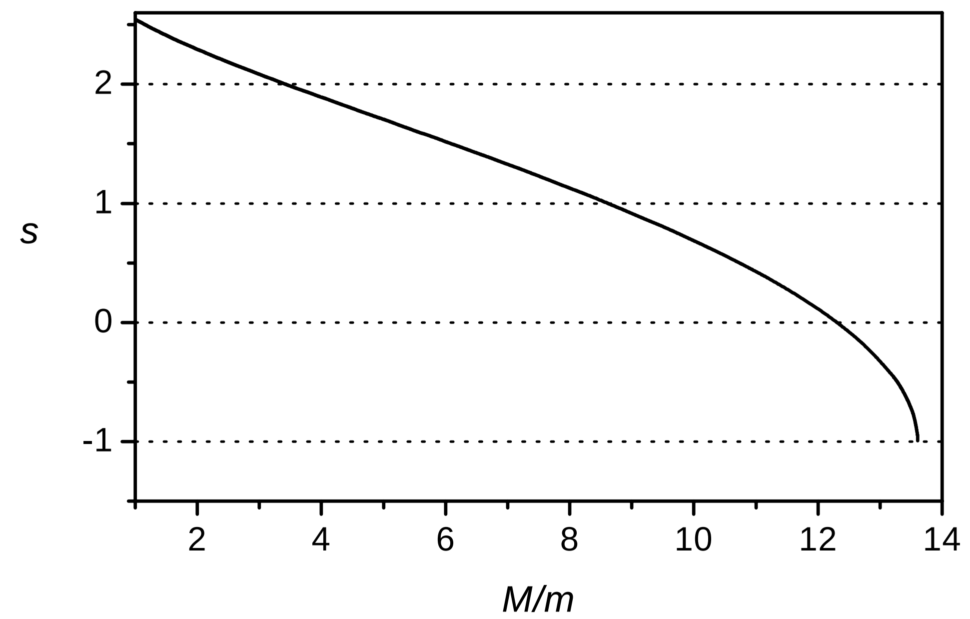


$$\alpha_{rel} \sim a^{-s}$$

$$\frac{M}{m} < 12.33 \;\Rightarrow\; U_{eff} + U_c > 0; \;\; s > 0$$

α_{rel} decreases with increasing a, but
s decreases with increasing M/m

Relaxation rate



$$\alpha_{rel} \sim \frac{1}{a^s}$$

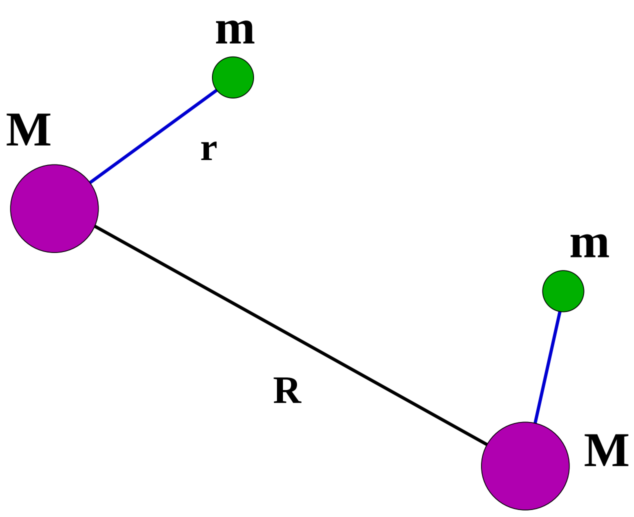
$M/m > 12.33 \rightarrow \ U_{eff} + U_c < 0, \ s < 0 \rightarrow \alpha_{rel}$ increases with a

$M/m = 13.6 \ \rightarrow \ s = -1 \ \rightarrow \ \alpha_{rel} \sim a$

$M/m > 13.6 \ \rightarrow$ fall into center short-range physics

Long-range repulsion between the molecules

Born-Oppenheimer picture



$R > a \Rightarrow$ 2 bound states of a light atom with two fixed heavy ones

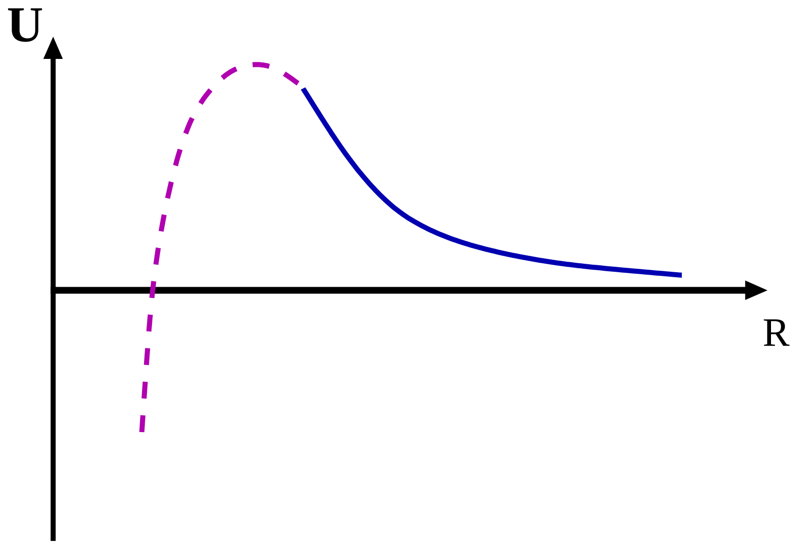
Suppression of relaxation ?

There is a suppression of relaxation for a large M/m

$$R \gg a$$

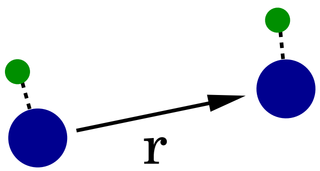
$$U_{eff}(R) \approx \left(\frac{\hbar^2}{2maR}\right) \exp(-2R/a)$$

$$P \sim \exp(-0.6\sqrt{M/m})$$



Fermionic molecules in Bose-Fermi mixtures

Heavy bosons and light fermions $\rightarrow$ long range repulsion



$$U(r) = \frac{\hbar^2}{2mar} \exp\left(-\frac{2r}{a}\right)$$

p-wave scattering $\rightarrow$ both elastic scattering and relaxation are suppressed

$$\alpha_{in} \sim (ka)^2 \frac{\hbar R_e}{M} P$$

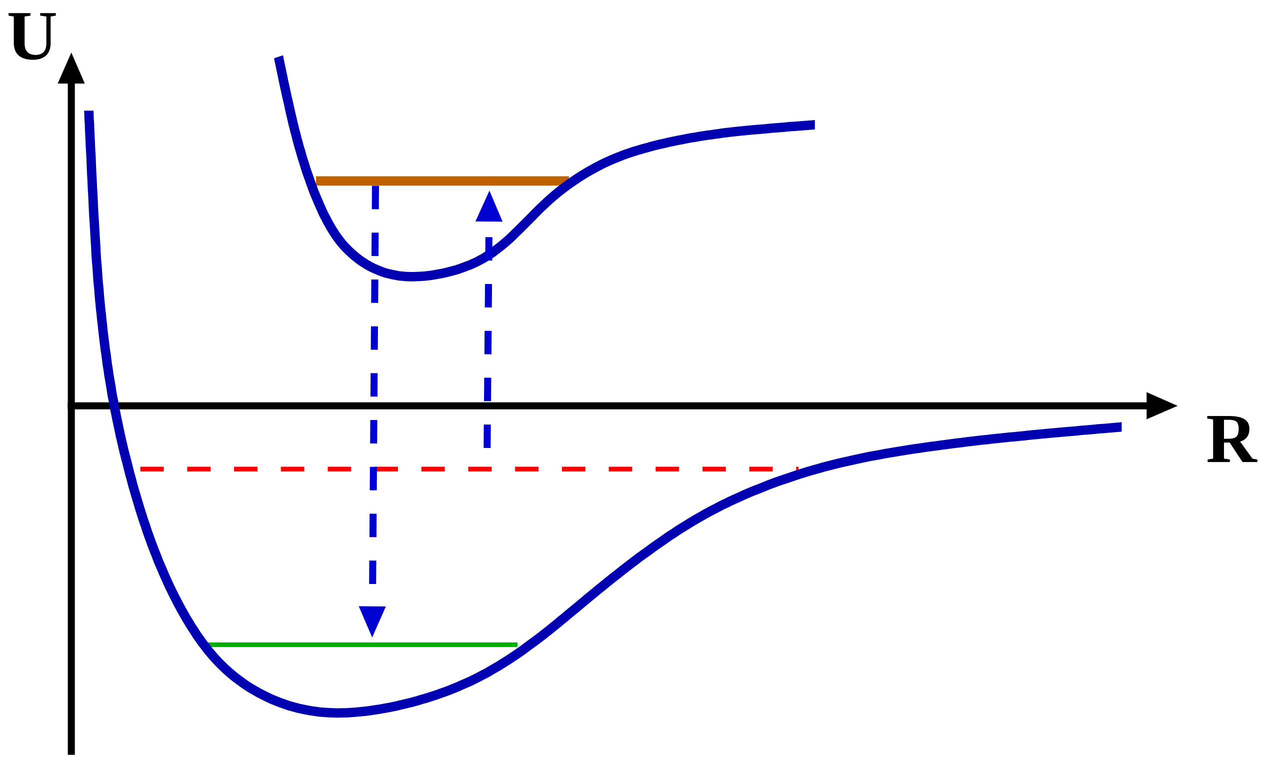
large life time even at high densities

$$\alpha_i \ll \alpha_{el} \rightarrow ?$$

Dipolar Fermi gas!

Ideas for future

Idea from Yalle studies of molecules of bosonic atoms

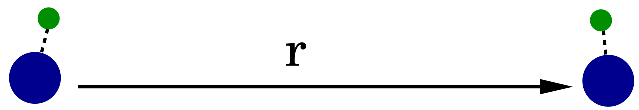


Replace bosons by fermions

Large n Large τ

$\longrightarrow$ Dipolar gas

It is a gas?



$$U(r) = \frac{\hbar^2}{2ma^2(r/a)} \exp\left(-\frac{2r}{a}\right)$$

$$K = -\frac{\hbar^2}{2Ma^2}\Delta_{(r/a)} = -\frac{m}{M}\frac{\hbar^2}{2ma^2}\Delta_{(r/a)}$$

$$H = \sum_i K(r_i) + \frac{1}{2}\sum_{i\neq j} U(r_{ij}) \quad \Rightarrow \quad \frac{\hbar^2}{2ma^2}\sum_i \tilde{H}\left(\frac{r_i}{a};\frac{M}{m}\right)$$

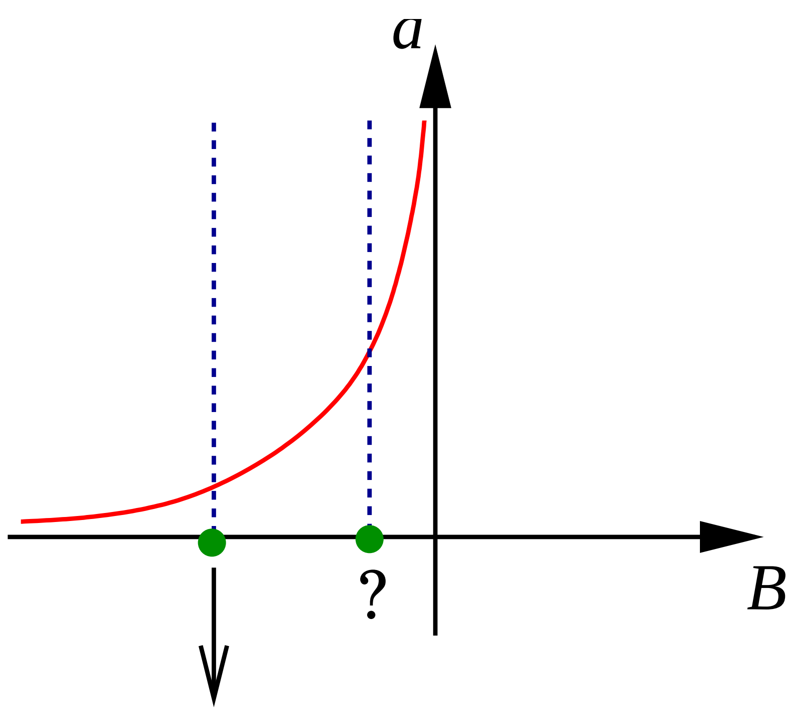
Large $\frac{M}{m}$ $\Rightarrow$ small $\frac{K}{U}$

$\rightarrow$ Wigner crystal for $\frac{M}{m} > \left(\frac{M}{m}\right)_c$

Quantum transitions

$$\frac{M}{m} > \left(\frac{M}{m}\right)_c \quad \text{and } n \text{ fixed}$$

Increase a



depends on $\frac{M}{m}$ but always $na^3 \ll 1$

Crystalline phase

$$\frac{M}{m} \sim 100$$

How to obtain the crystalline phase?

Optical lattice for heavy fermions $\Rightarrow$

Increase of M/m

Formation of a superlattice

Conclusions

- Remarkable physics of weakly bound molecules in cold Fermi gases
- Novel physics of molecular collisional stability in mixtures of Fermi gases
- Possibilities to create new macroscopic quantum systems