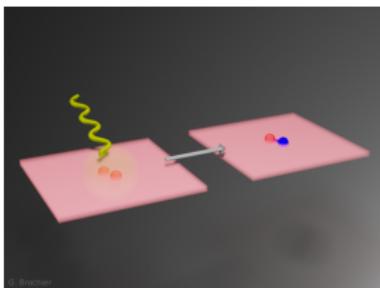


# PRECISION MEASUREMENT OF ATOM-DIMER INTERACTION IN A UNIFORM PLANAR BOSE GAS



D. Broquier

PRR, 5 L012020 (2023)

Chloé Maury

Laboratoire Kastler Brossel

Tuesday, July 4<sup>th</sup> 2023

## challenging experiments

- many degrees of freedom
- moderately degenerate gases of molecules but no BEC yet
- limited understanding of the atom-dimer interactions and dimer-dimer  
→ experimentally: limited to inelastic interactions

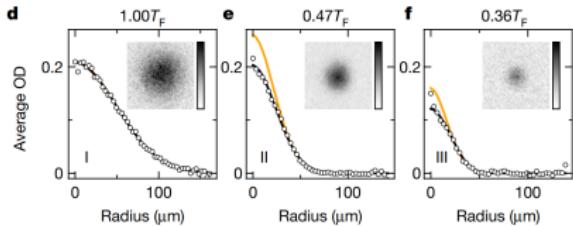
# Cold molecules and interactions

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## motivations

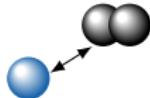
- Bose-Einstein condensation
- cold polar molecules with strong dipole-dipole interactions
- cold chemistry, quantum simulation, sensitive probe...



A. Shindewolf et al. (2022)

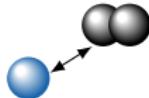
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**few-body physics:** interaction  
between a **dimer** and a free **atom**



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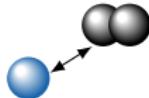
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→ determination of the atom-dimer scattering length  $a_{ad}$

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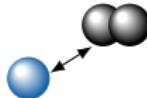
first theoretical predictions for  $|a| \rightarrow +\infty$

**fermions:** determination of  $a_{ad}$  and  $a_{dd}$

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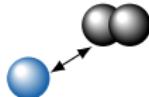
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→ uniform planar ultracold gas of rubidium 87

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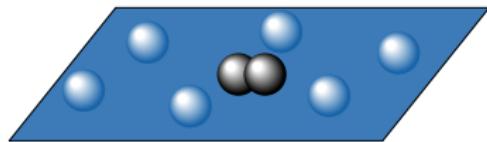
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interaction between a **dimer** and an **atomic bath** in a mean field framework



1. Preparation of a uniform planar bath of ultracold atoms
2. Creation of dimers from a cold atomic bath
3. Precise measurement of the atom-dimer scattering length

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- planar ultracold Bose gas, rubidium  
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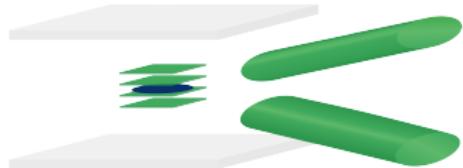
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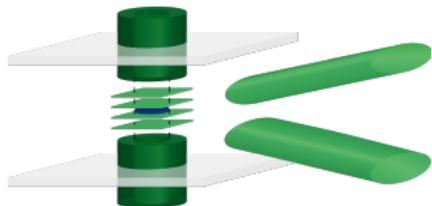
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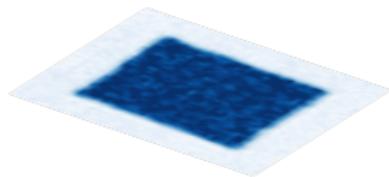
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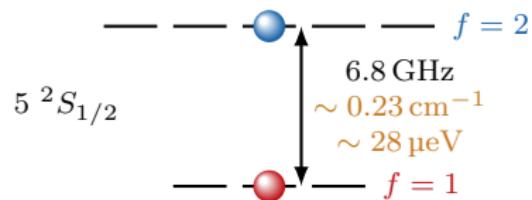
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- tunable hard-wall box potential (DMD)
- **uniform density**



**single atom energy diagram**

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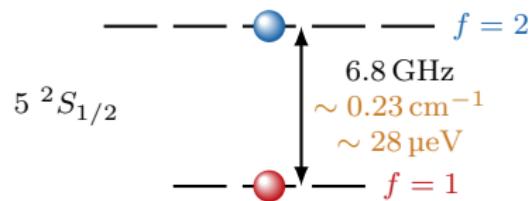


# Photoassociation of ultracold atoms

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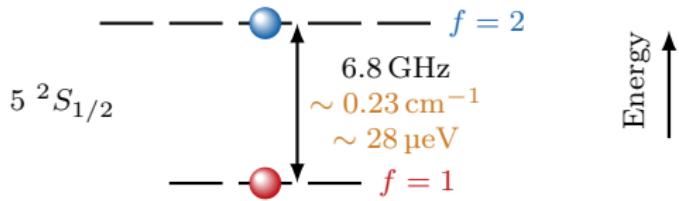
two atoms energy diagram

$$\ell = 0$$



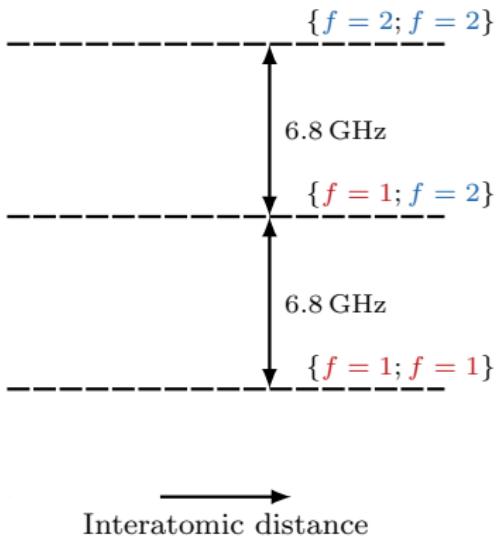
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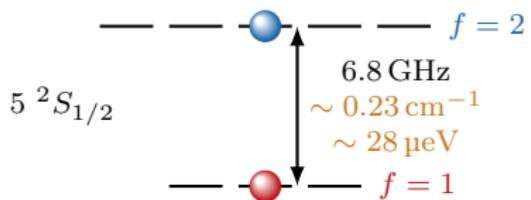
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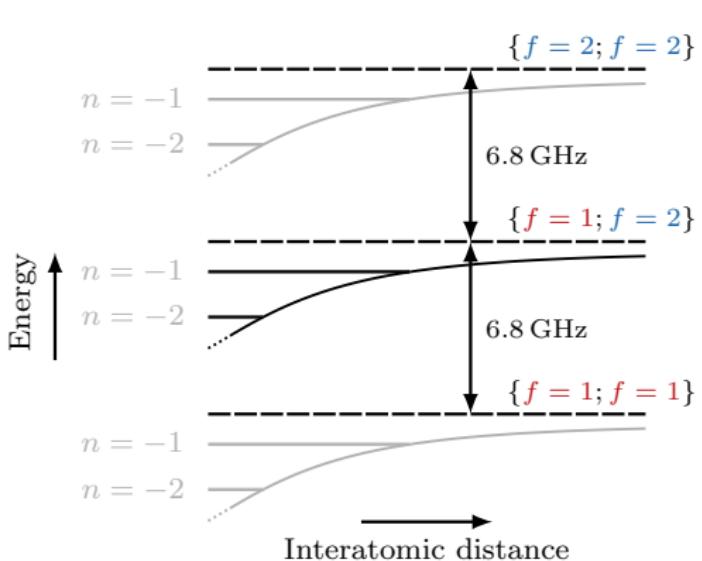


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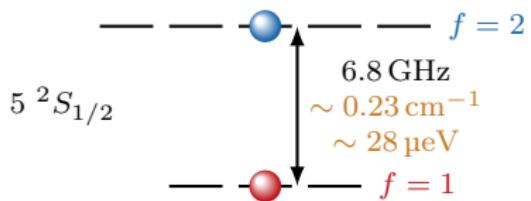


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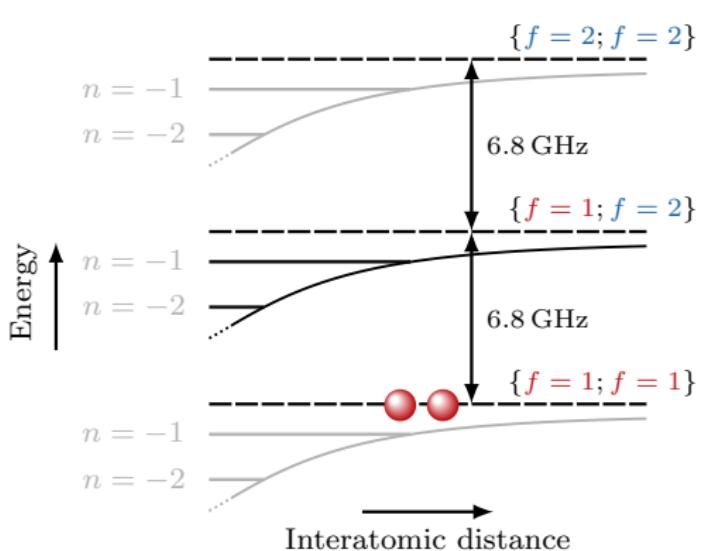


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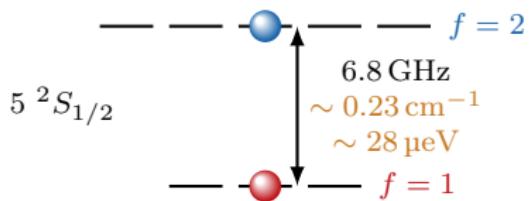


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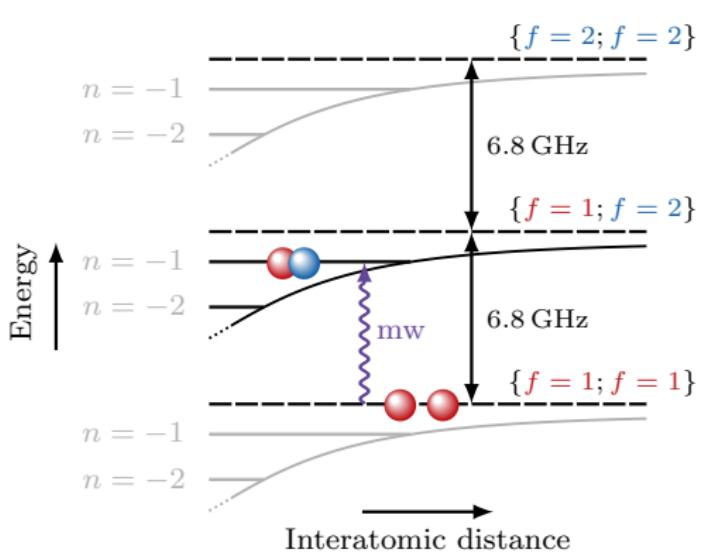


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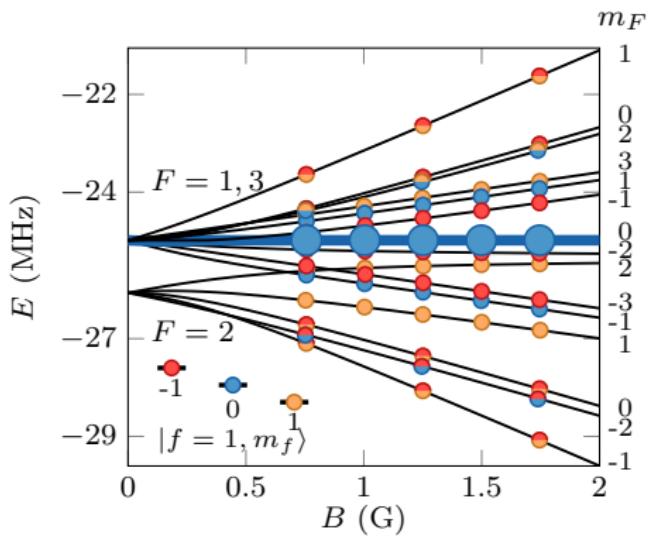


## Least-bound state

in real life → hyperfine structure, singlet-triplet coupling, Zeeman diagram: simple model  
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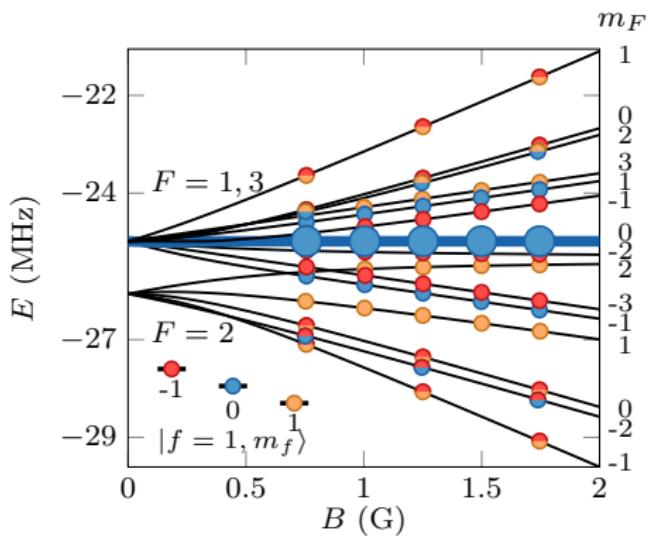
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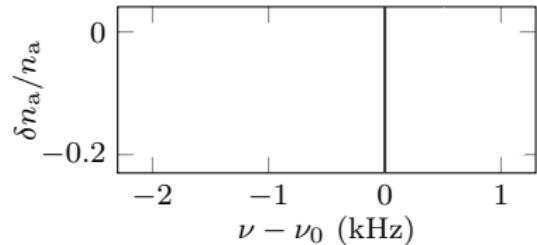
### precise measurement:

- $T = 0$ : no kinetic broadening
- uniform surface density
- magnetic-insensitive line

## Density dependence of the atom-dimer line

### initial atomic gas:

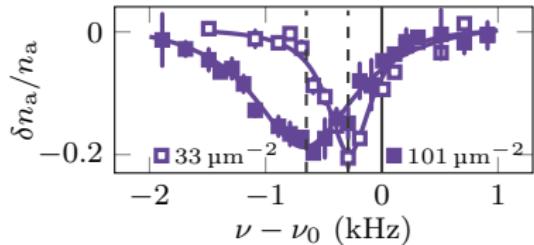
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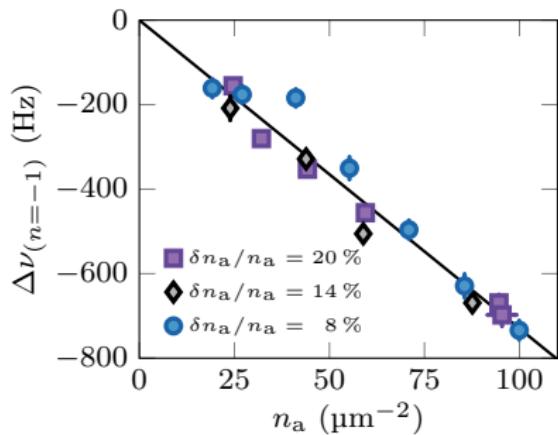
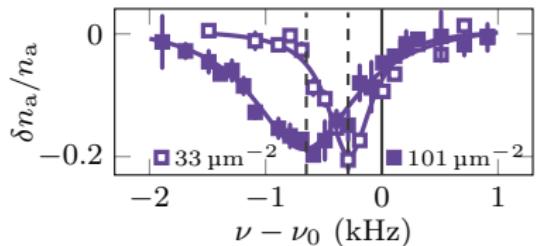
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### atom-dimer line shift

$$\Delta\nu/n_a = h\nu - h\nu_0 = -7.3(3) \text{ Hz}/\mu\text{m}^{-2}$$

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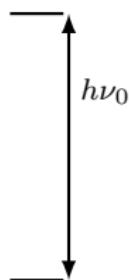
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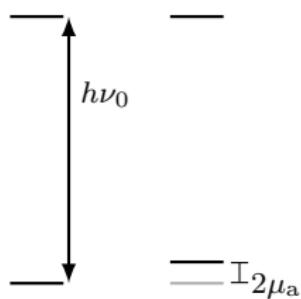
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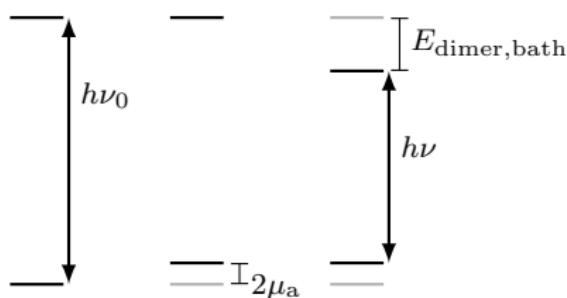
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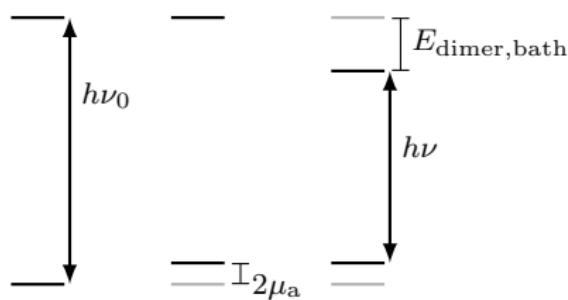
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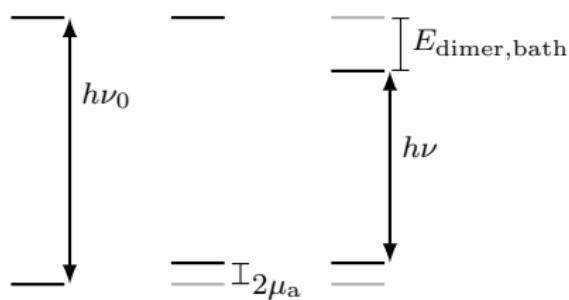
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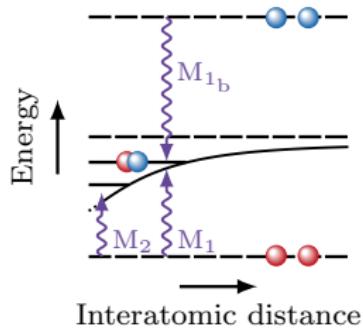
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→ experimental determination of an atom-dimer scattering length

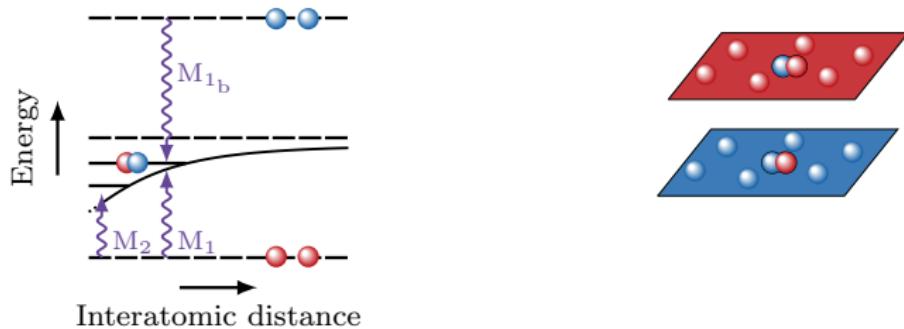
$$a_{ad} = 184(2) a_0$$

see also R. Wynar et al. Science, 287 (2000) error bar ∼ signal

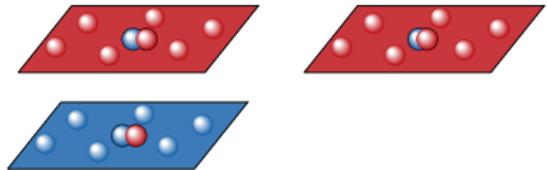
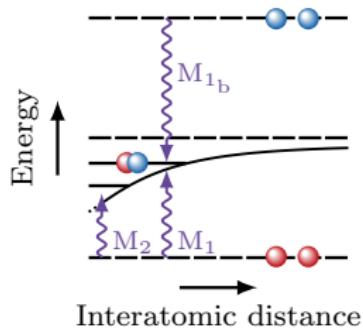
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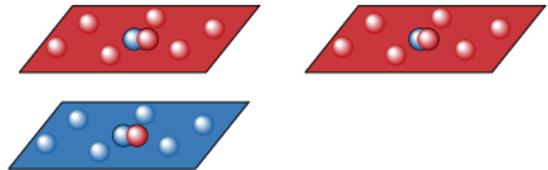
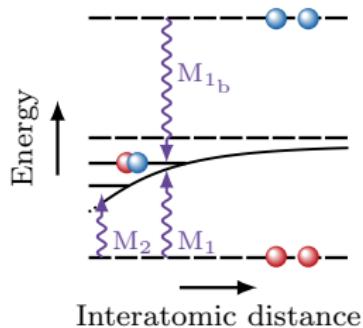
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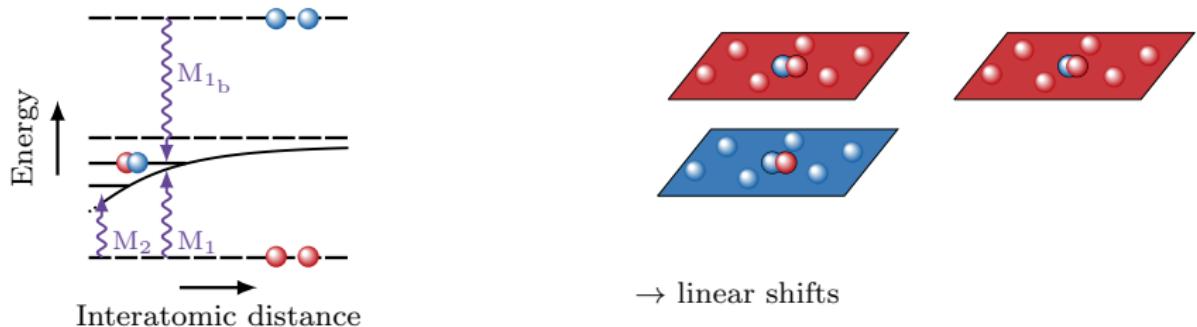


## Determination of atom-dimer scattering lengths



→ linear shifts

# Determination of atom-dimer scattering lengths



**same dimer, different atomic bath**

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$$M_{1b}: \quad a_{ad} = 165(7) a_0$$

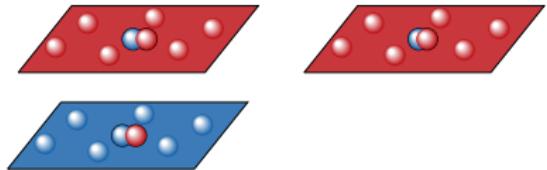
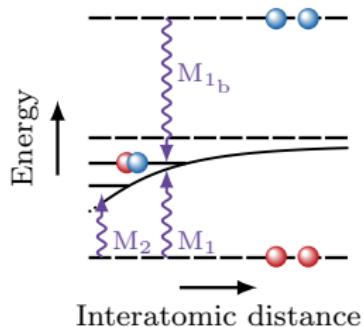
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$a \leftrightarrow a_{ad}$  ?

van der Waal universality ?

P. M. A. Mestrom PRA (2017)

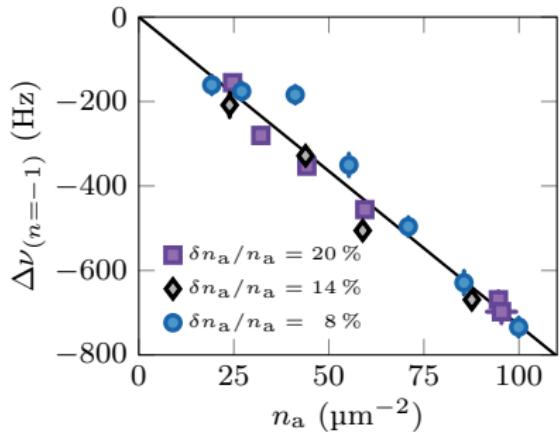
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## Conclusion

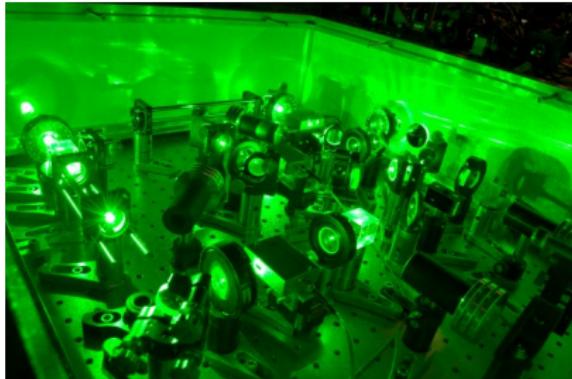
→ first quantitative measurement of the atom-dimer scattering length



are these results species dependent? → new calculations for  $^{87}\text{Rb}$

is there universality for the least bound states?  $C_6 \rightarrow a \rightarrow a_{ad}$

Thank you!



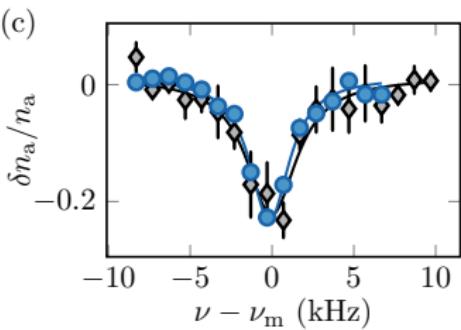
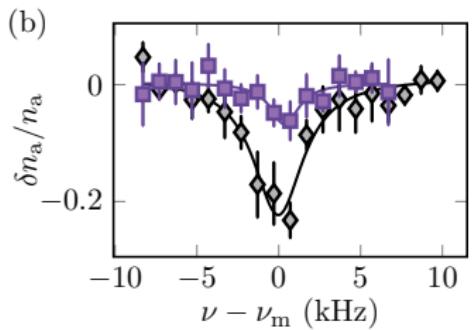
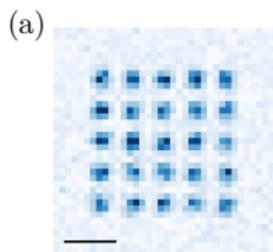
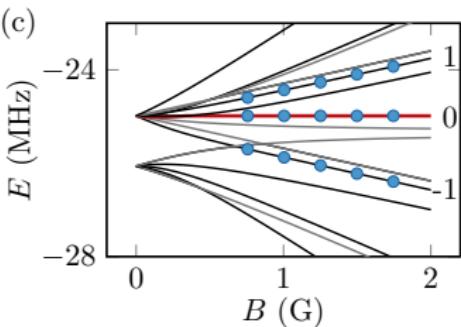
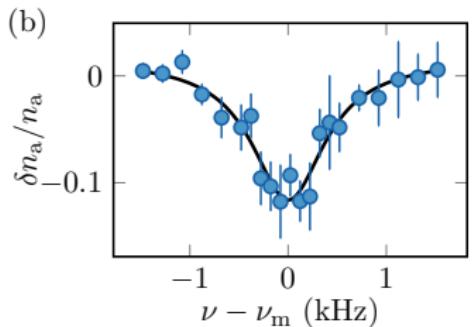
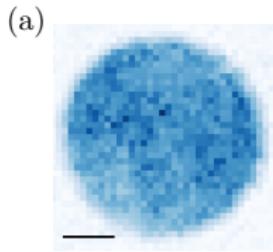
## Contributors

Brice Bakkali Hassani  
Guillaume Chauveau  
Franco Rabec

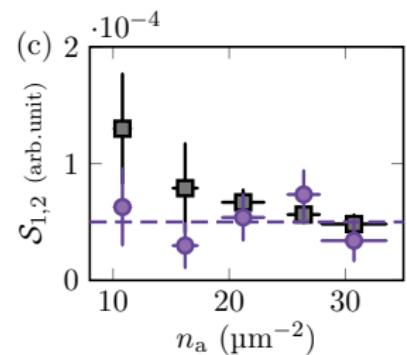
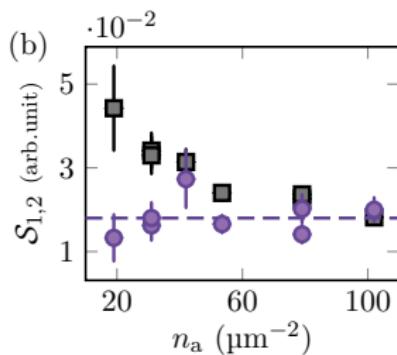
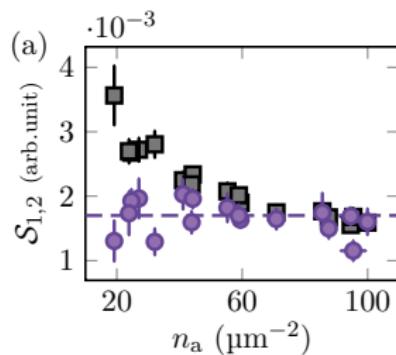
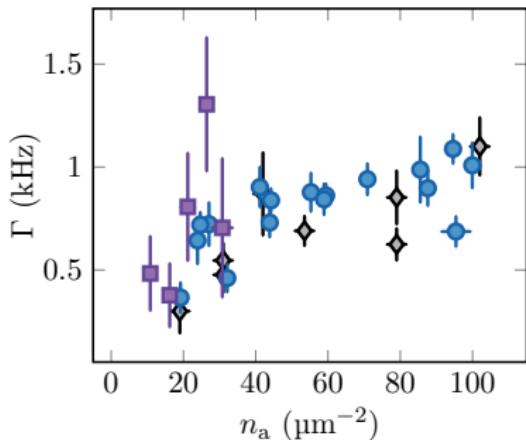
Jérôme Beugnon  
Sylvain Nascimbène  
Jean Dalibard

C. Maury et al. Physical Review Research, **5** L012020 (2023)

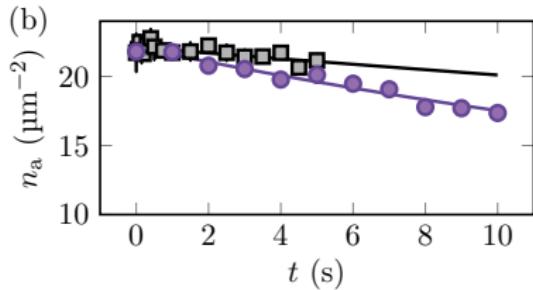
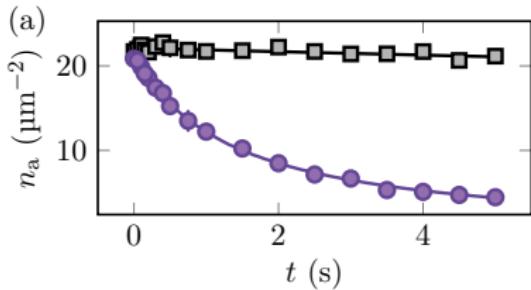
# Photoassociation



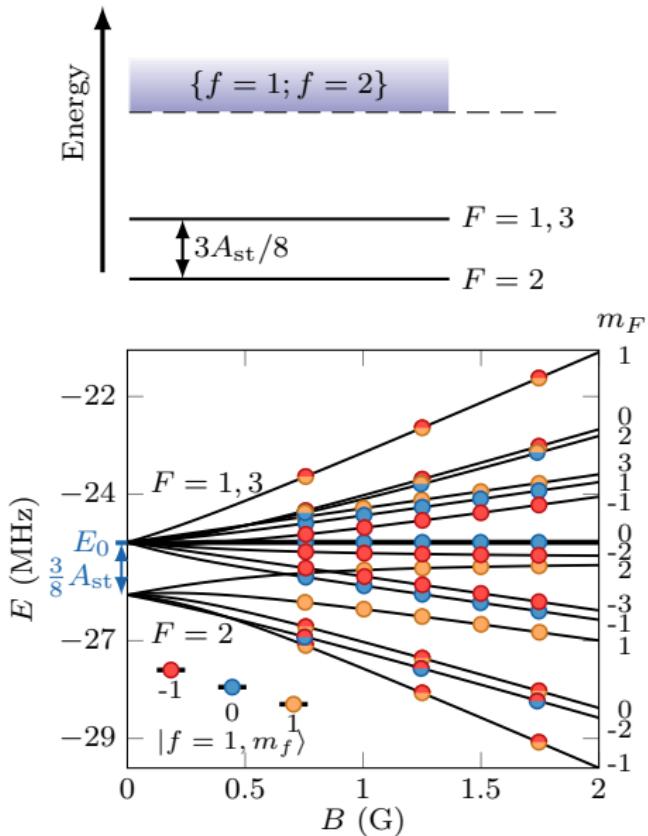
## Line width and scaling



## Atomic losses



## Least vibrational state spectroscopy



simple model for a weakly bound state  
 $A_{\text{st}} \ll A_{\text{hfs}}$ :

$$\hat{H} = \hat{H}_{\text{hfs}} + \hat{H}_Z + \hat{H}_{\text{st}}$$

$$\hat{H}_{\text{st}} = A_{\text{st}} \hat{\mathbf{s}}_1 \cdot \hat{\mathbf{s}}_2$$

$n = -1$ :

$$E_0 = -h \cdot 24.985(1) \text{ MHz}$$

$$A_{\text{st}} = h \cdot 2.875(5) \text{ MHz}$$

$n = -2$ :

$$E_0 = -h \cdot 642.219(1) \text{ MHz}$$

van der Waals:

$$n = -1 \rightarrow \sim 1 \text{ kHz},$$

$$n = -2 \rightarrow \sim 11 \text{ kHz}$$

## Density dependence of the atom-dimer lines

