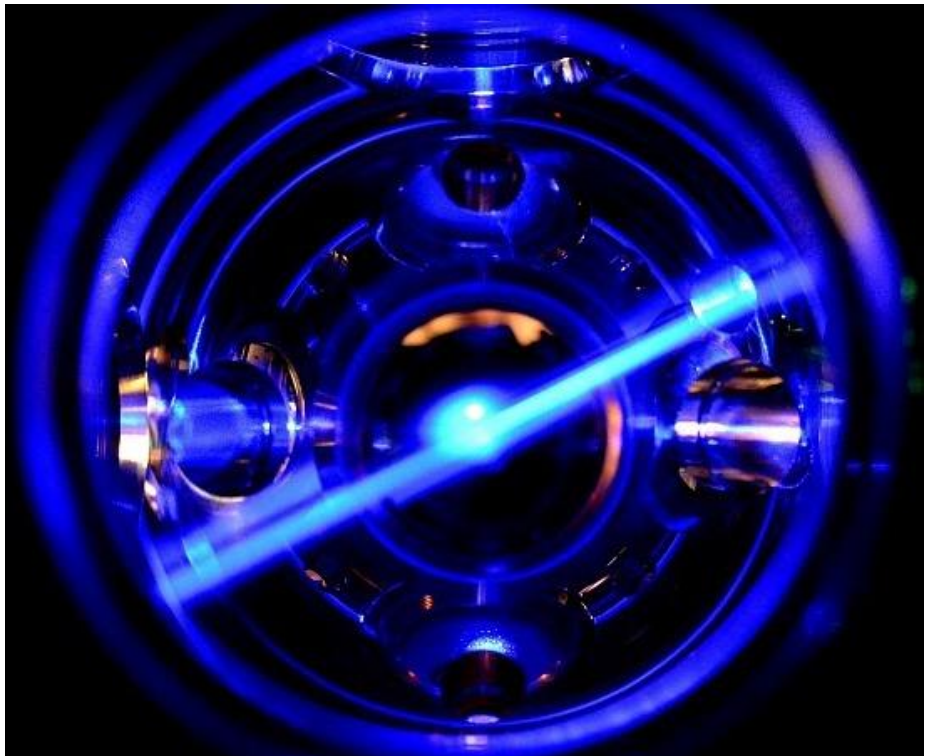
Old and New Physics with Ultracold $^{88}Sr_2$ Molecules

Tanya Zelevinsky

B. H. McGuyer, C. B. Osborn, M. McDonald, G. Reinaudi

Columbia University



Why?

next talk

- Pathway to dipolar gas of SrAlkali, SrYb

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✓

- All-optical ultracold molecules in known quantum state
- High-*Q* study of quantum chemistry
- Anomalously large magnetizability

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current

- QED in heavy molecules
- nm scale test of Newtonian gravity

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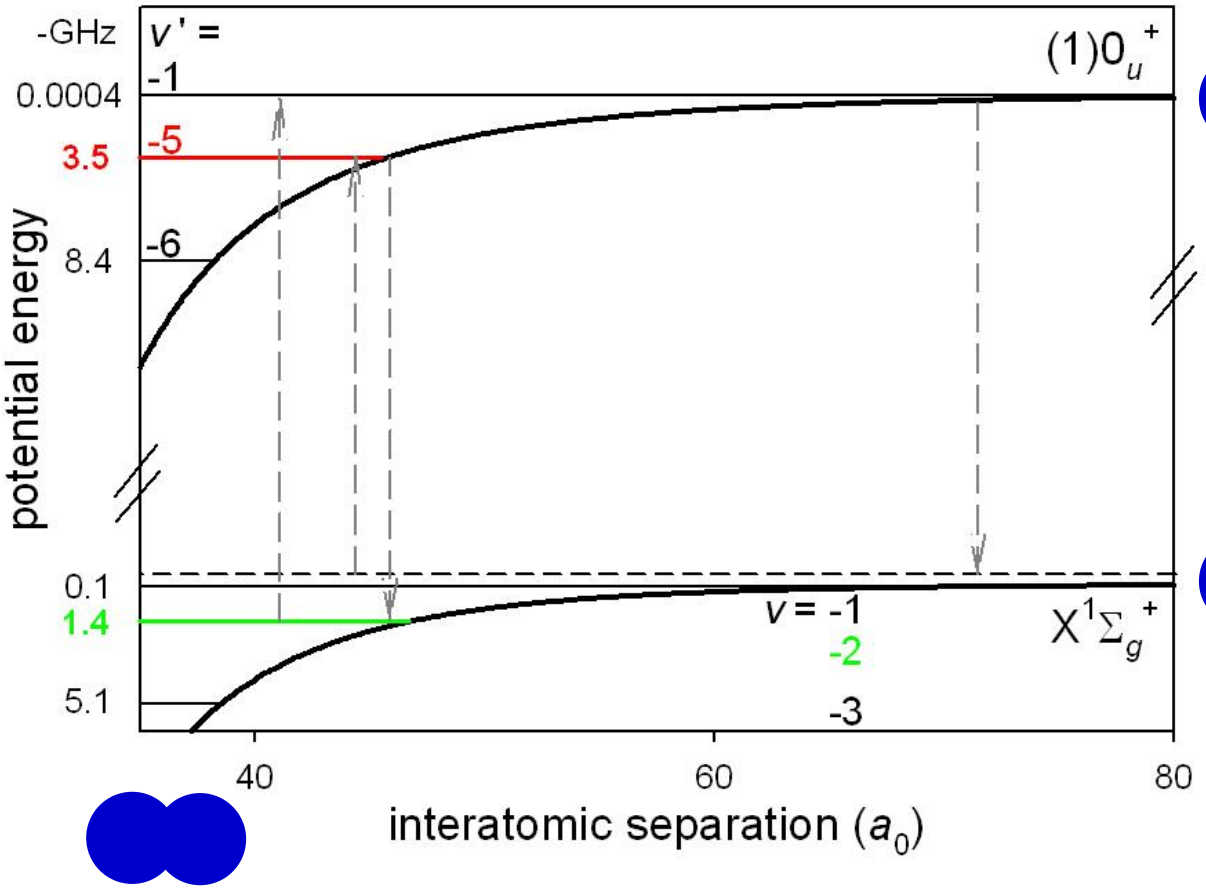
future

- molecular clock based test of m_e/m_p variations
- Bridging time metrology gap between RF and optical

Sr_2: Optical Possibilities



$^1S_0$ $^3P_1$

metastable

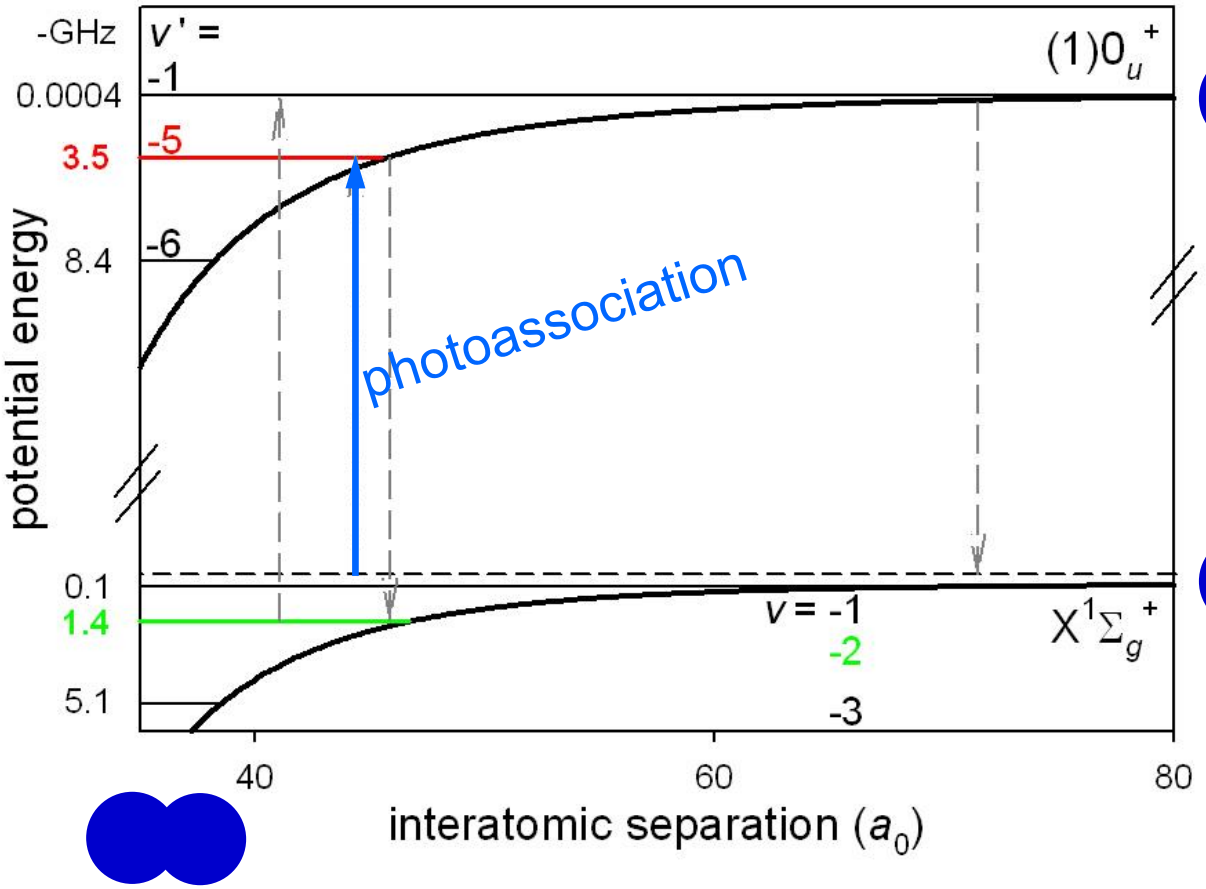
~10 μs

$^1S_0$ $^1S_0$

single potential

Sr_2: Optical Possibilities

molecule creation



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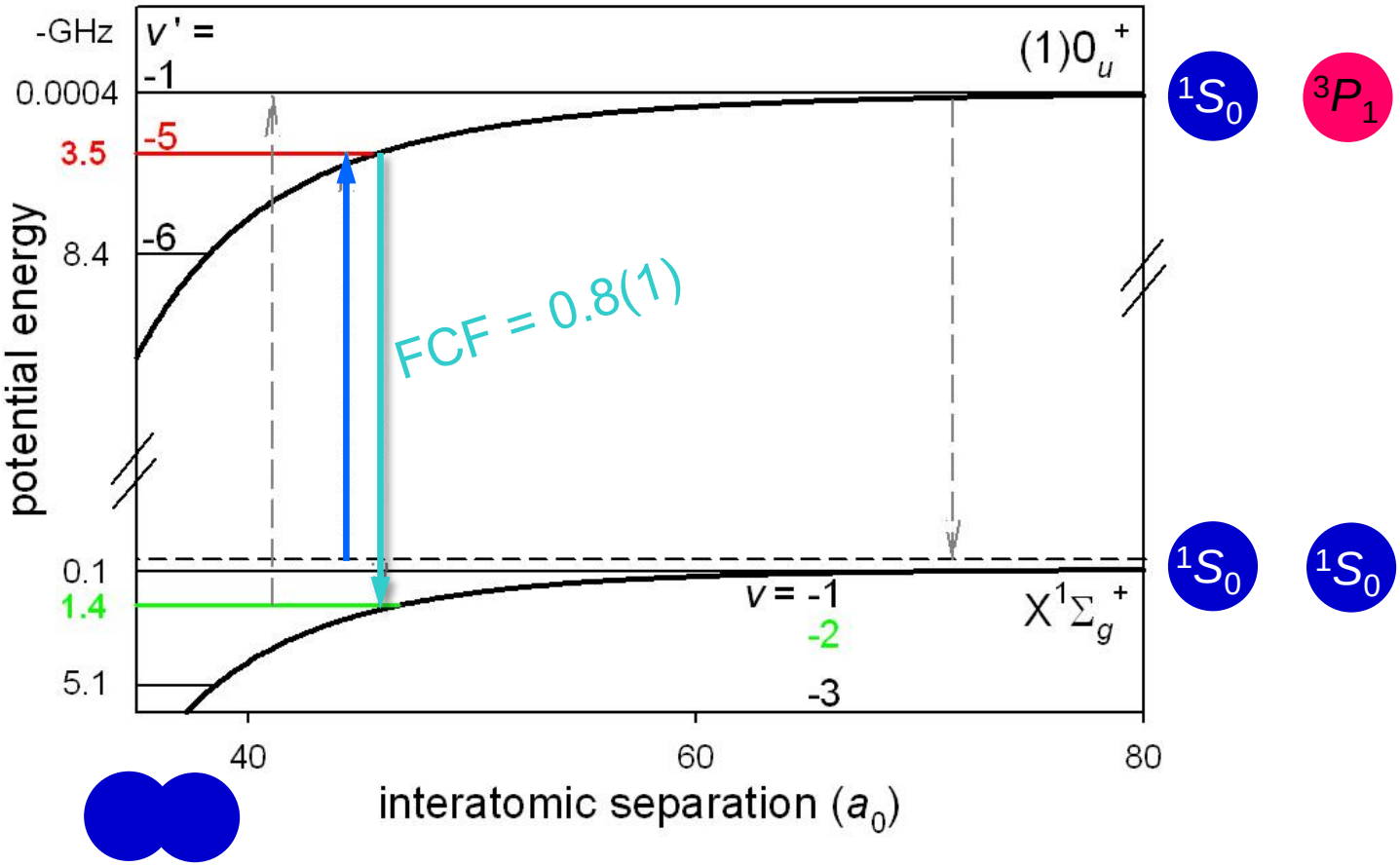
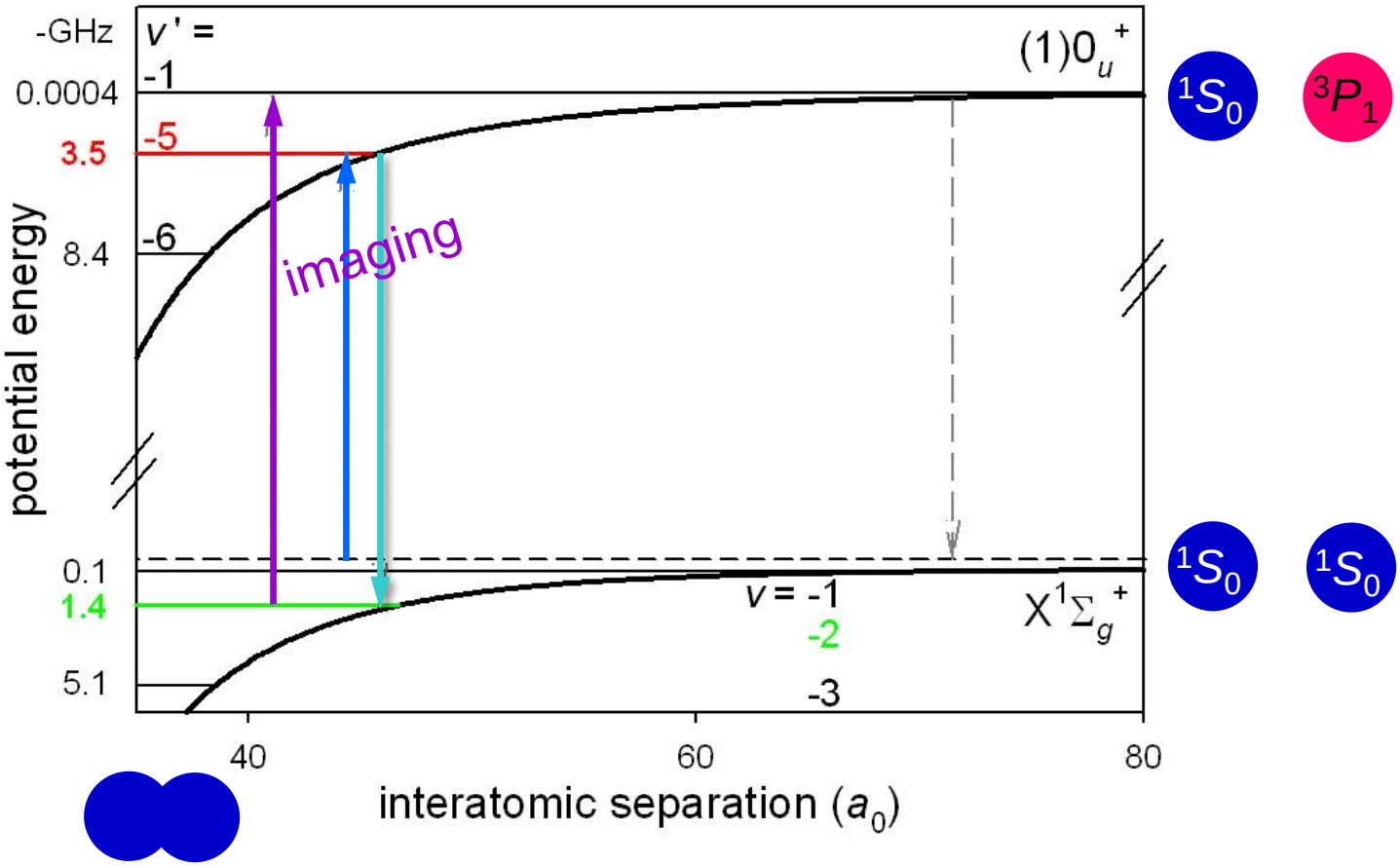


Sr_2: Optical Possibilities

molecule imaging



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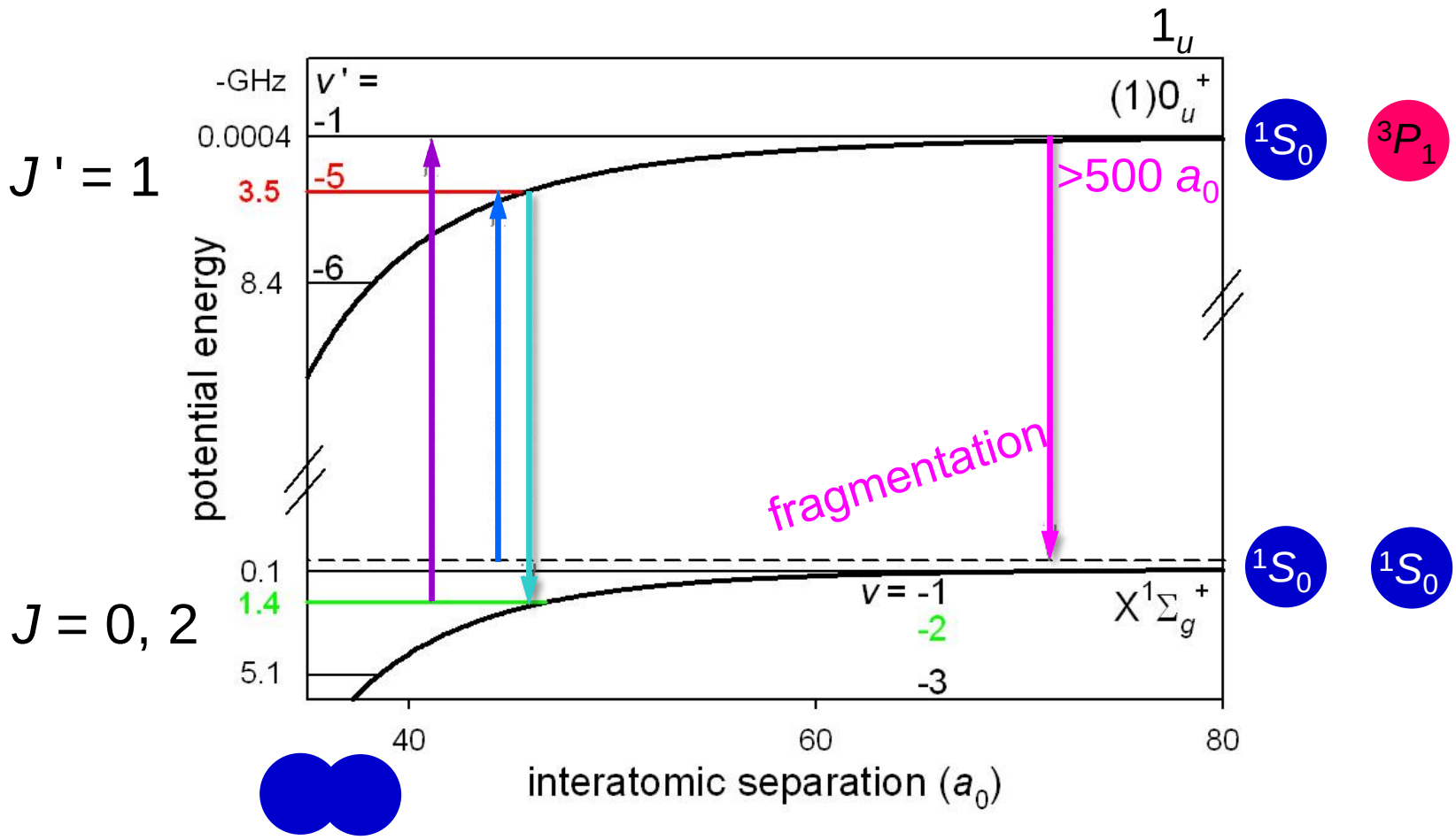
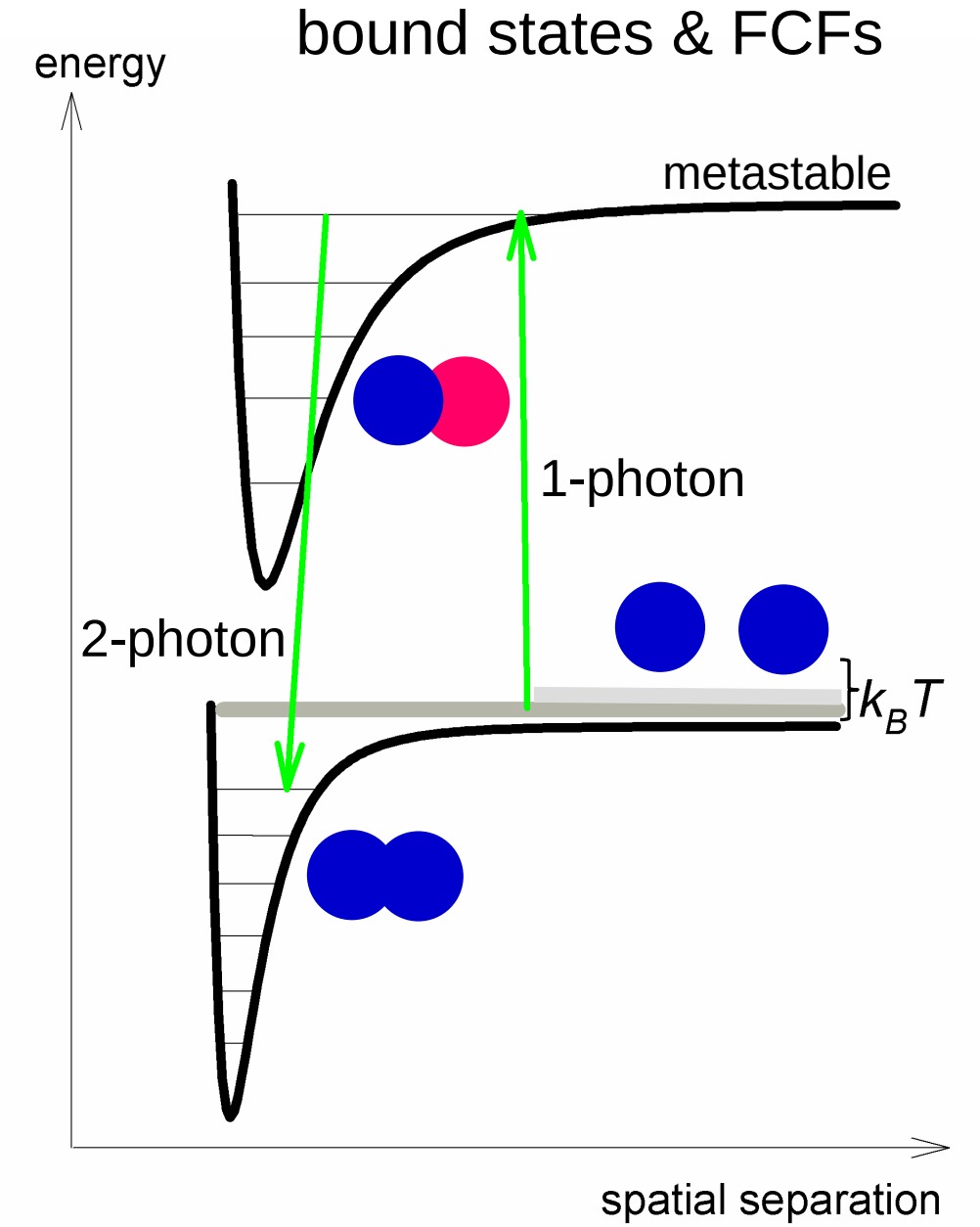
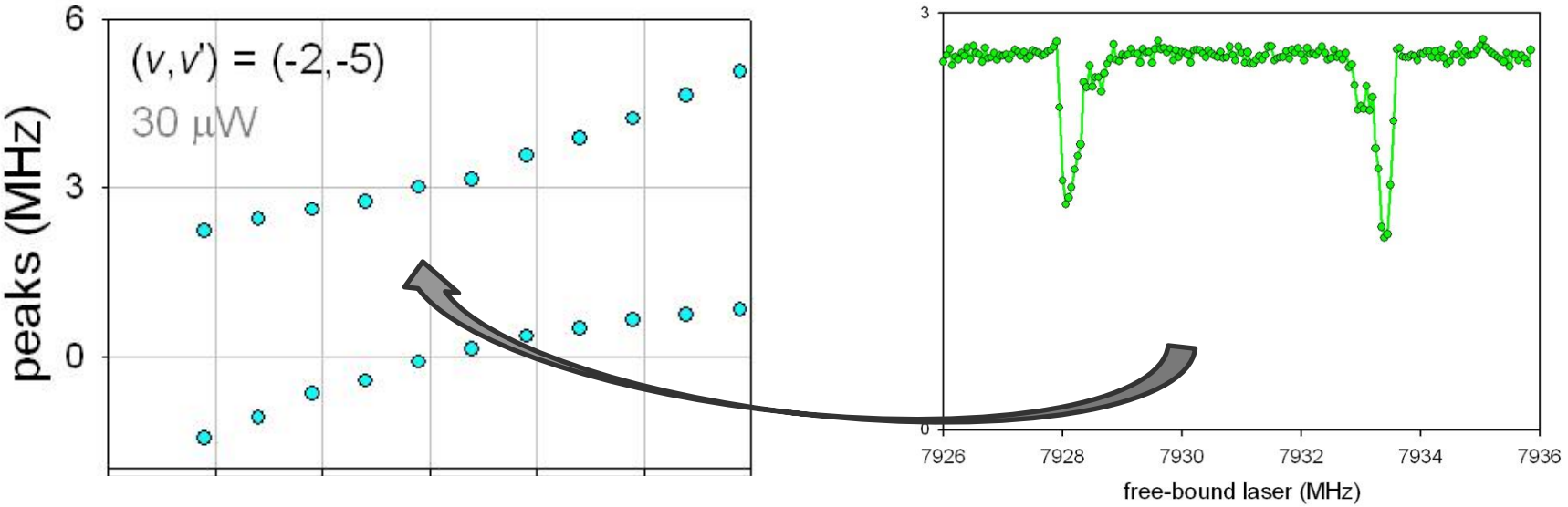


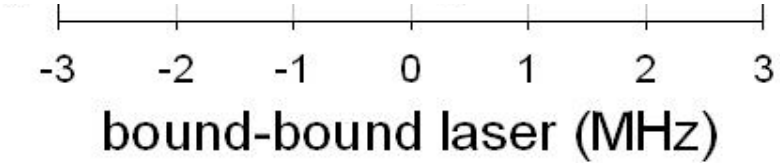
Photoassociation Spectroscopy



Two-Photon Photoassociation

$X^1\Sigma_g^+$ bound states & FCFs





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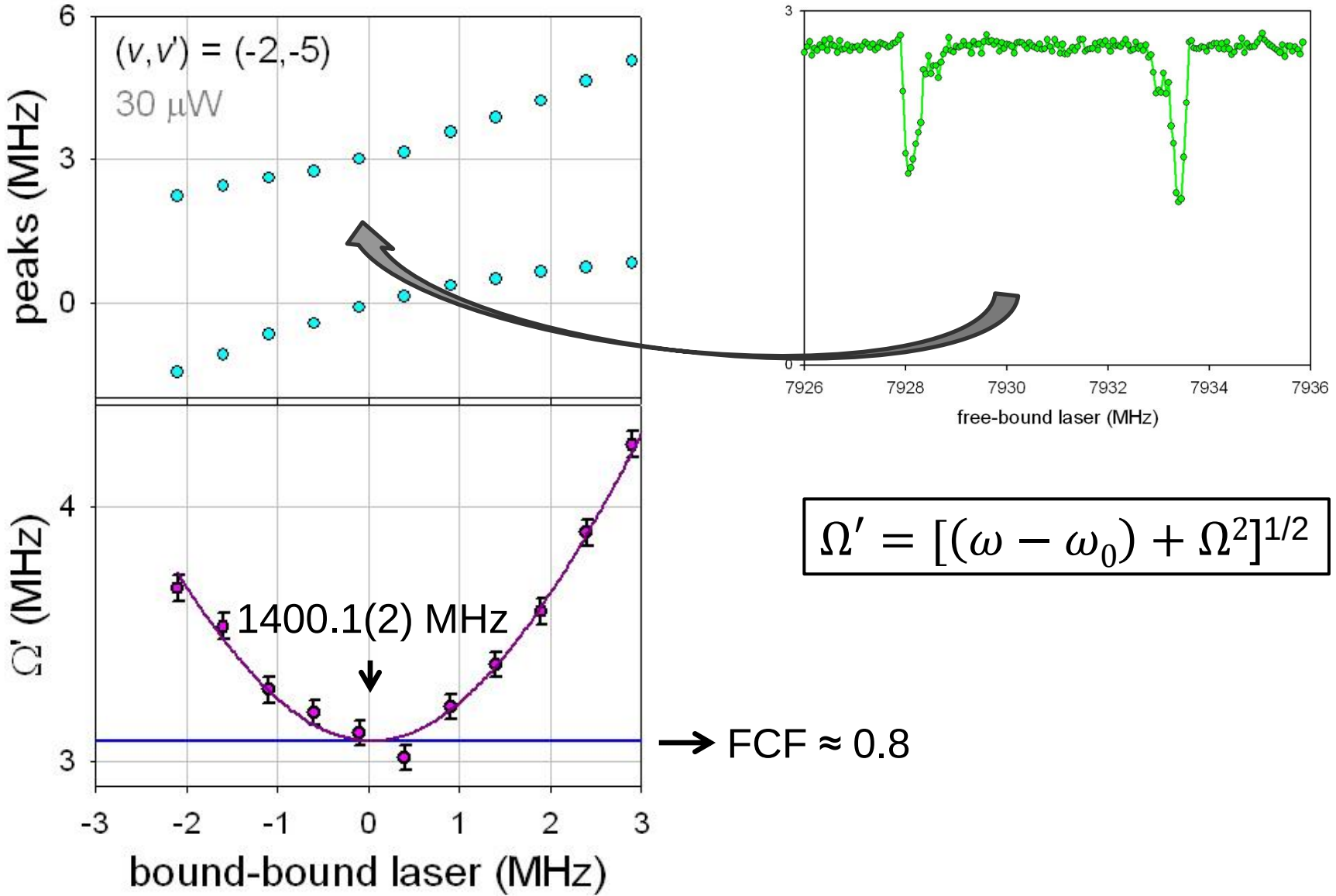


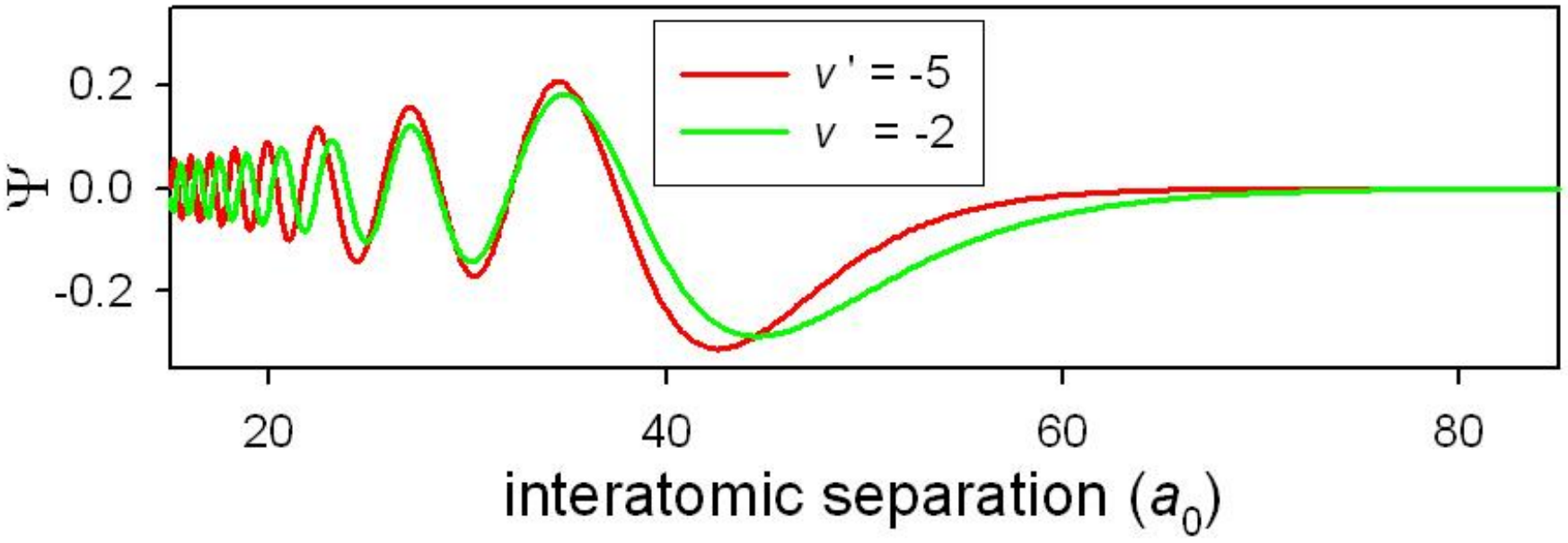
$$\Omega' = [(\omega - \omega_0) + \Omega^2]^{1/2}$$

→ FCF ≈ 0.8

G. Reinaudi *et al.*, *PRL* **109**, 115303 (2012)

Sr_2: Optical Possibilities

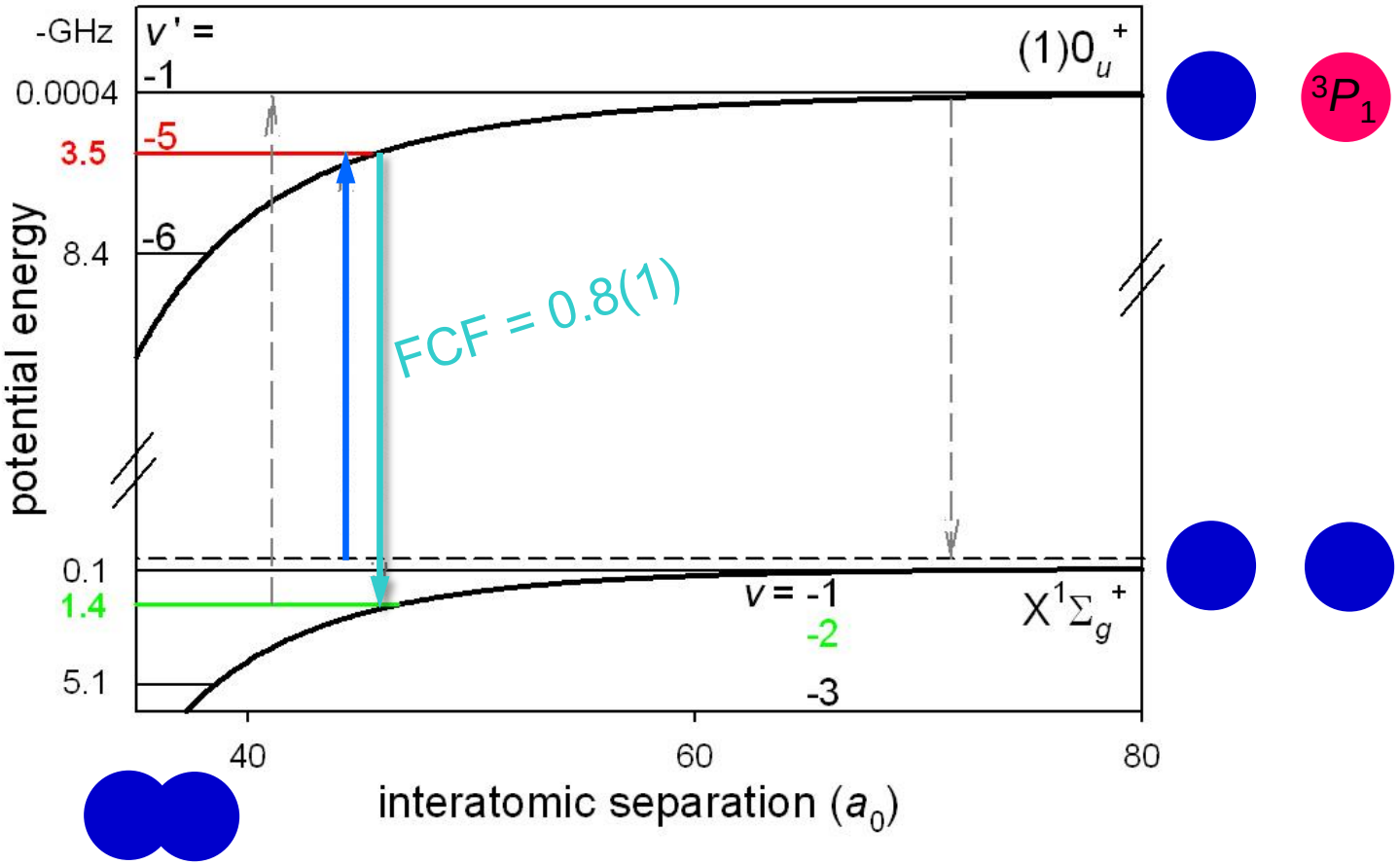
$X^1\Sigma_g^+$ bound states & FCFs



R. Moszynski *et al*.

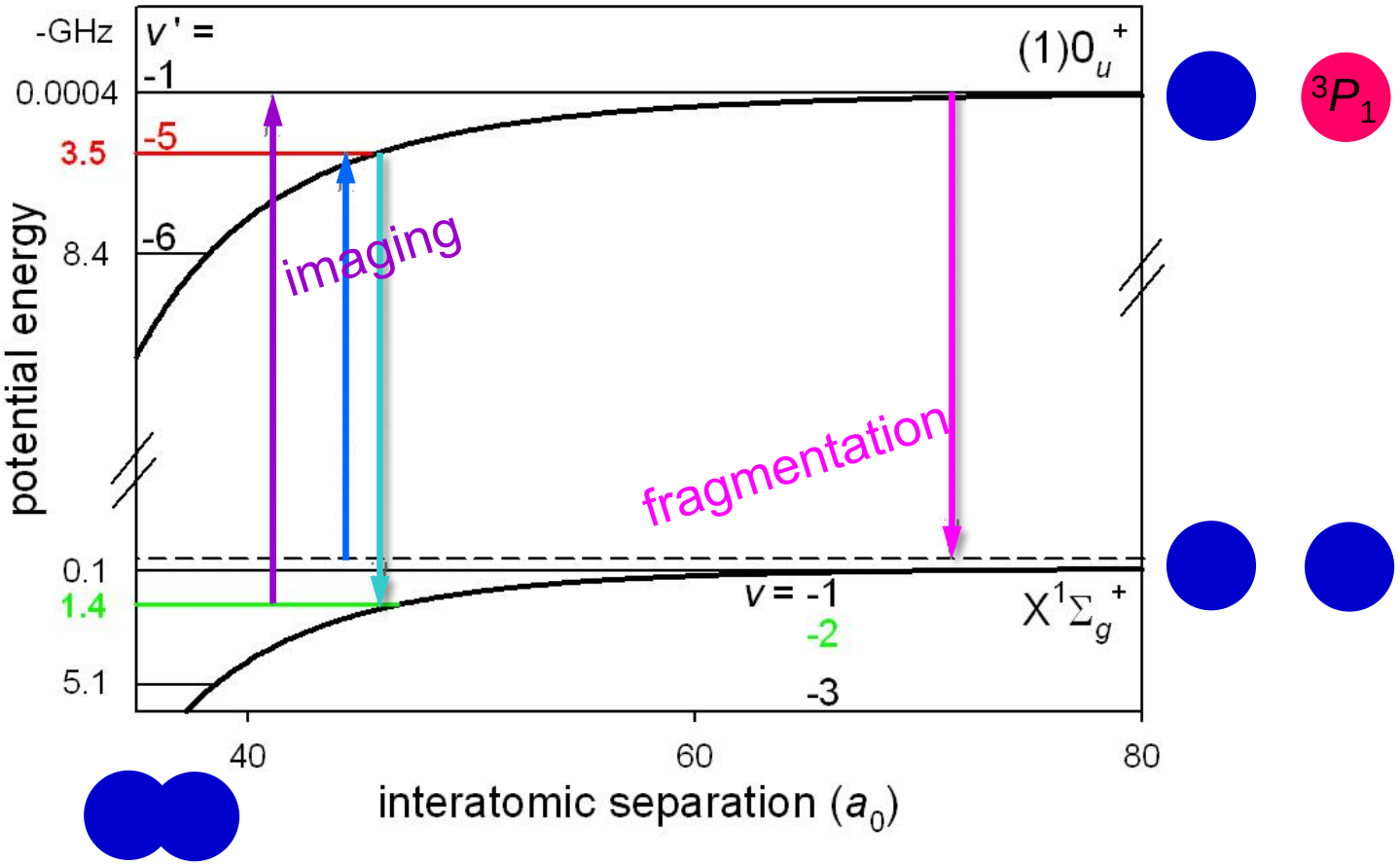
Sr_2: Optical Possibilities

molecule creation



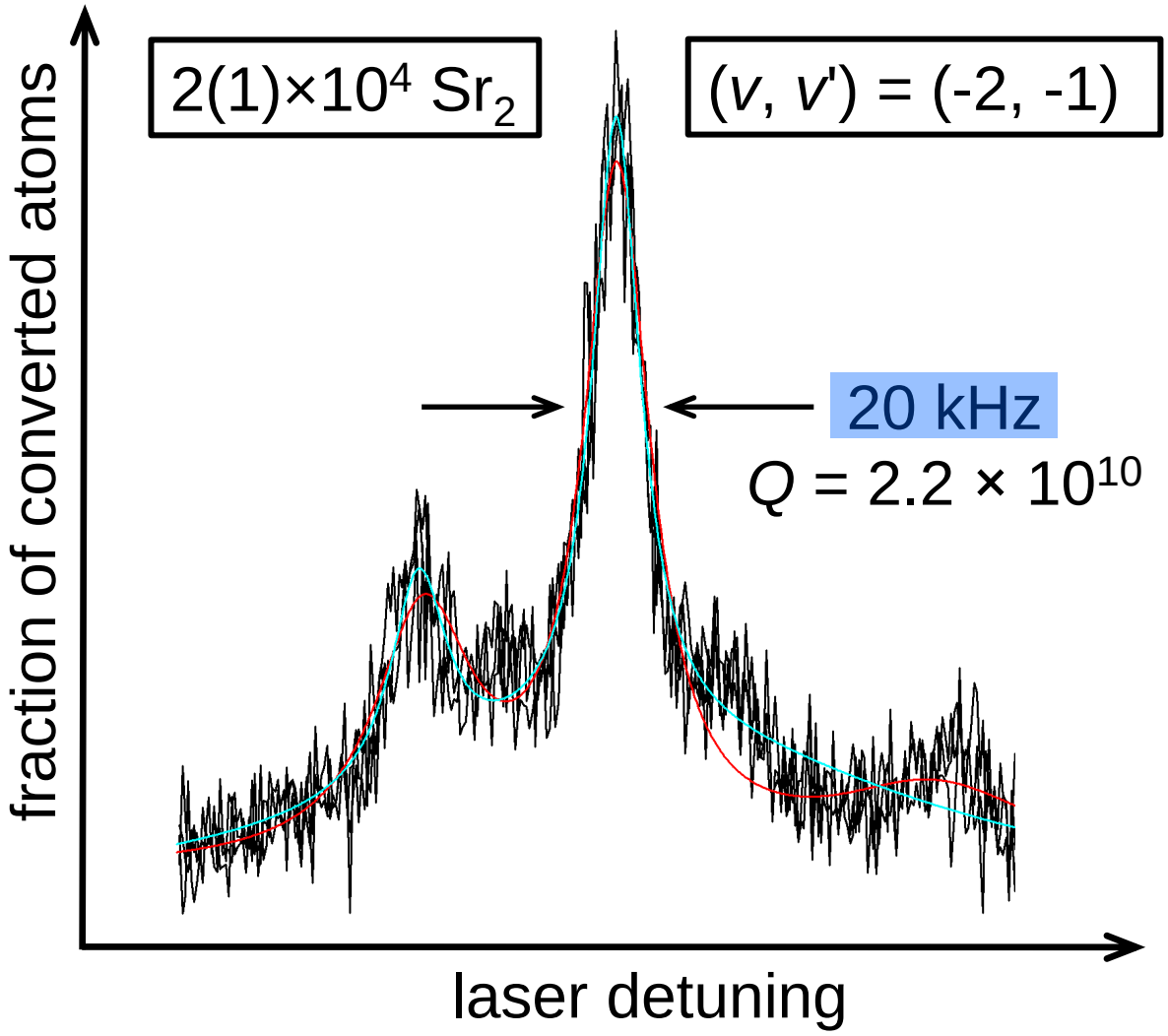
Sr_2: Optical Possibilities

molecule imaging



Molecule Imaging in the Lattice

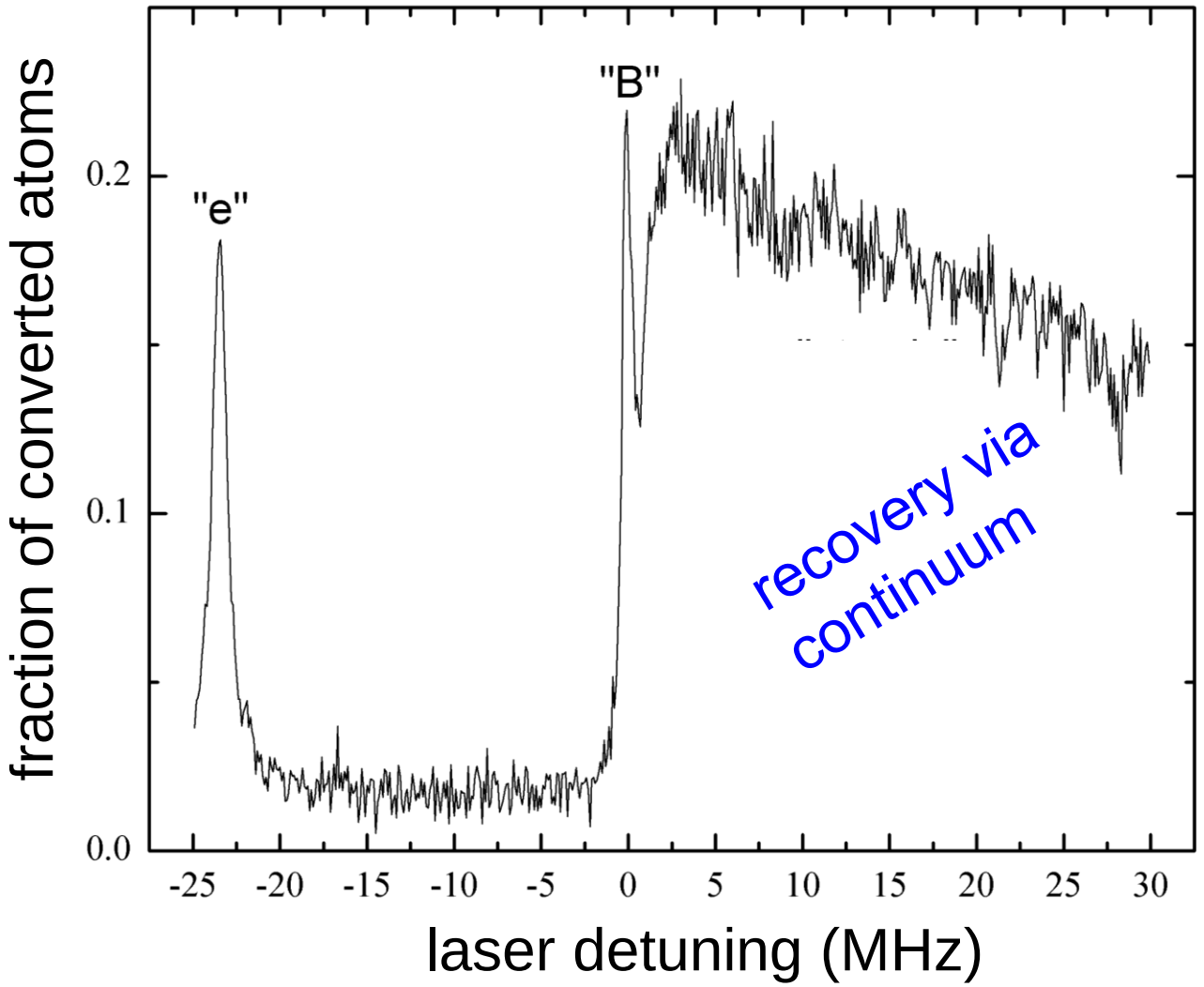
high-Q



Bound-to-Free Imaging in the Lattice

broadband

from $v = -2$, $J = 2$



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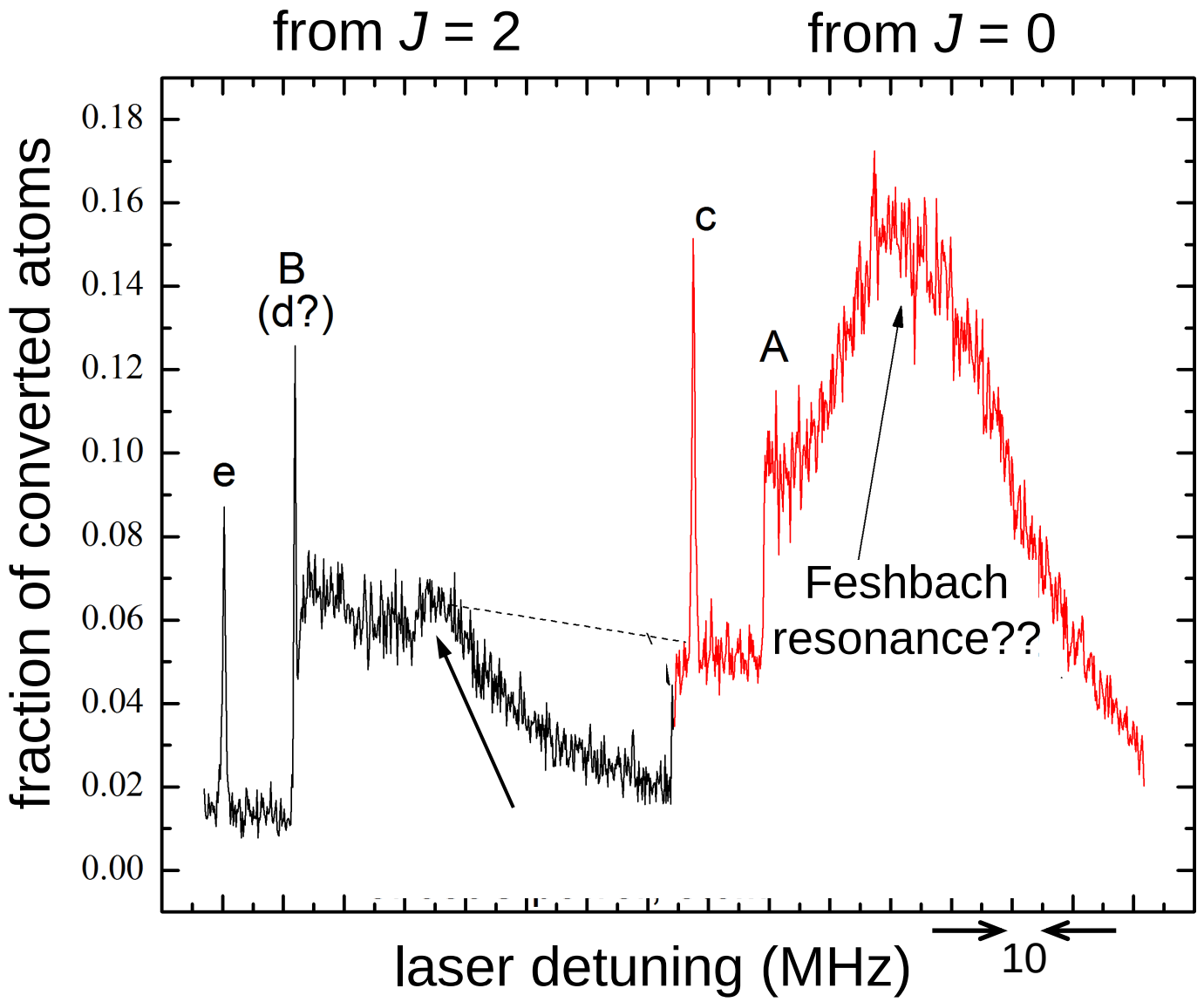

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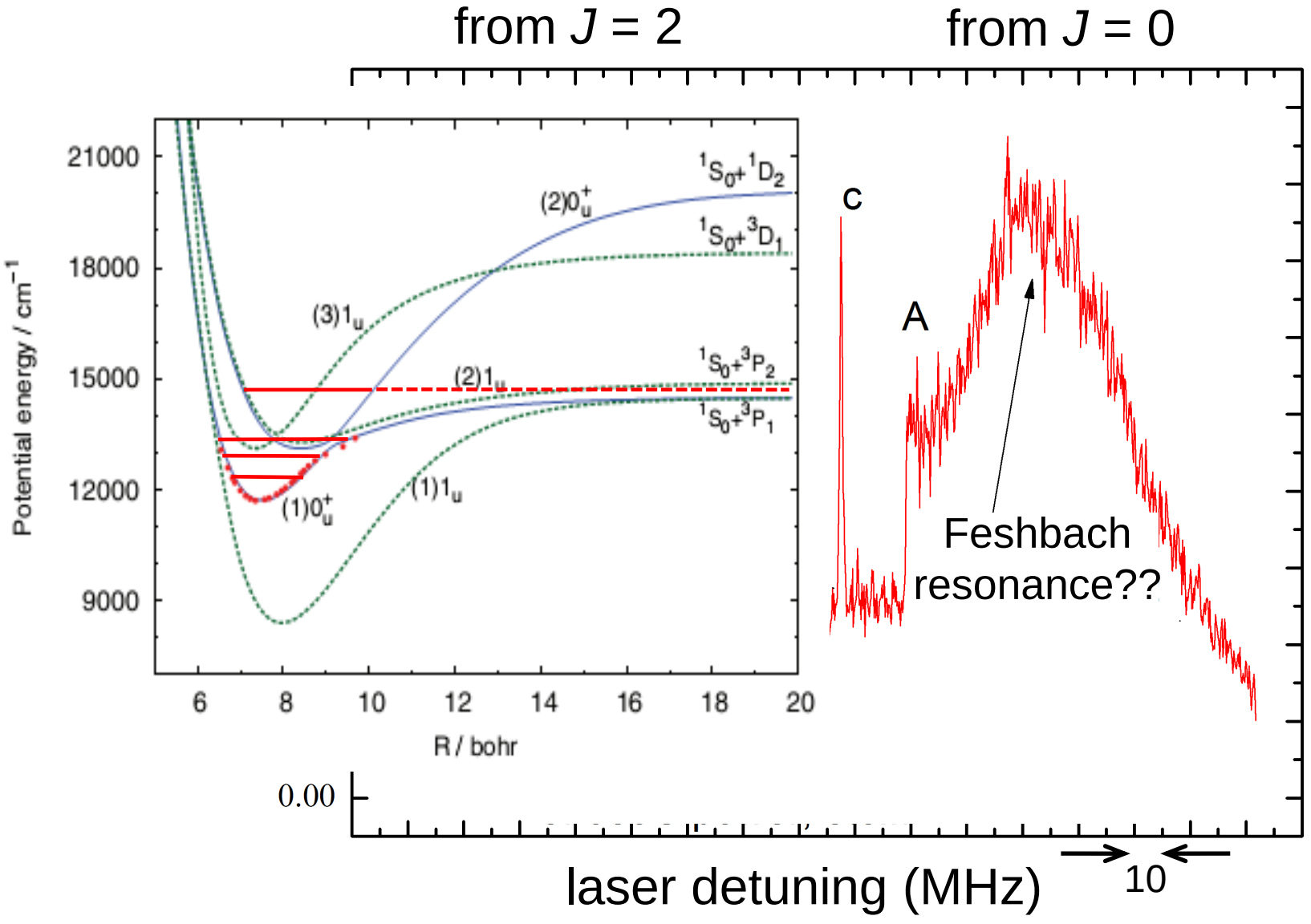

W. Skomorowski *et al.*, *JCP* **136**, 194306 (2012)

Bound-to-Free Imaging in the Lattice

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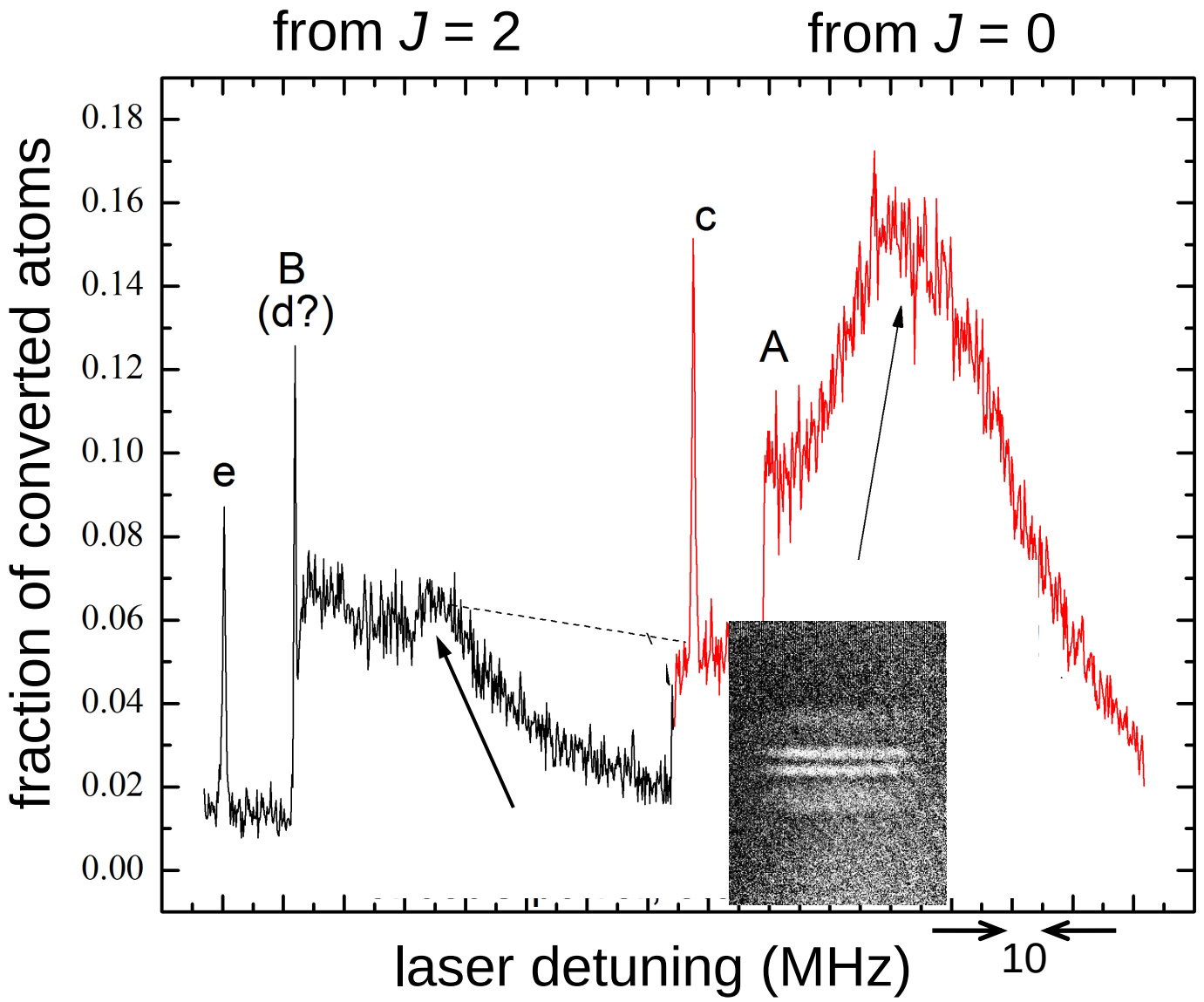
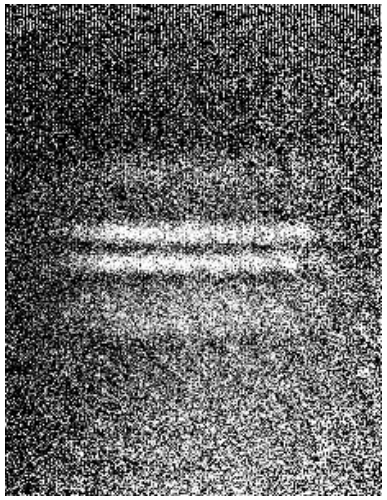
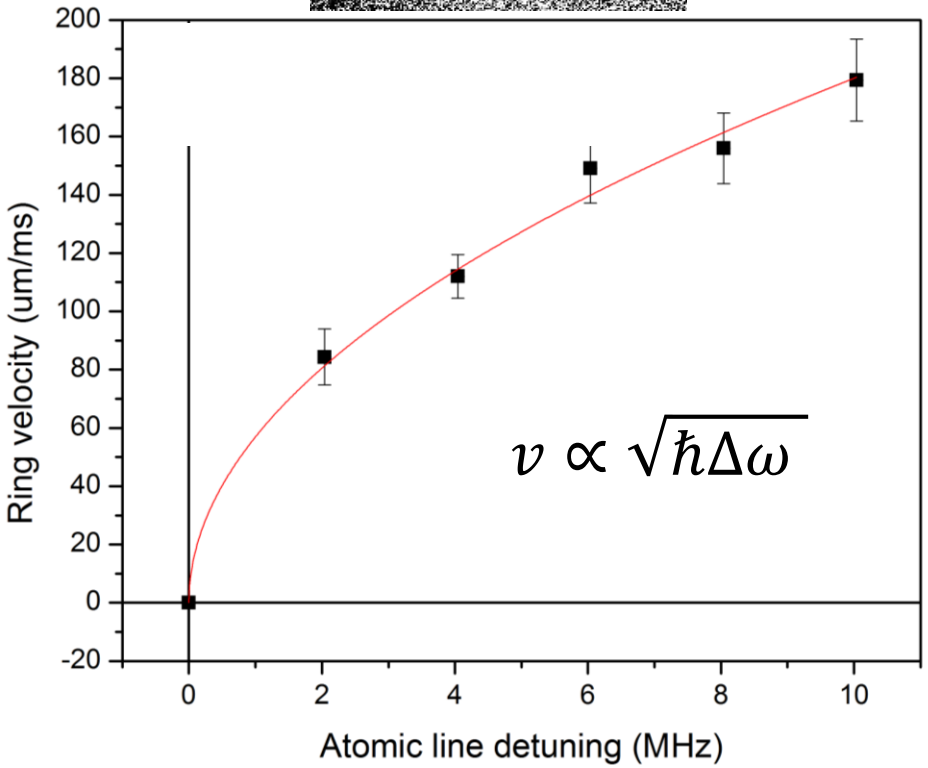


Ultracold Photodissociation





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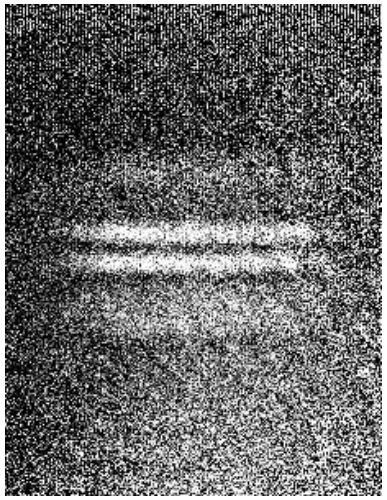
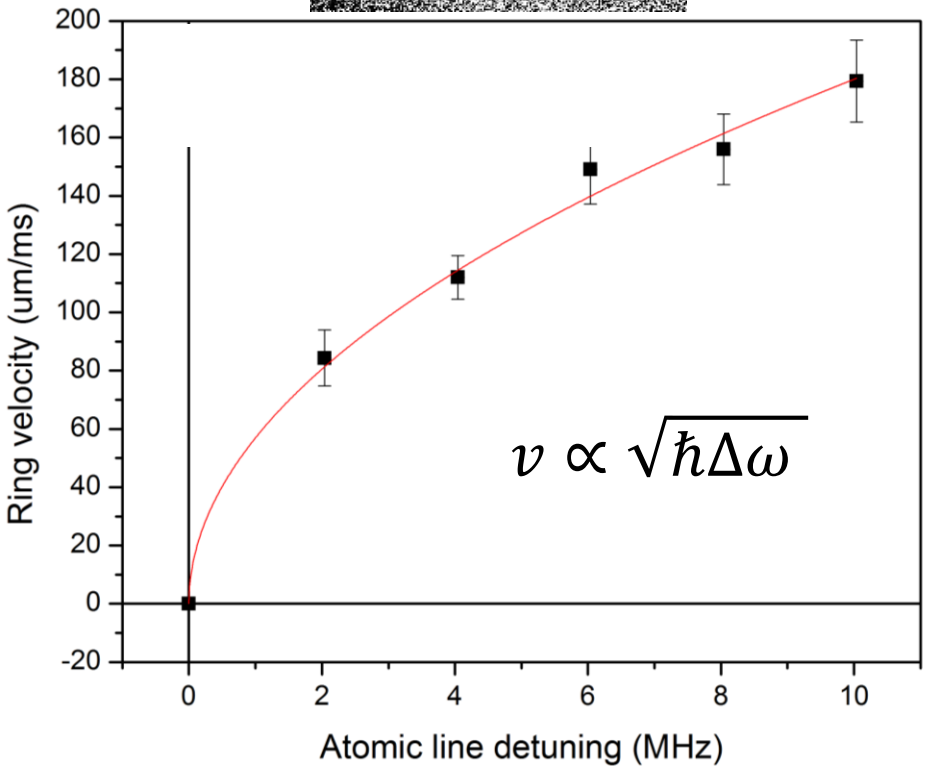
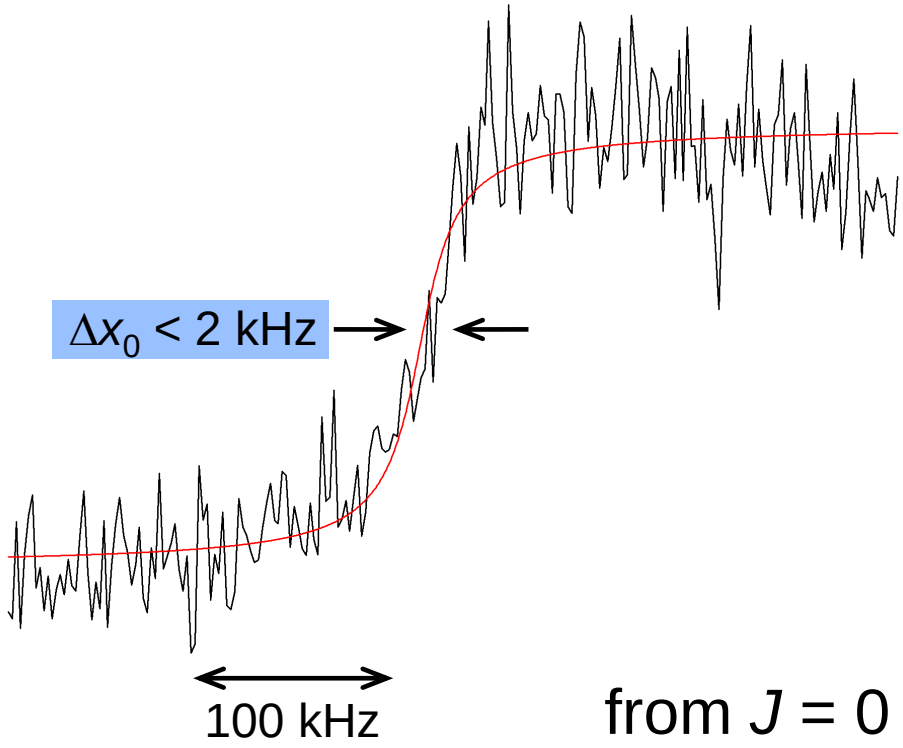


$$S \propto \int_0^\infty L(\omega) d\epsilon \propto \mathrm{C} + \tan^{-1}\frac{2\delta}{\gamma}$$

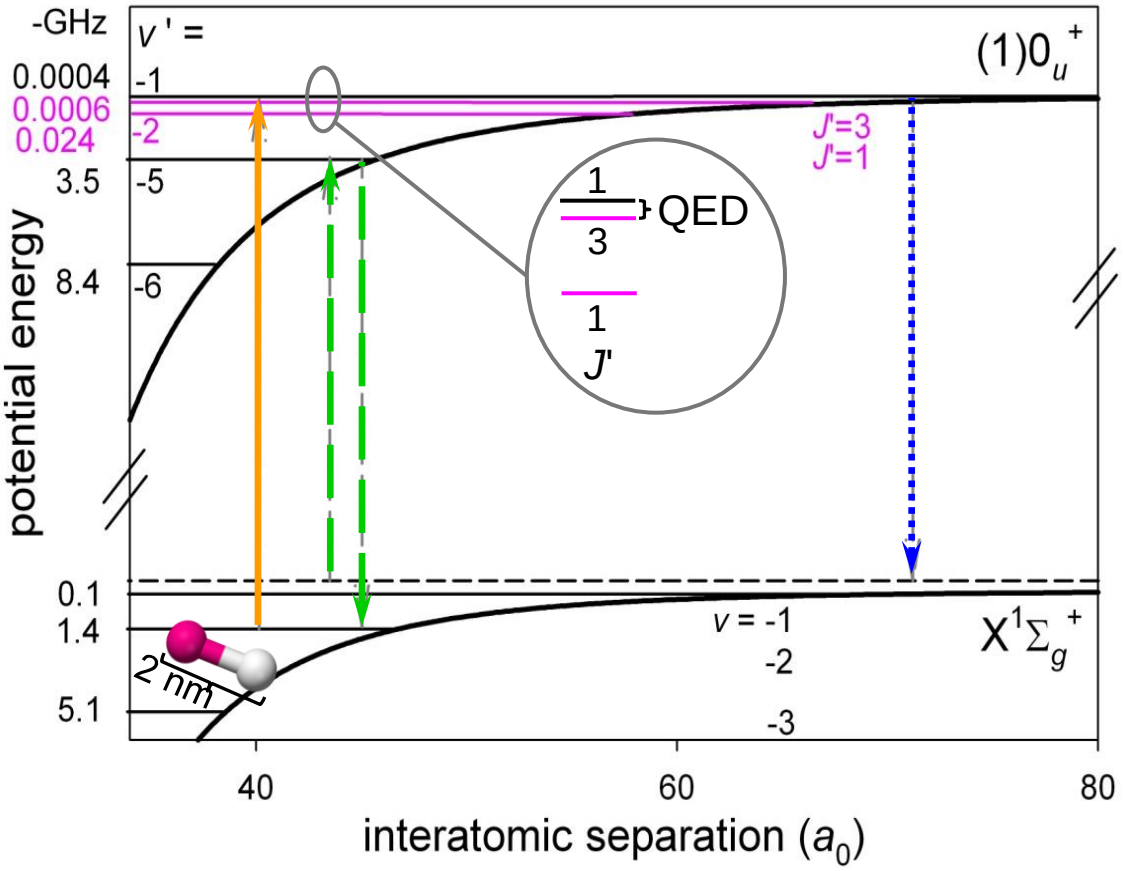
7-fold improvement on E_b





from $J = 0$

Old & New Physics with Sr_2



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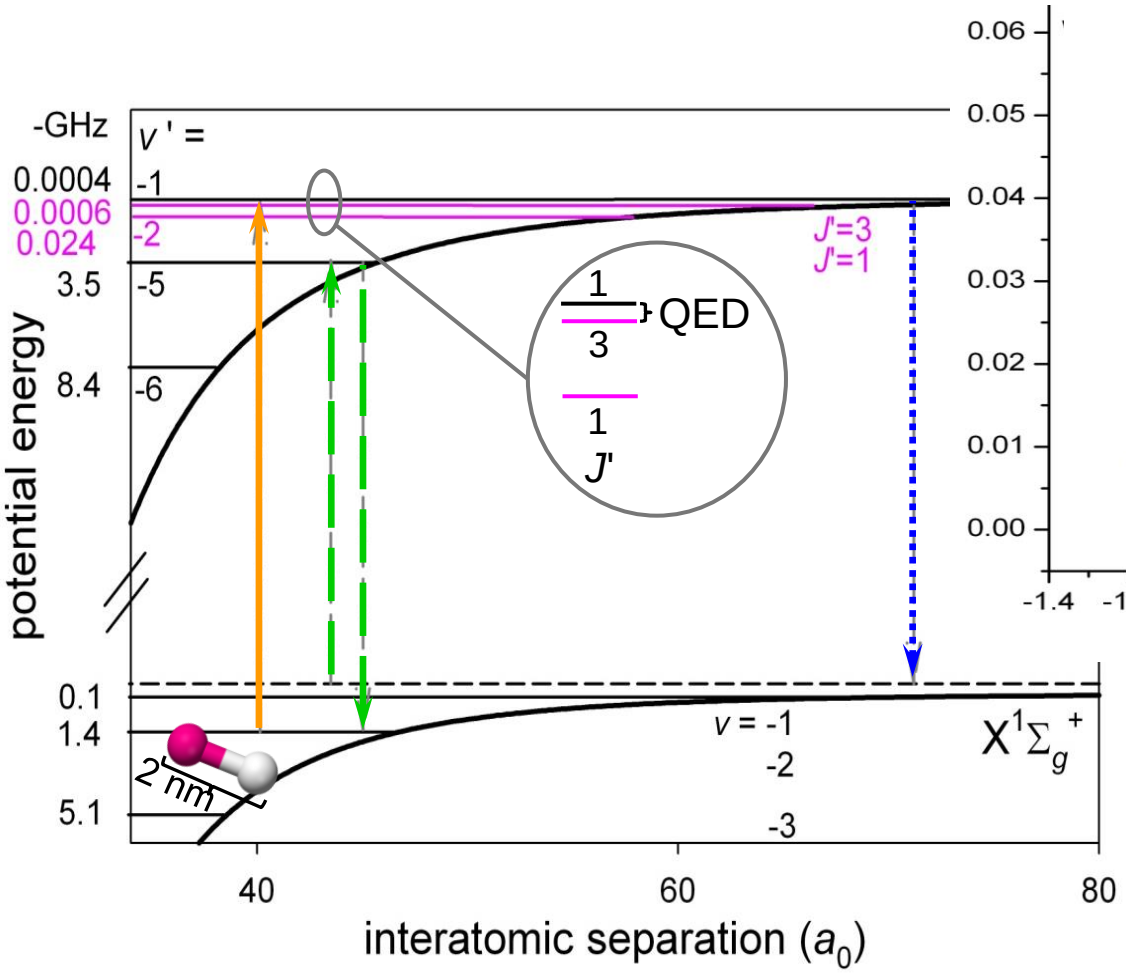

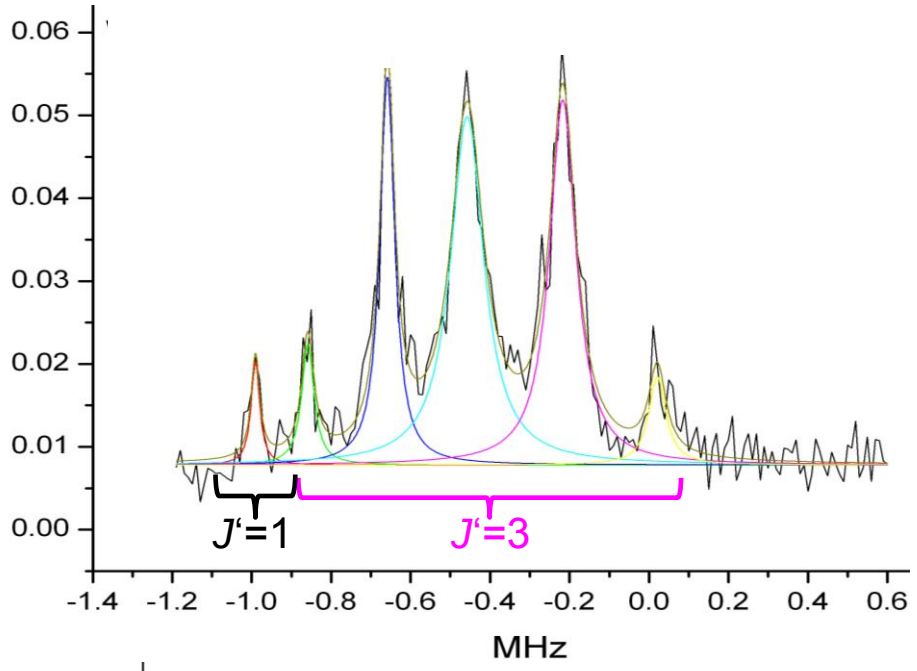

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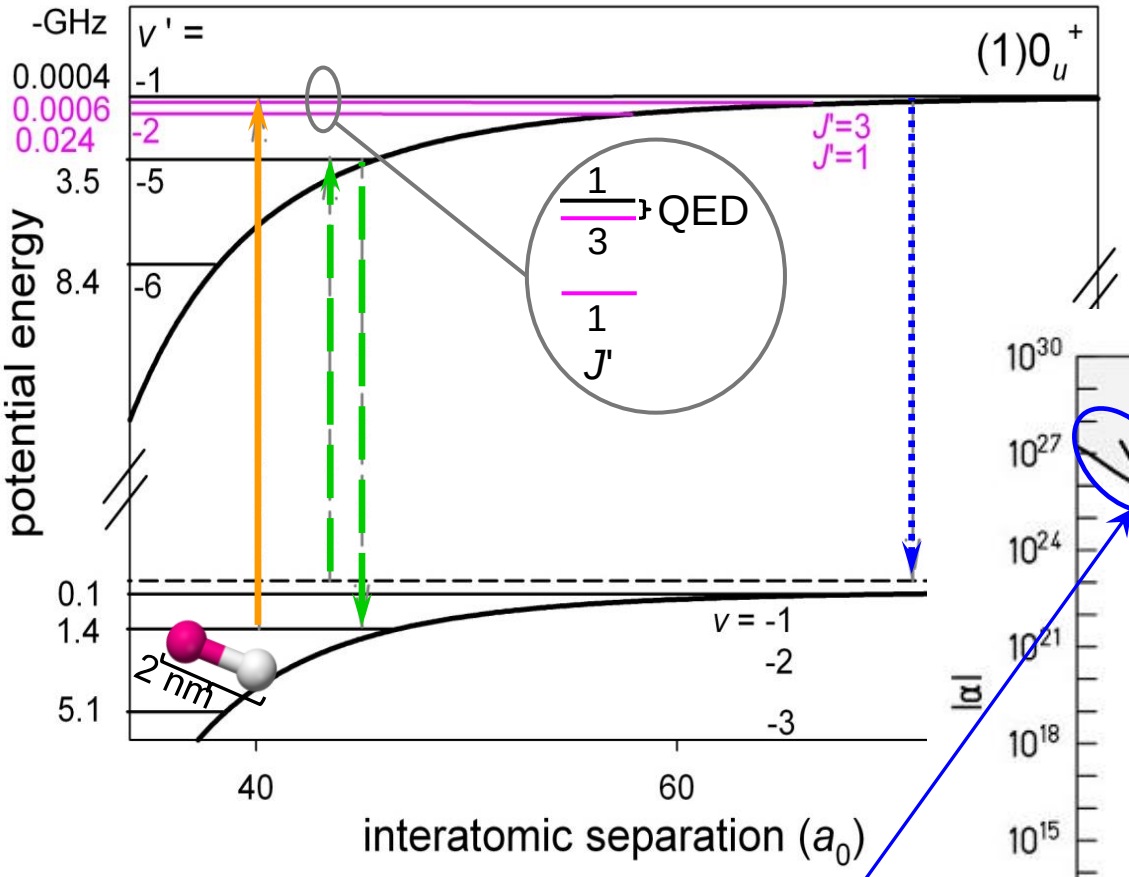

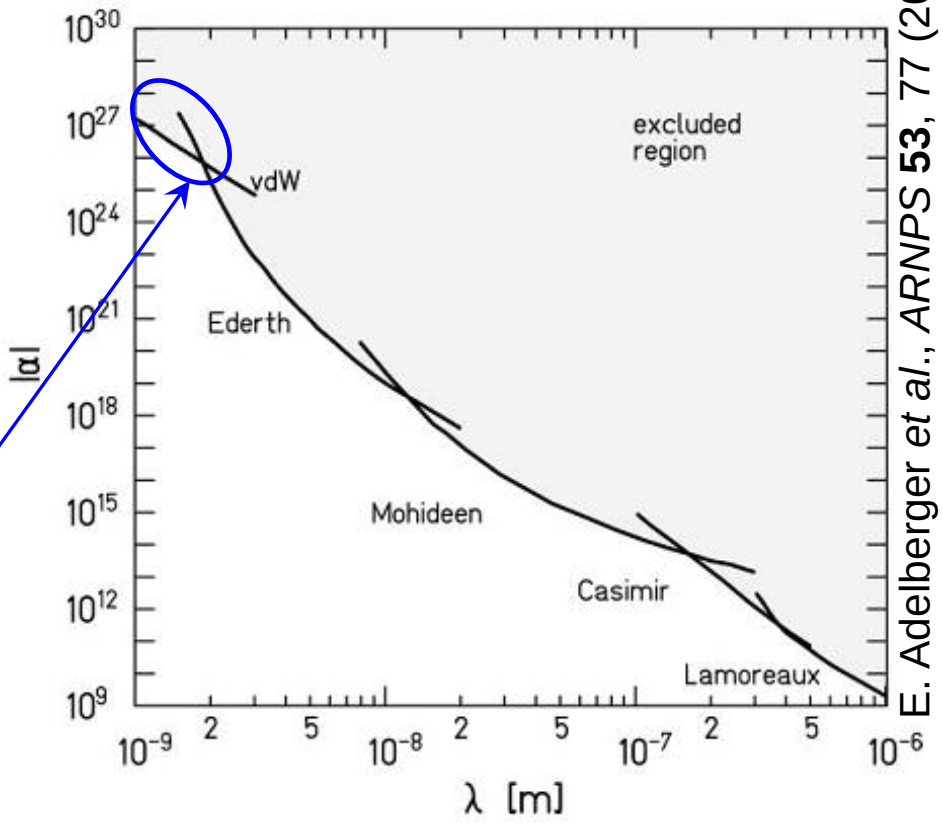

E. Adelberger *et al.*, *ARNPS* **53**, 77 (2003)

nm scale gravity

$$V(r) = -G\frac{m_1 m_2}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$

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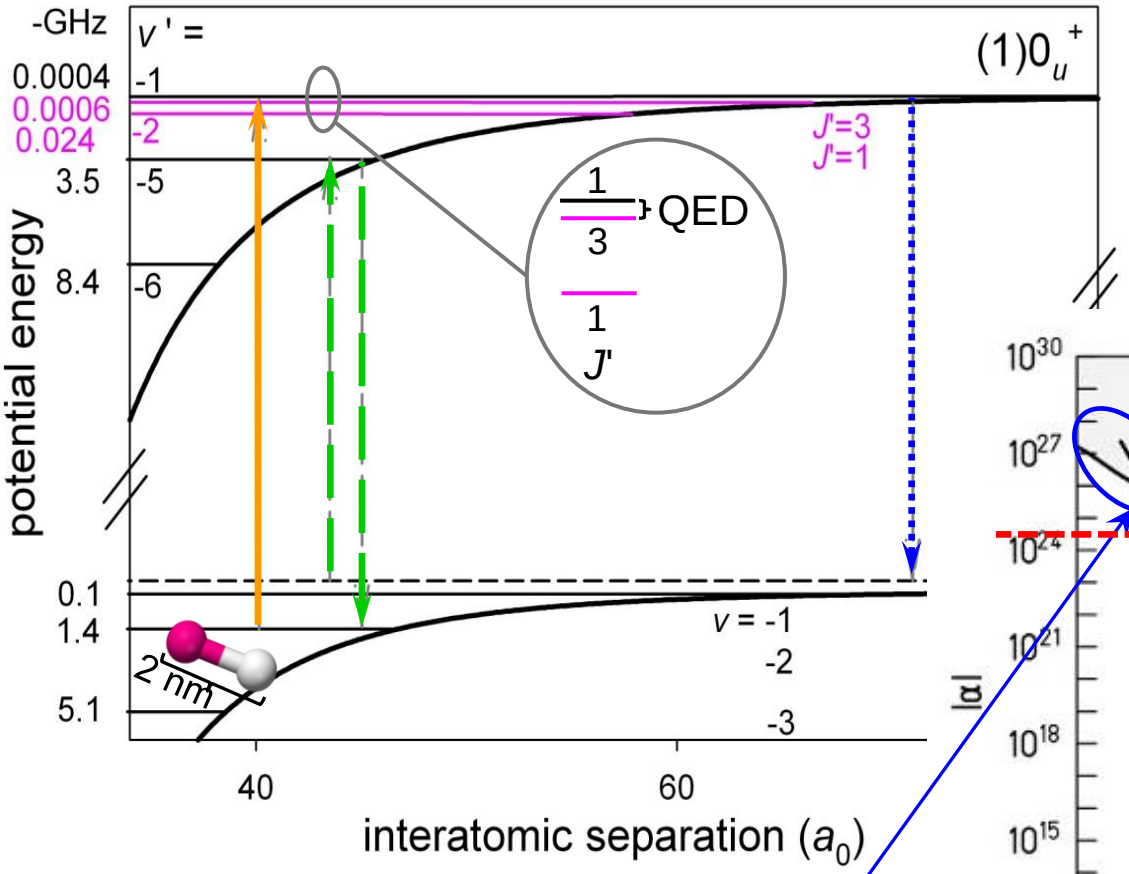
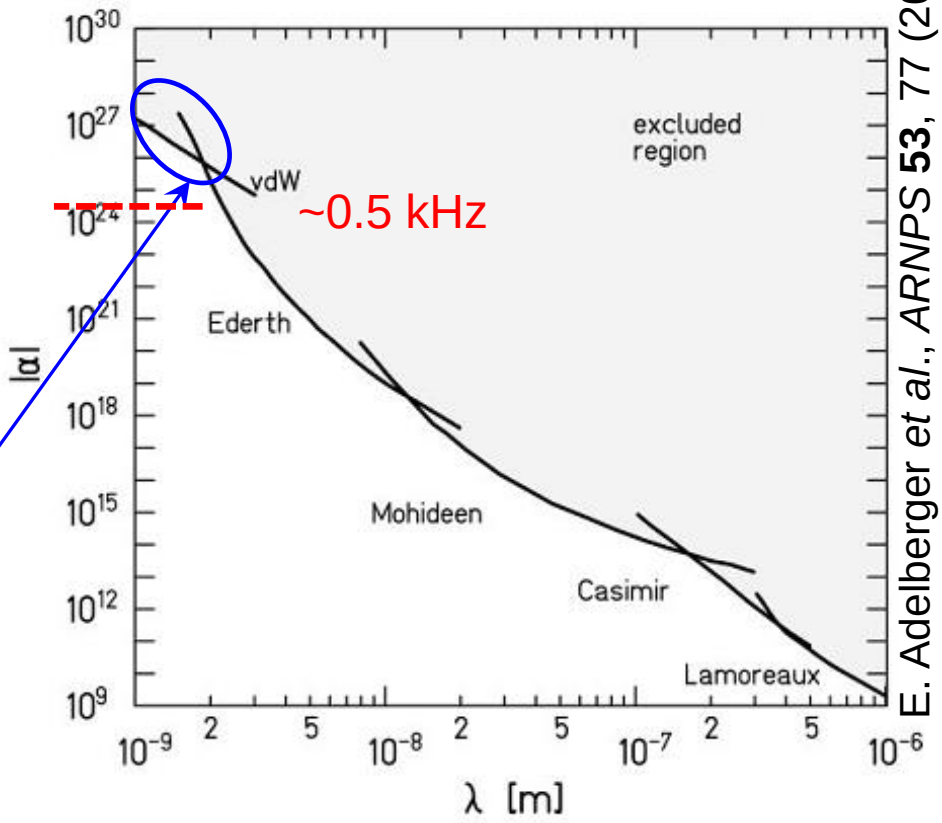


accurate Sr_2 potentials

A. Stein *et al*., *PRA* **78**, 042508 (2008)

A. Stein *et al*., *EPJD* **57**, 171 (2010)

R. Ciuryło *et al*.



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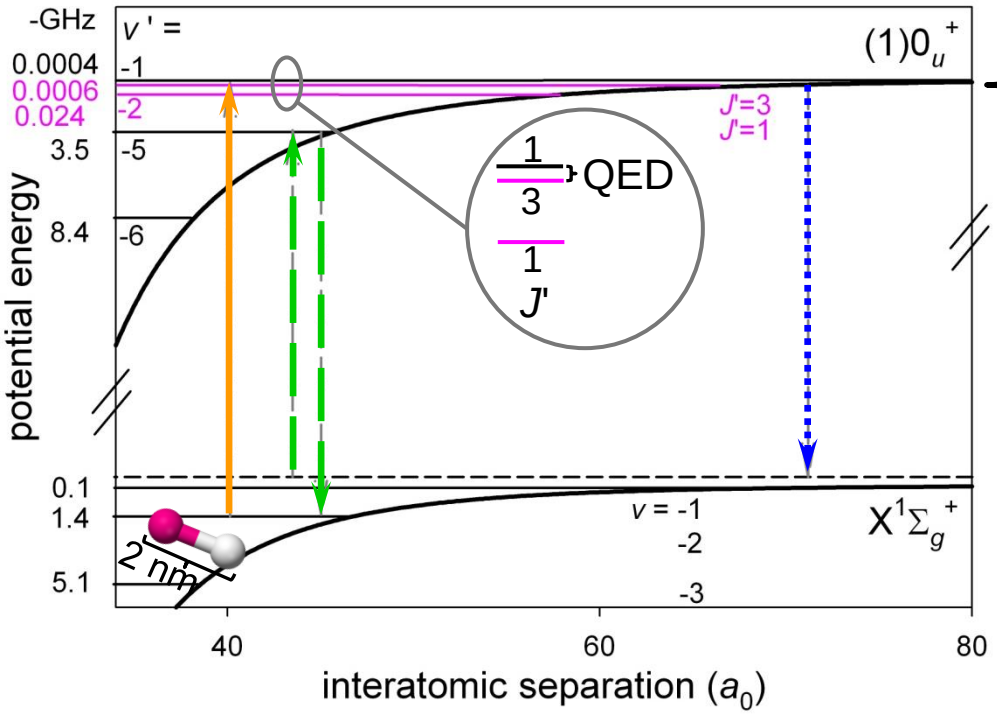
Anomalous Magnetic Susceptibility



nonadiabatic mixing

$$V_{0u} = -C_{6,0u}/R^6 - 2C_3/R^3 + h^2A_{0u}/(8\pi^2\mu R^2),$$

$$V_{1u} = -C_{6,1u}/R^6 + C_3/R^3 + h^2A_{1u}/(8\pi^2\mu R^2),$$

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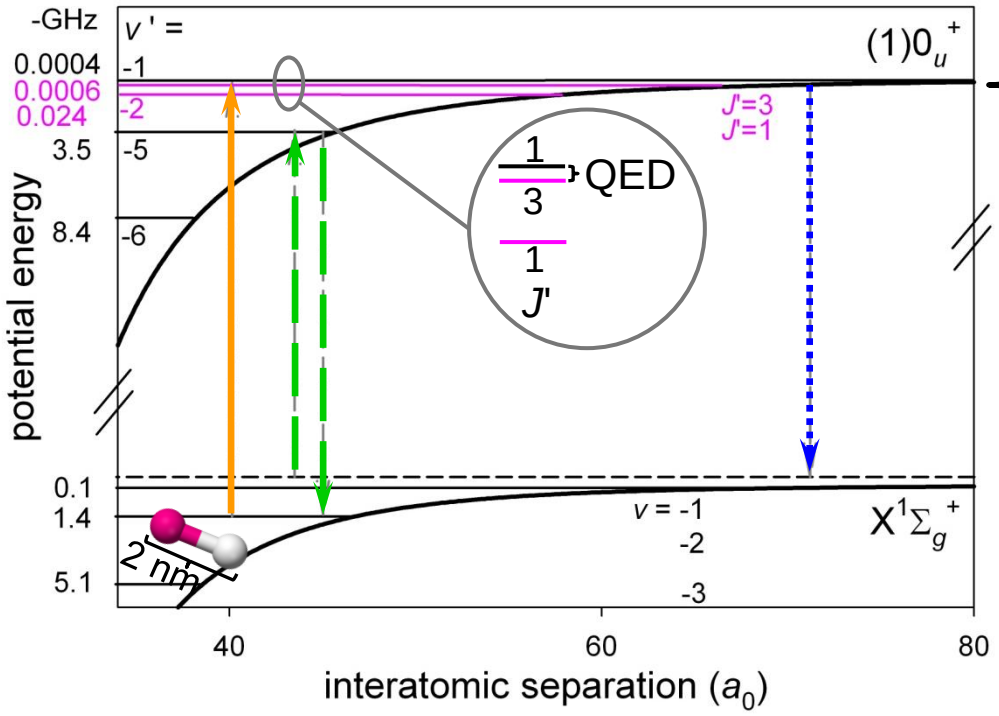

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1st & 2nd Zeeman

$$H_Z^{(1)} \approx \mu_B (g_l \vec{L} + g_S \vec{S}) \cdot \vec{B}$$

$$H_Z^{(2)} \approx -\frac{1}{2}\chi \vec{B}^2$$

magnetic susceptibility χ

$$\chi^{0_u^+}(R) \approx \frac{1}{2}\mu_B^2 \frac{|\langle 1_u|\vec{L}|0_u^+\rangle|^2}{V^{0_u^+}(R) - V^{1_u}(R)}$$

$$\chi^{0_u^+}(R) \approx -\mu_B^2 \frac{R^3}{3\delta C_3}$$

$R \approx 500\ a_0$!

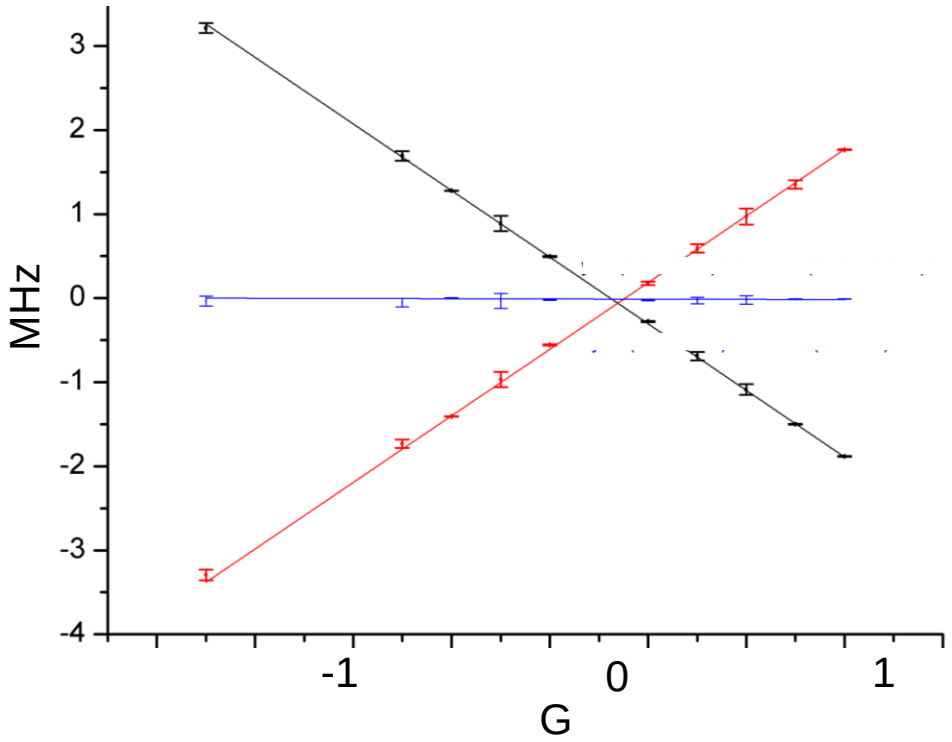
R. Moszynski *et al*.

Anomalous Magnetic Susceptibility

$^1S_0 - {}^3P_1$ Sr transition

$g = 1.5$

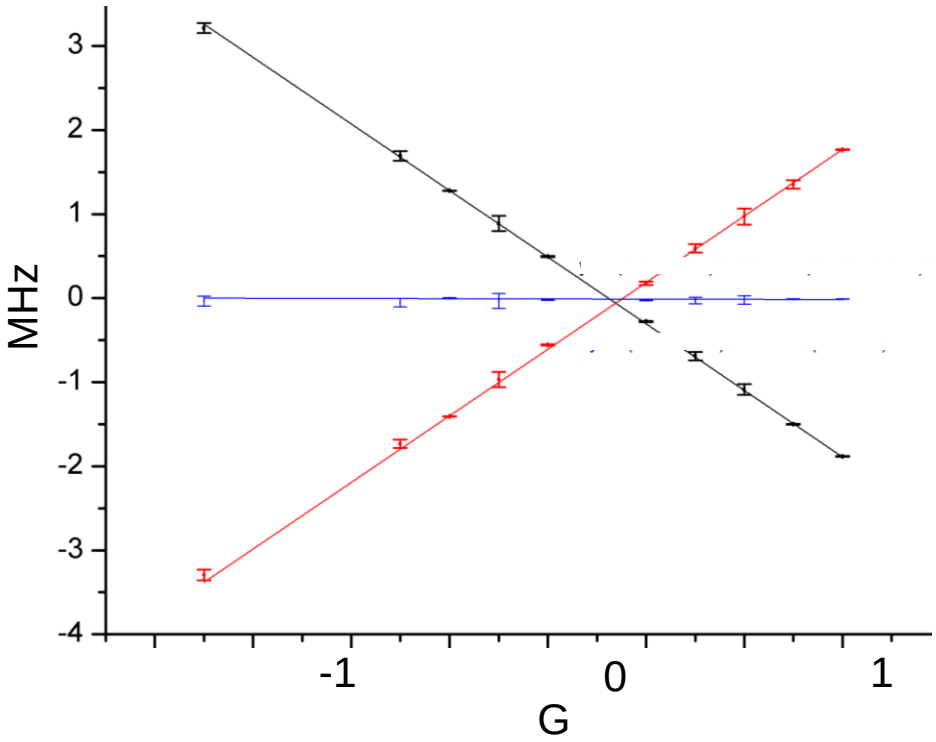
$\chi \approx 0.4$ Hz/G^2

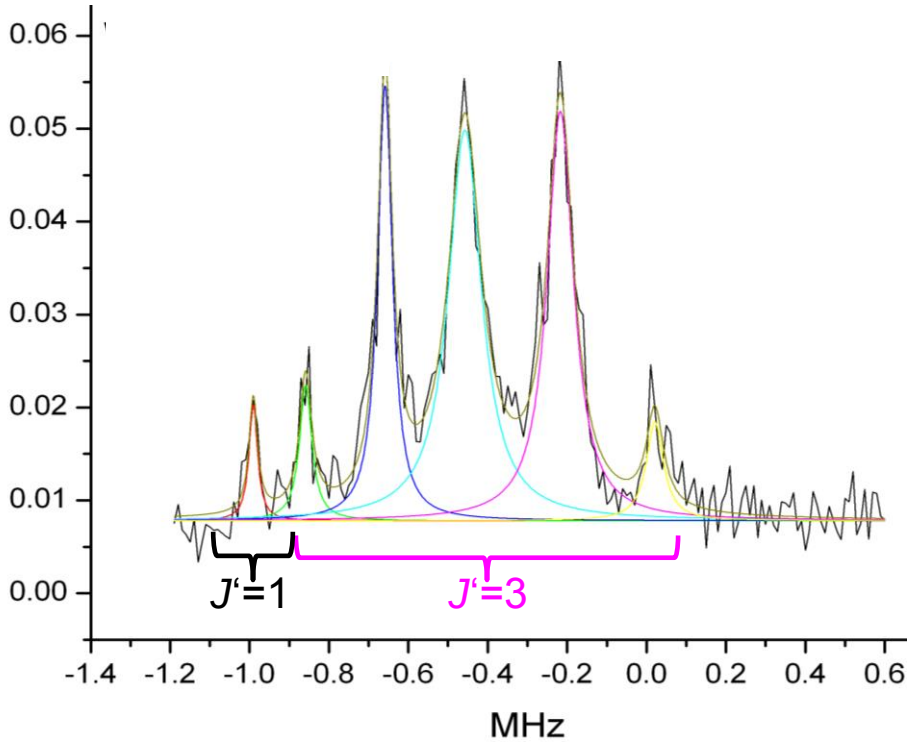


Anomalous Magnetic Susceptibility

10^6 enhancement !

$^1S_0 - {}^3P_1$ Sr transition	$X - 0_u^+$ Sr_2 transition (near $^1S_0 + {}^3P_1$)
$g = 1.5$	$g = 0.2 - 0.7$!
$\chi \approx 0.4$ Hz/G^2	$\chi \approx 0.4$ MHz/G^2 !





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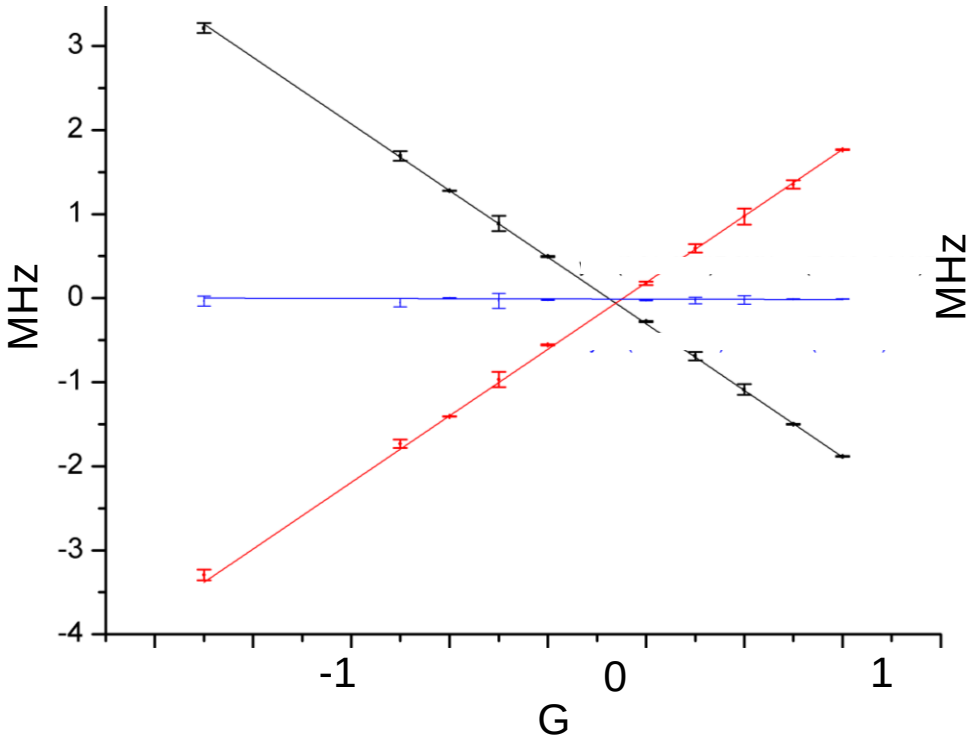

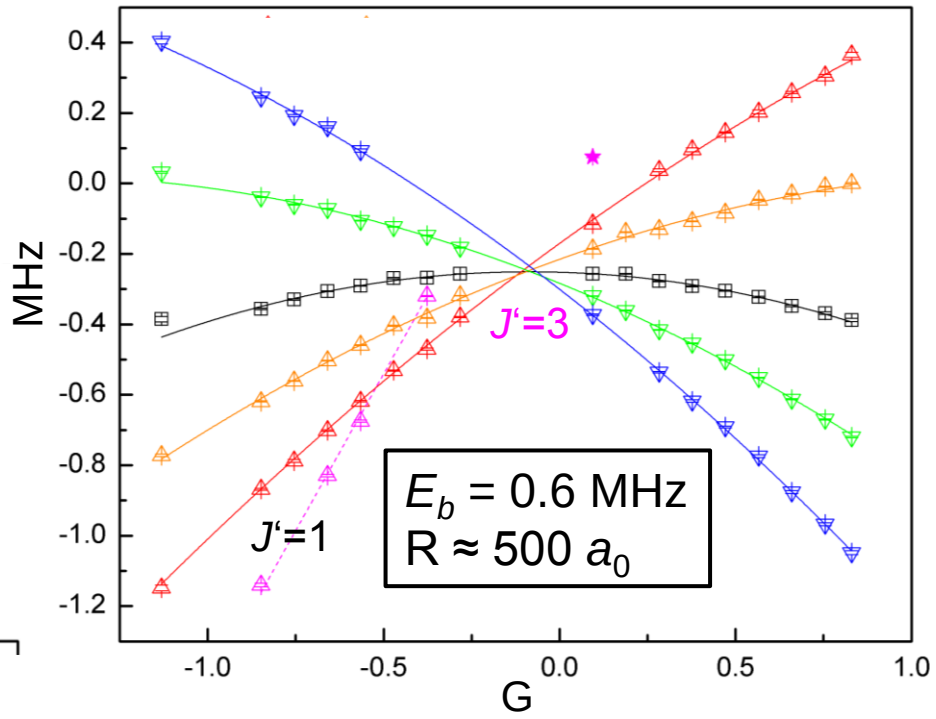

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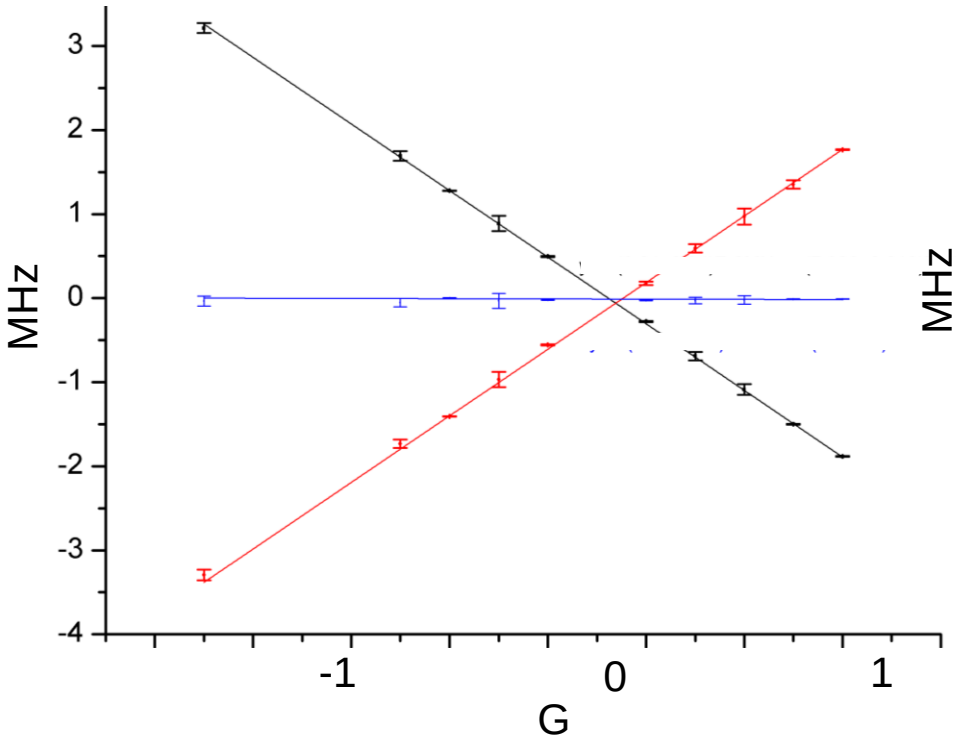
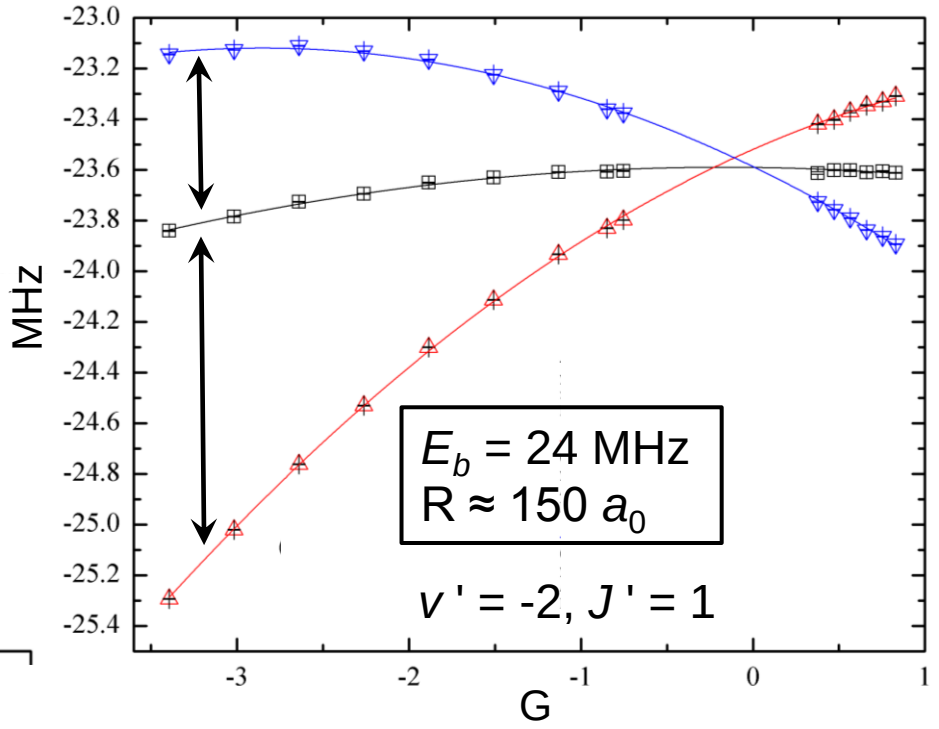


$X - 0_u^+$ Sr_2 transition (near $^1S_0 + {}^3P_1$)

$g = 0.2 - 0.7$!

$\chi \approx 0.04$ MHz/G^2 (10÷)



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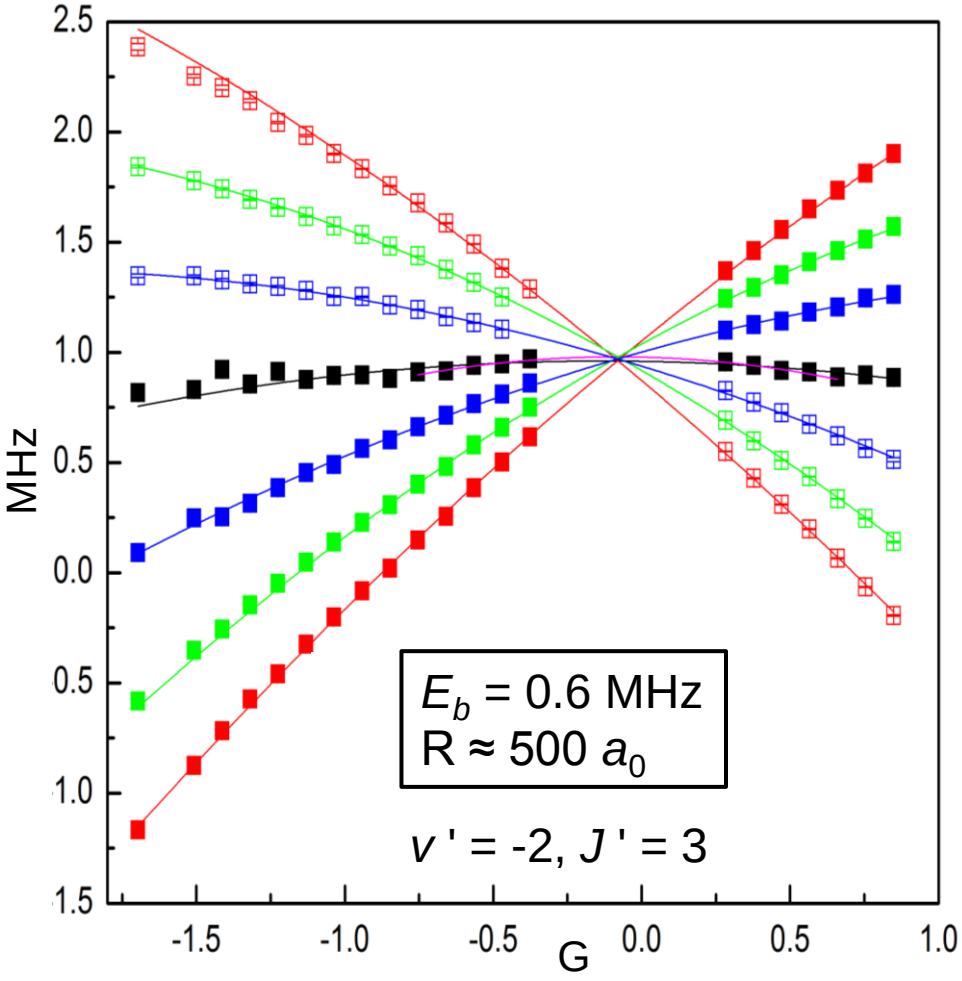

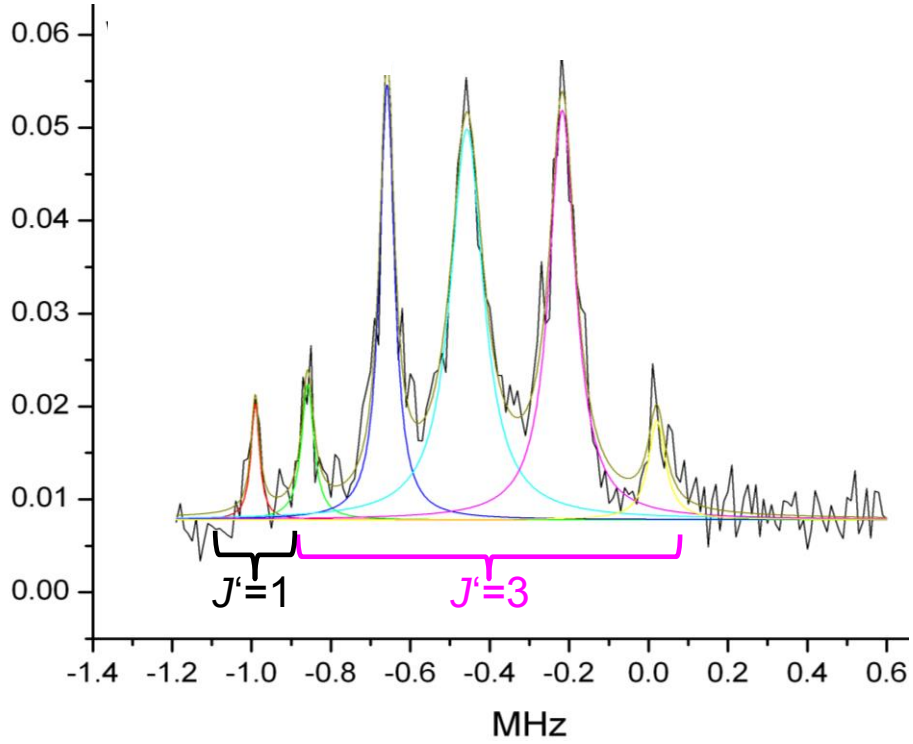

Why?

next talk

- Pathway to dipolar gas of SrAlkali, SrYb

✓

- All-optical ultracold molecules in known quantum state
- High-*Q* study of quantum chemistry
- Anomalously large magnetizability

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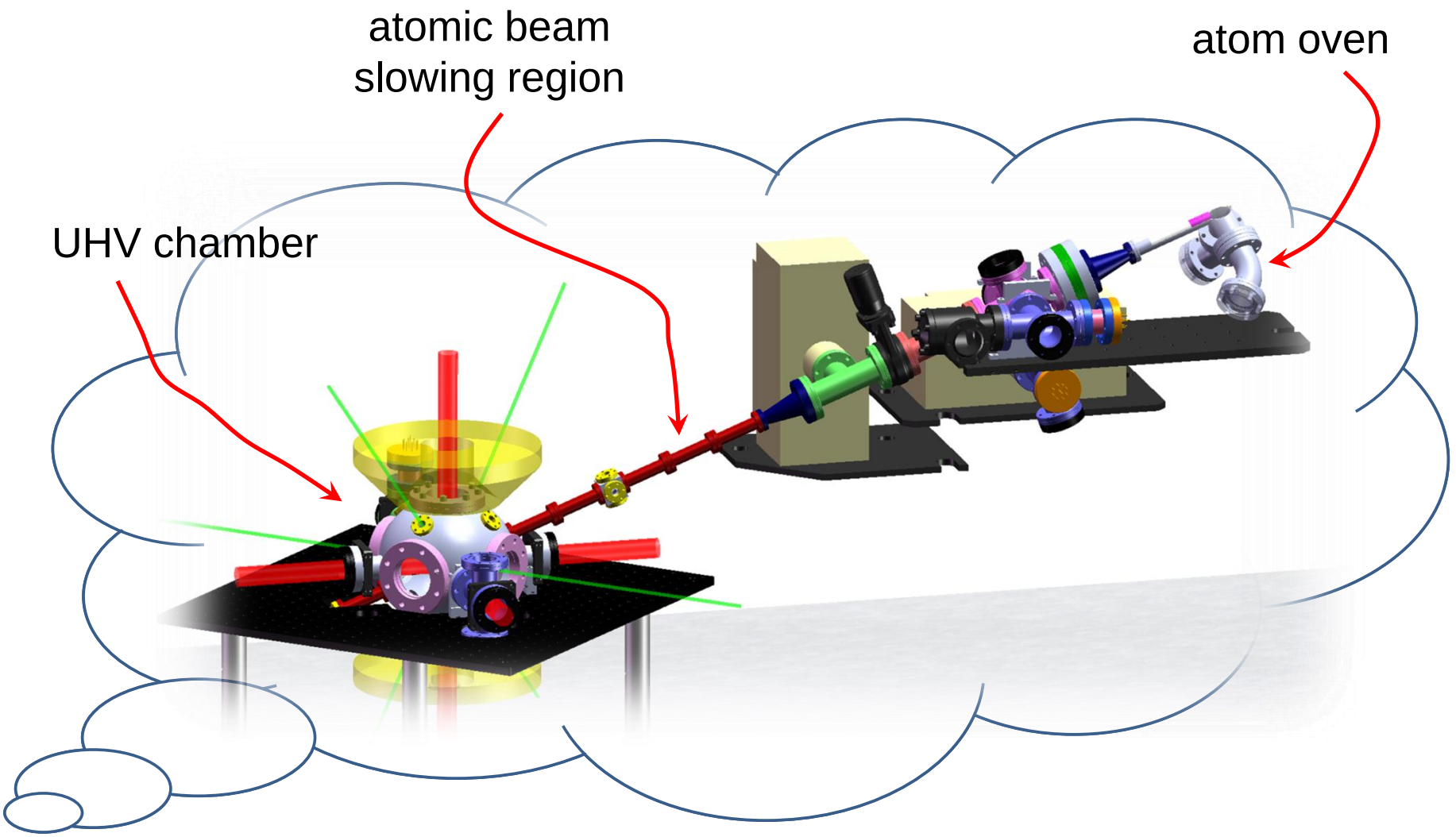
- QED in heavy molecules
- nm scale test of Newtonian gravity

future

- molecular clock based test of m_e/m_p variations
- Bridging time metrology gap between RF and optical

Lab Tour



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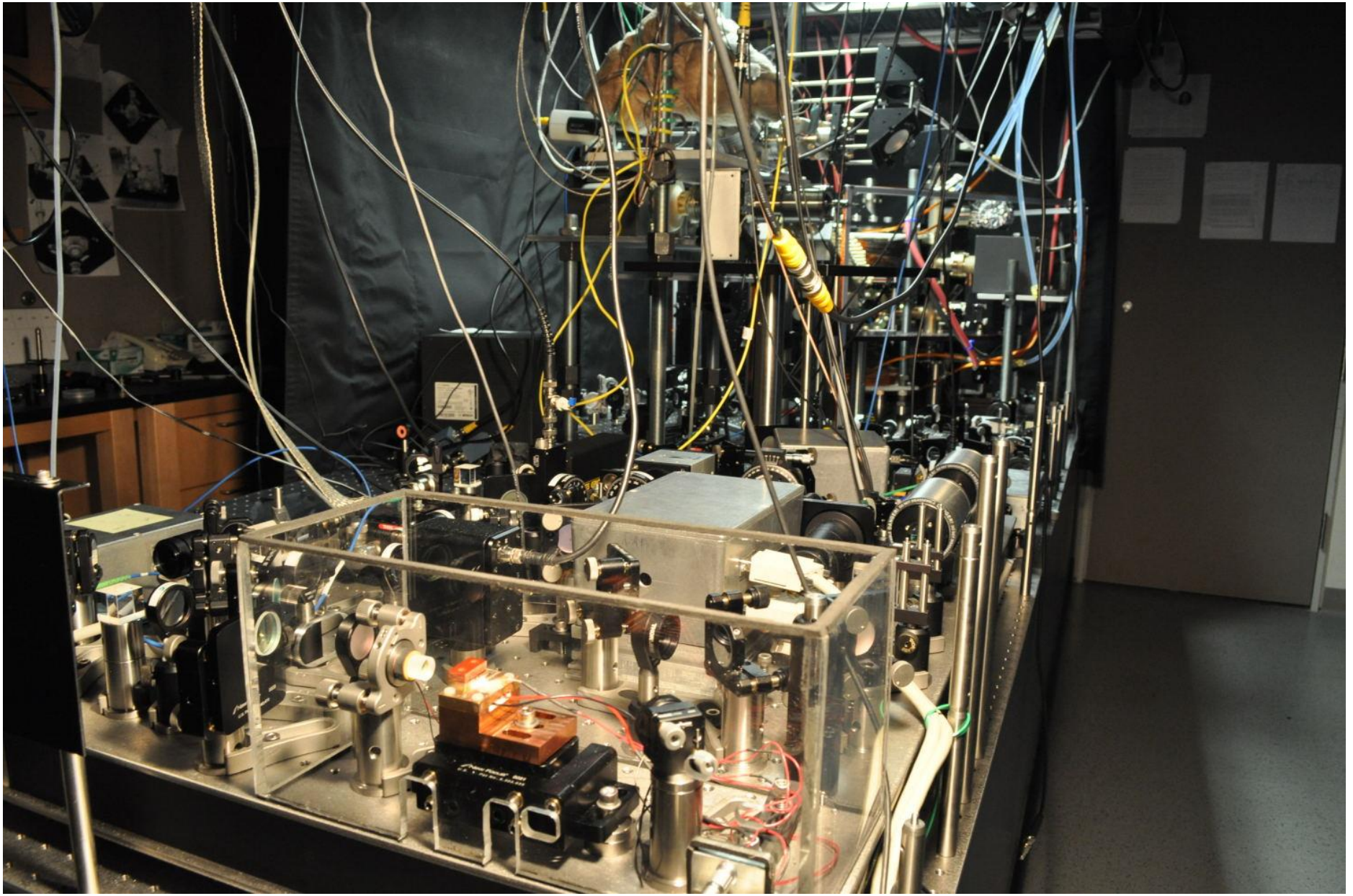

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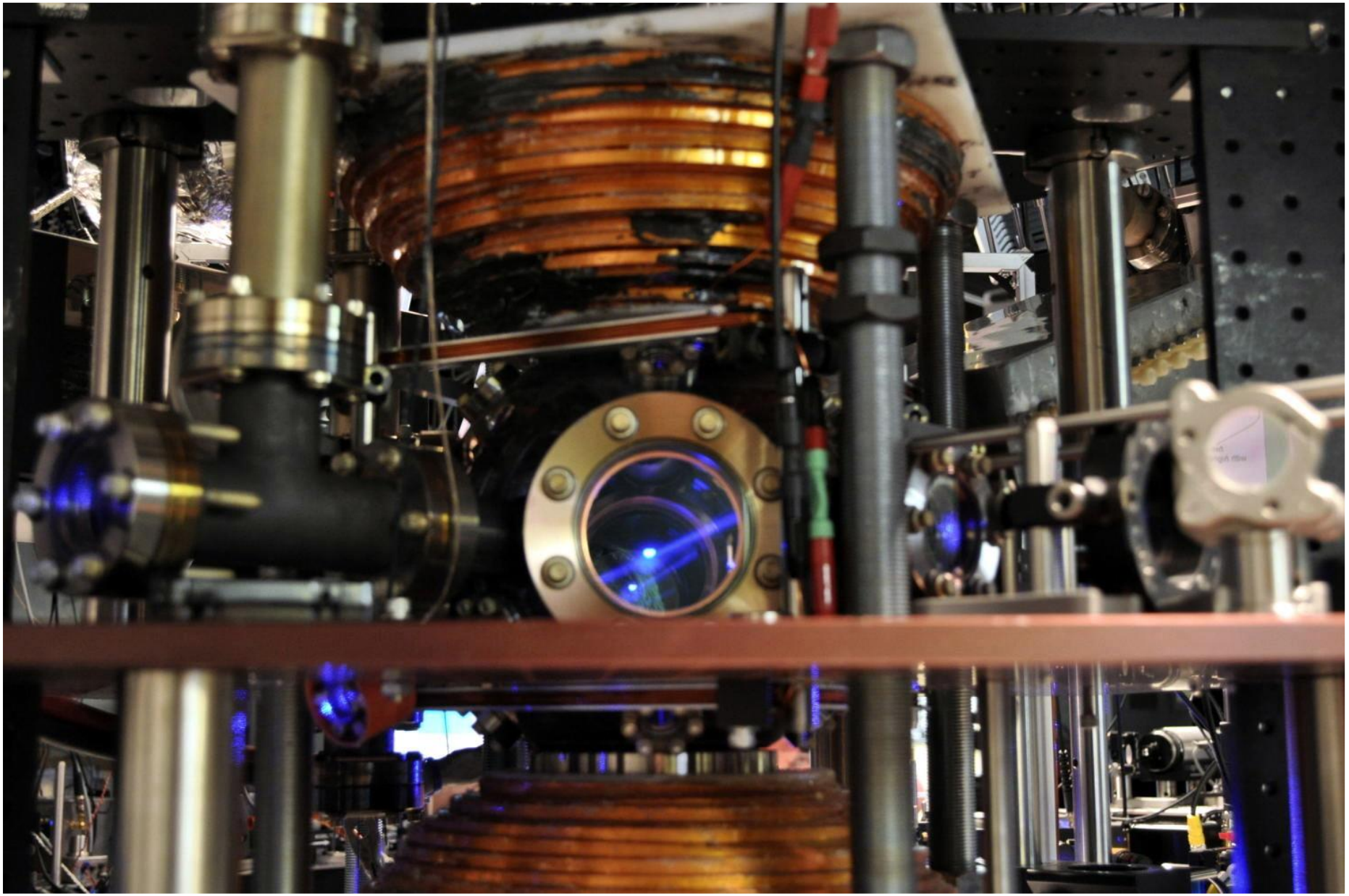
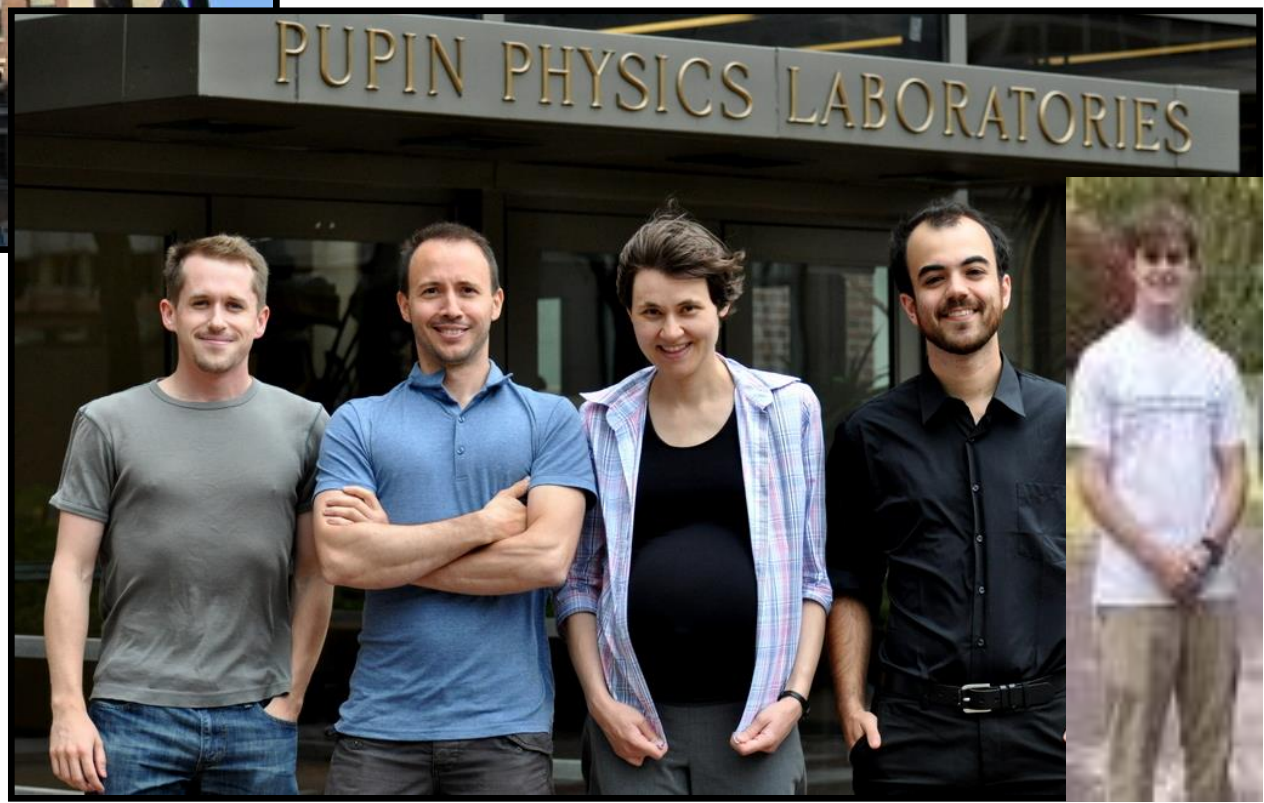


Columbia Ultracold Team



Theory collaborations:
R. Moszynski,
S. Kotochigova,
R. Ciuryło, *et al.*

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ARO,
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