# Rotational and vibrational cooling of $H_3^+$ in laboratory experiments

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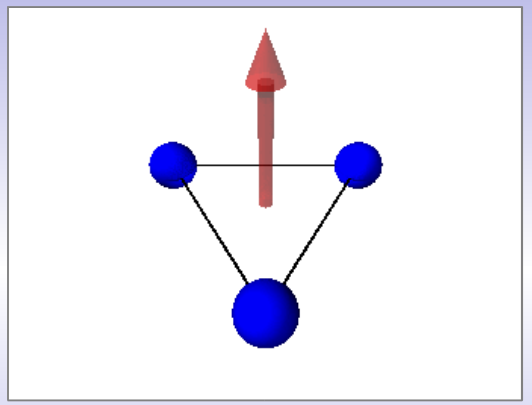
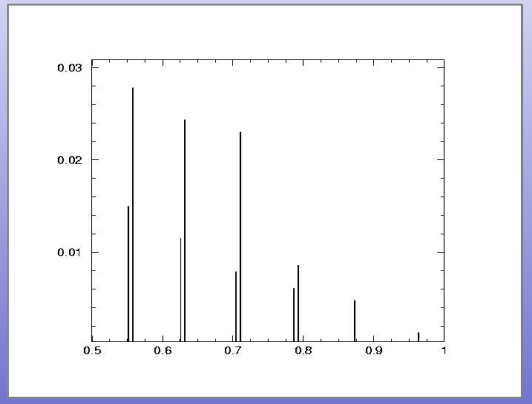
# Rotational and vibrational cooling of $H_3^+$ in laboratory experiments

## Outline

- Motivation,
- TSR Experiments,
- Relaxation model,
  - Vibrational decay,
  - Longlived rotational states,
  - Radiative heating,
- Conclusions.





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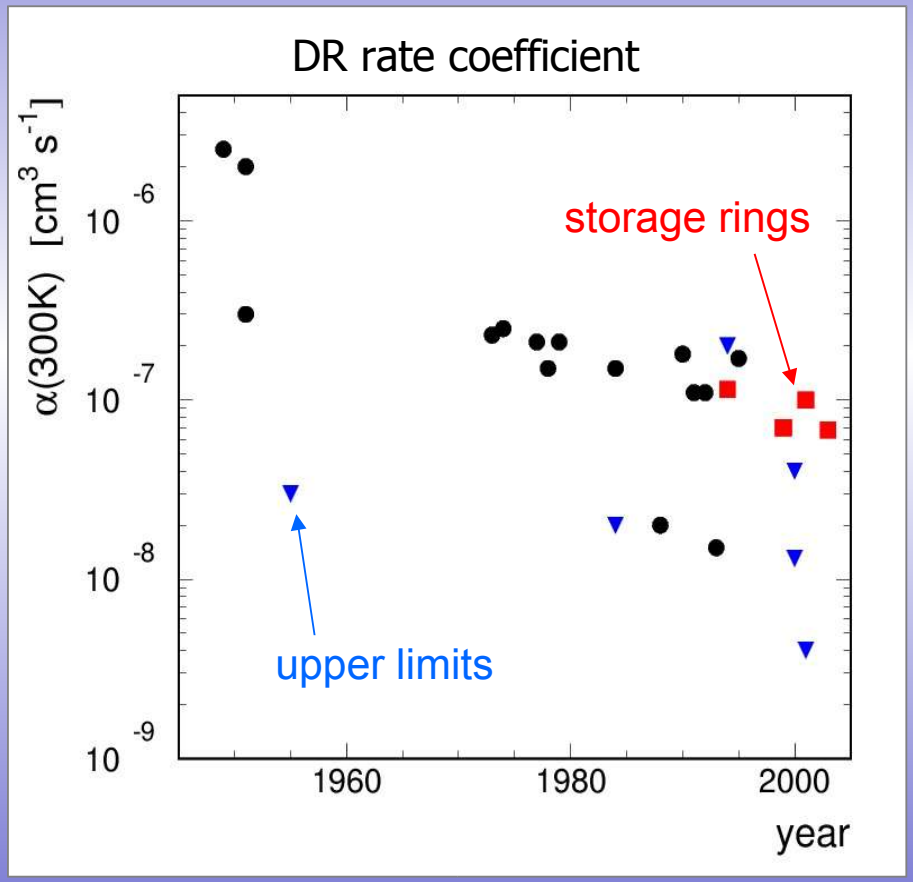
# Motivation: the $H_3^+$ DR dilemma




Dissociative Recombination (DR)

$$H_3^+ + e^- \rightarrow \begin{cases} H_2 + H \\ H + H + H \end{cases}$$

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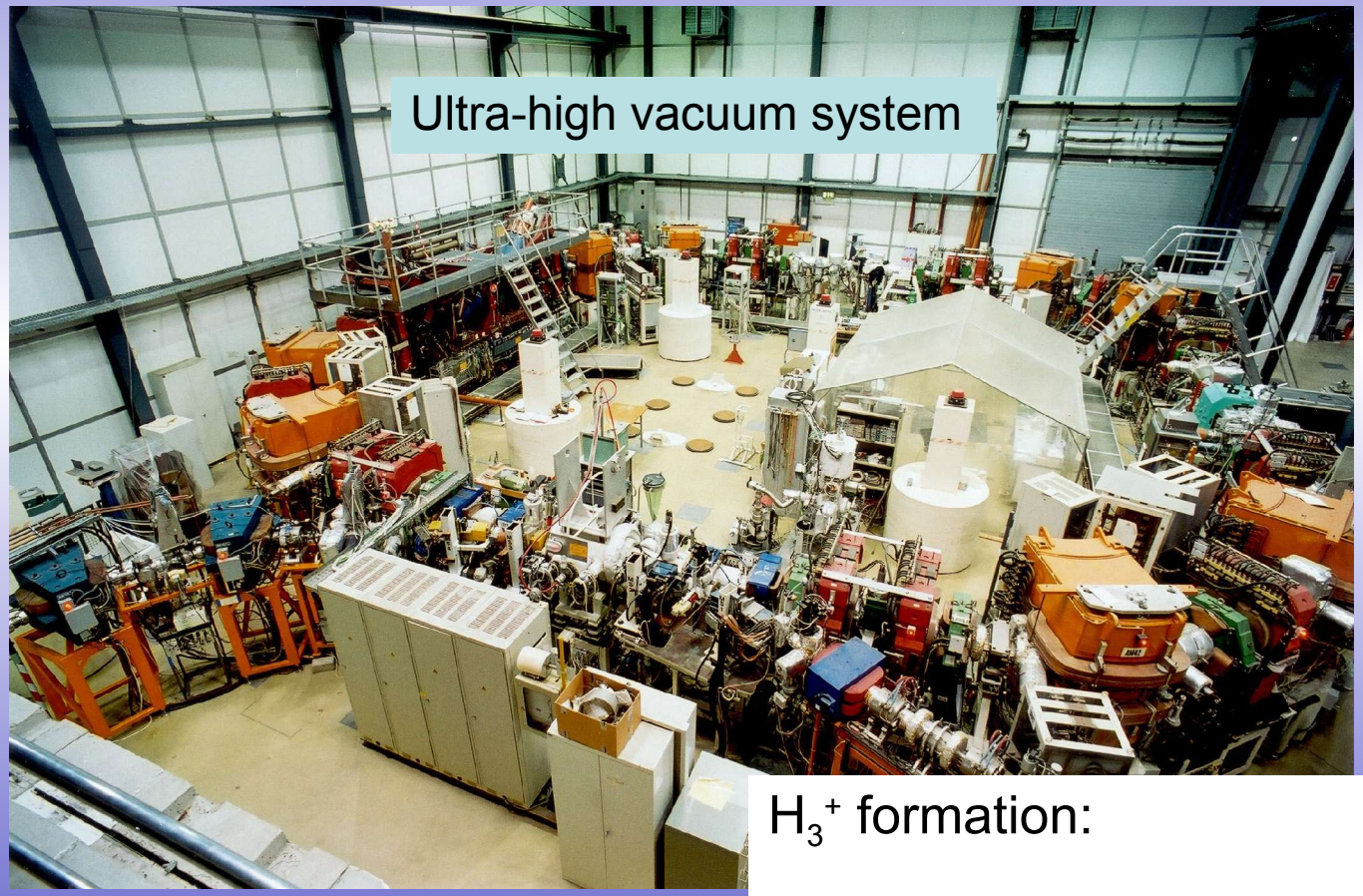
# The TSR storage ring




$H_3^+$ formation:

$H_2^+ + H_2 \longrightarrow H_3^+ + H$ **+ 1.7eV!**

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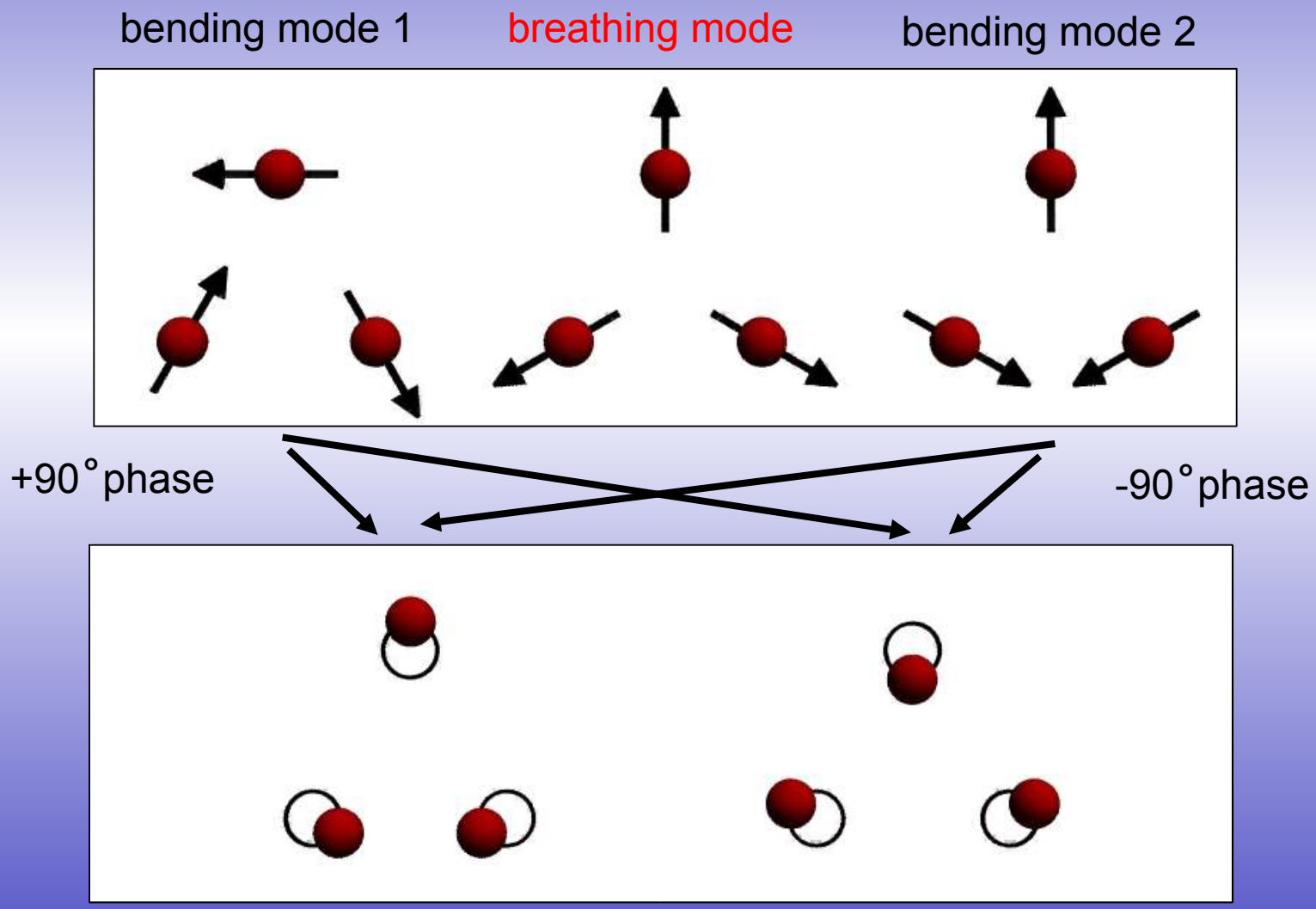
# $H_3^+$ vibrational excitation



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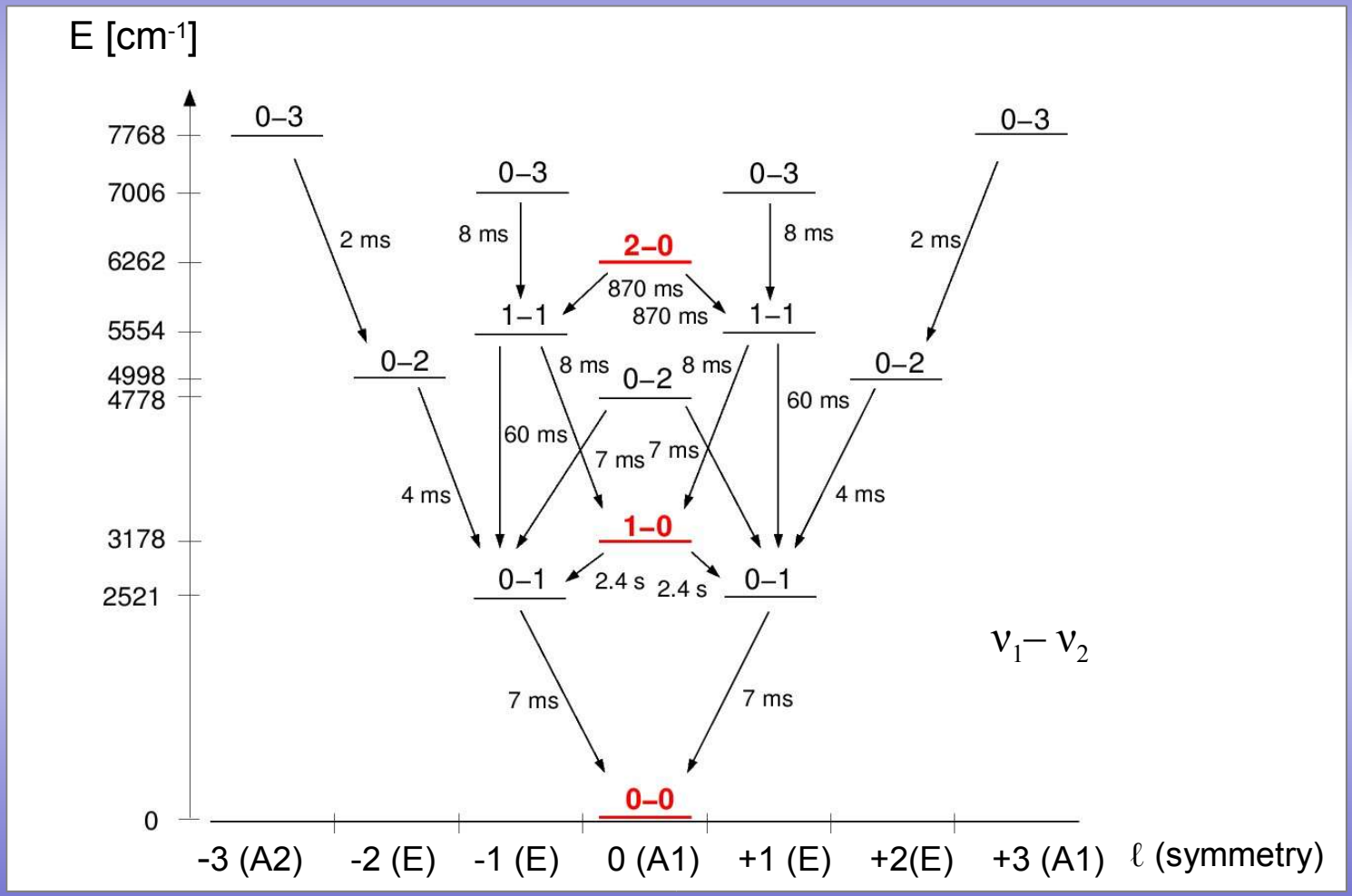
# $H_3^+$ vibrational levels



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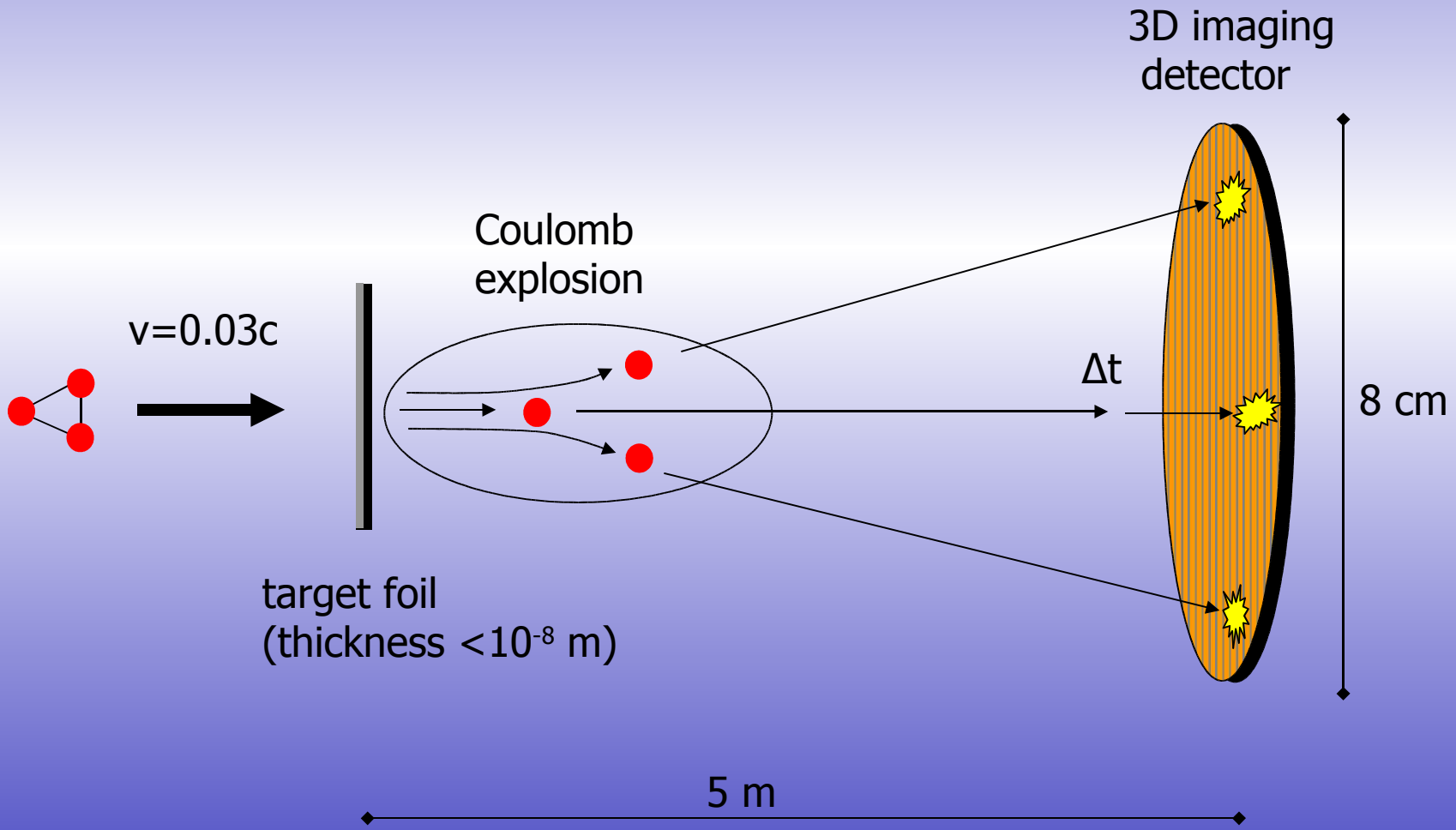
# Coulomb Explosion Imaging Technique (CEI)



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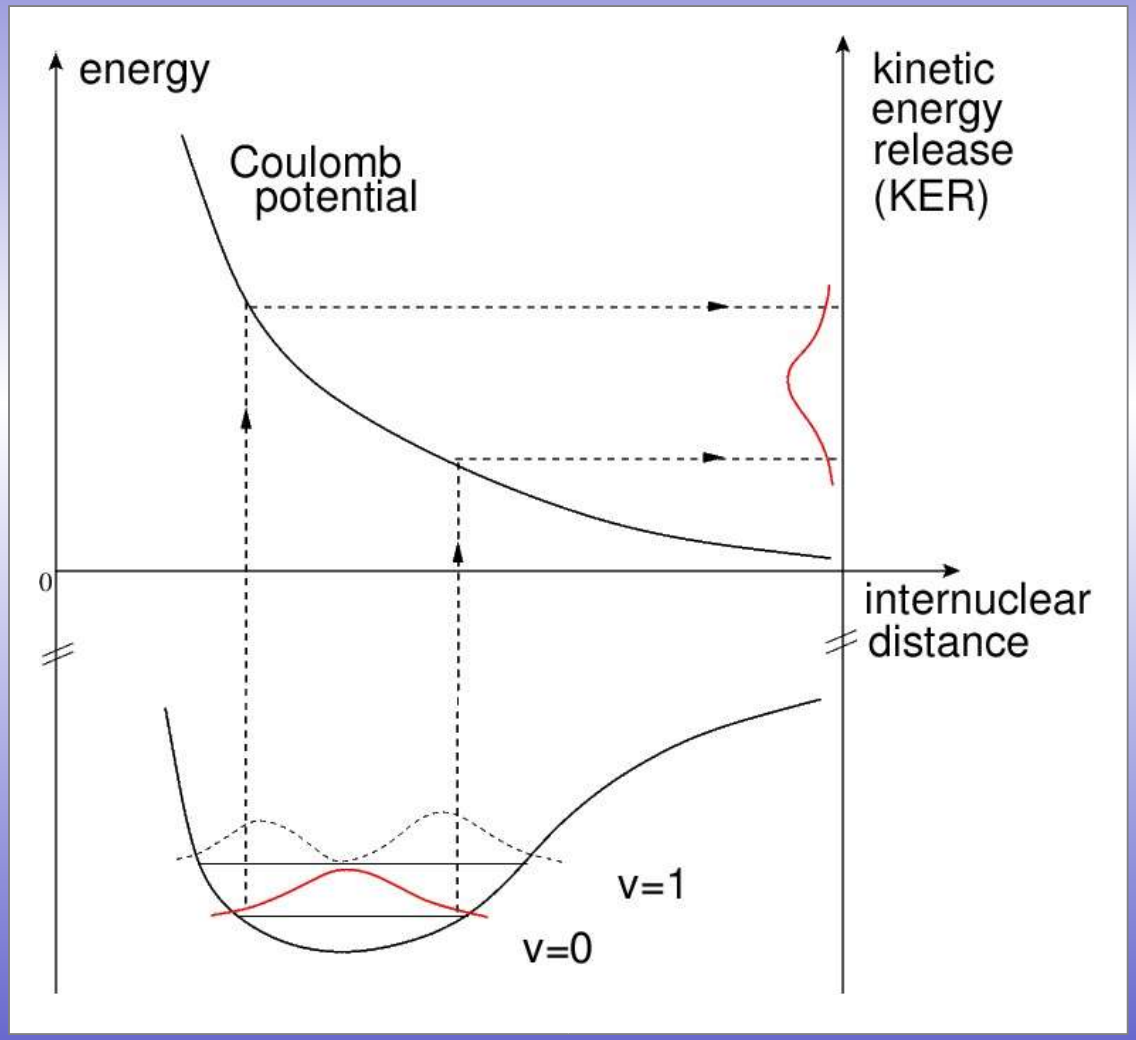
# Coulomb explosion principle



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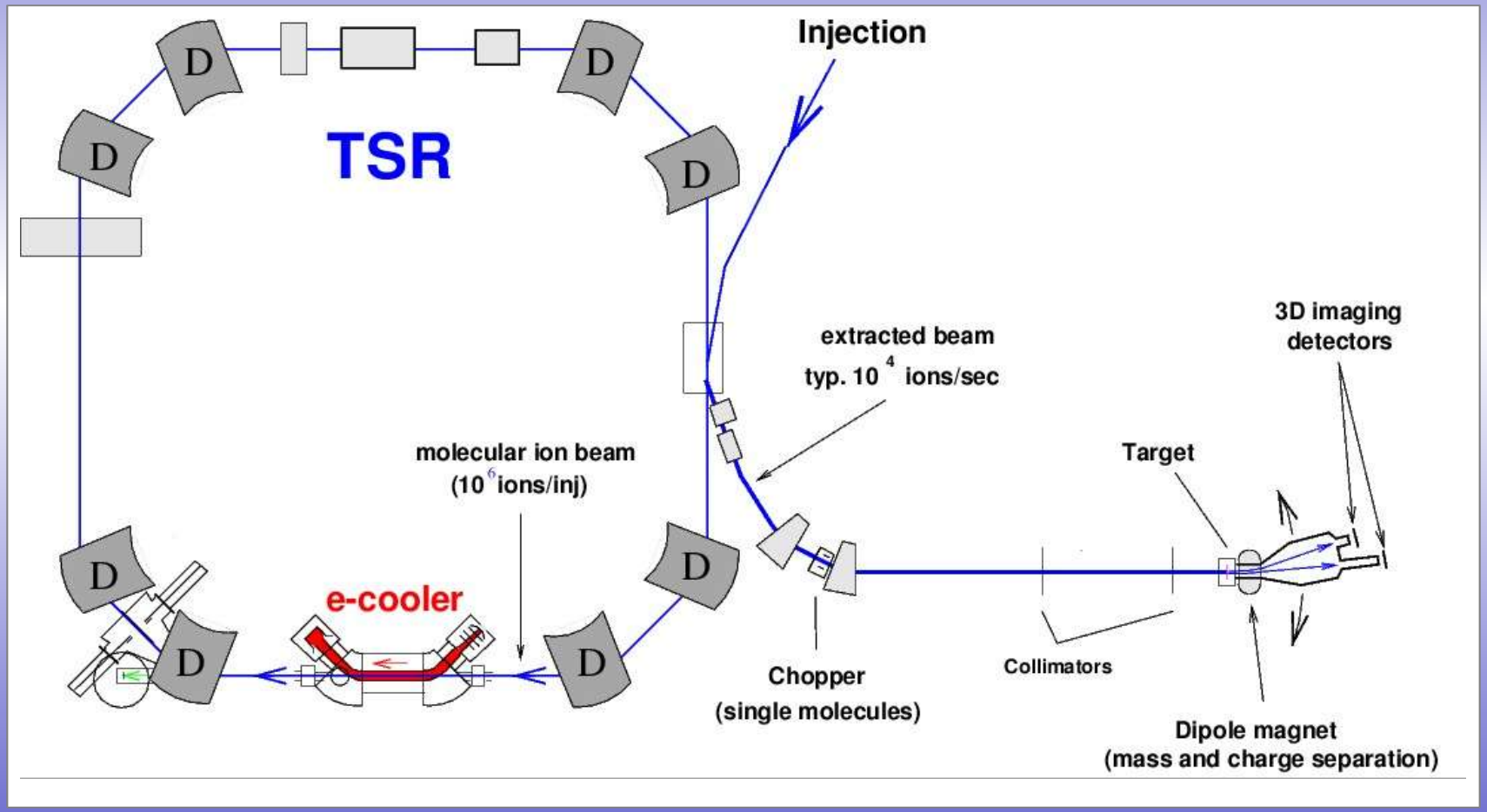
# CEI Setup: Slow extraction



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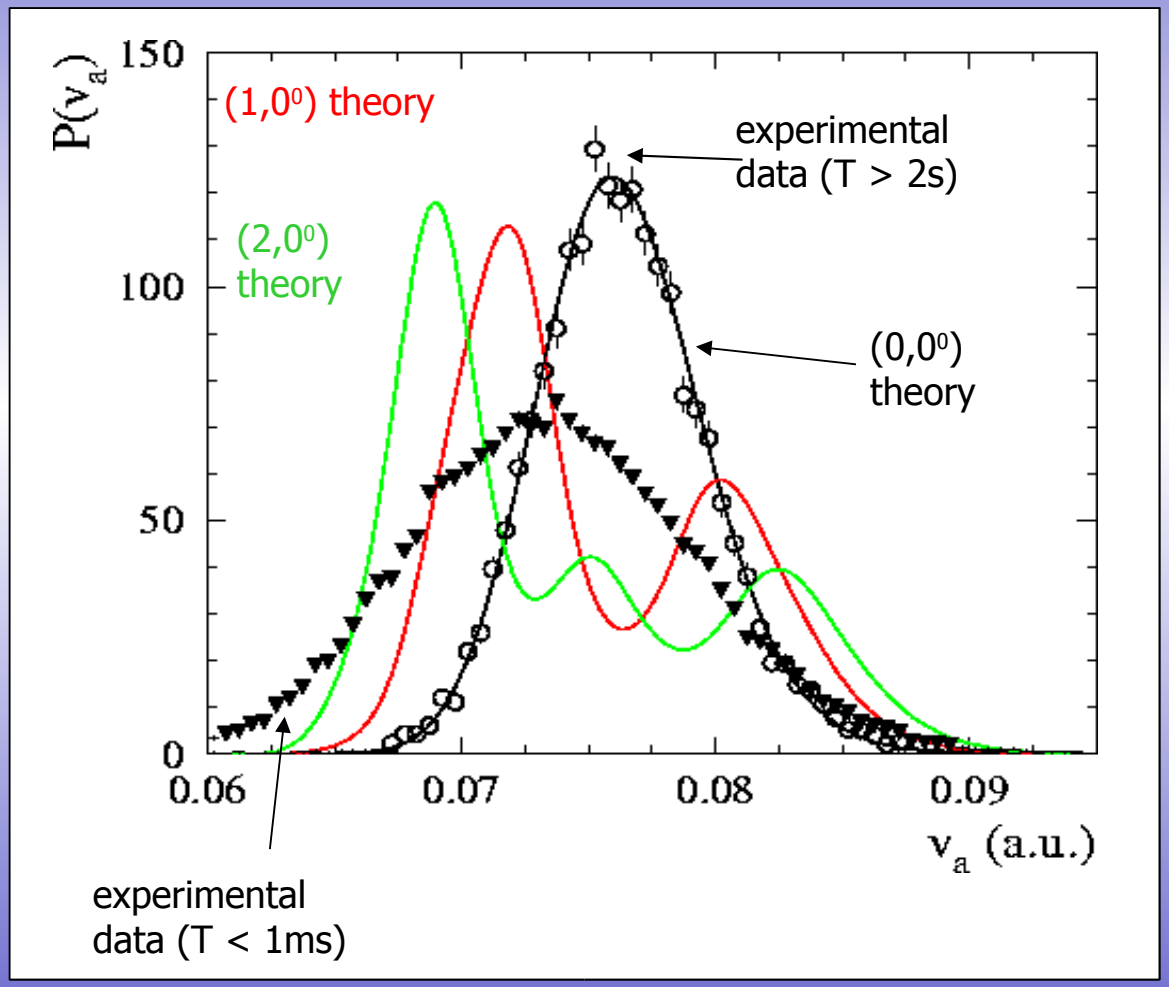
# Coulomb explosion results $H_3^+$



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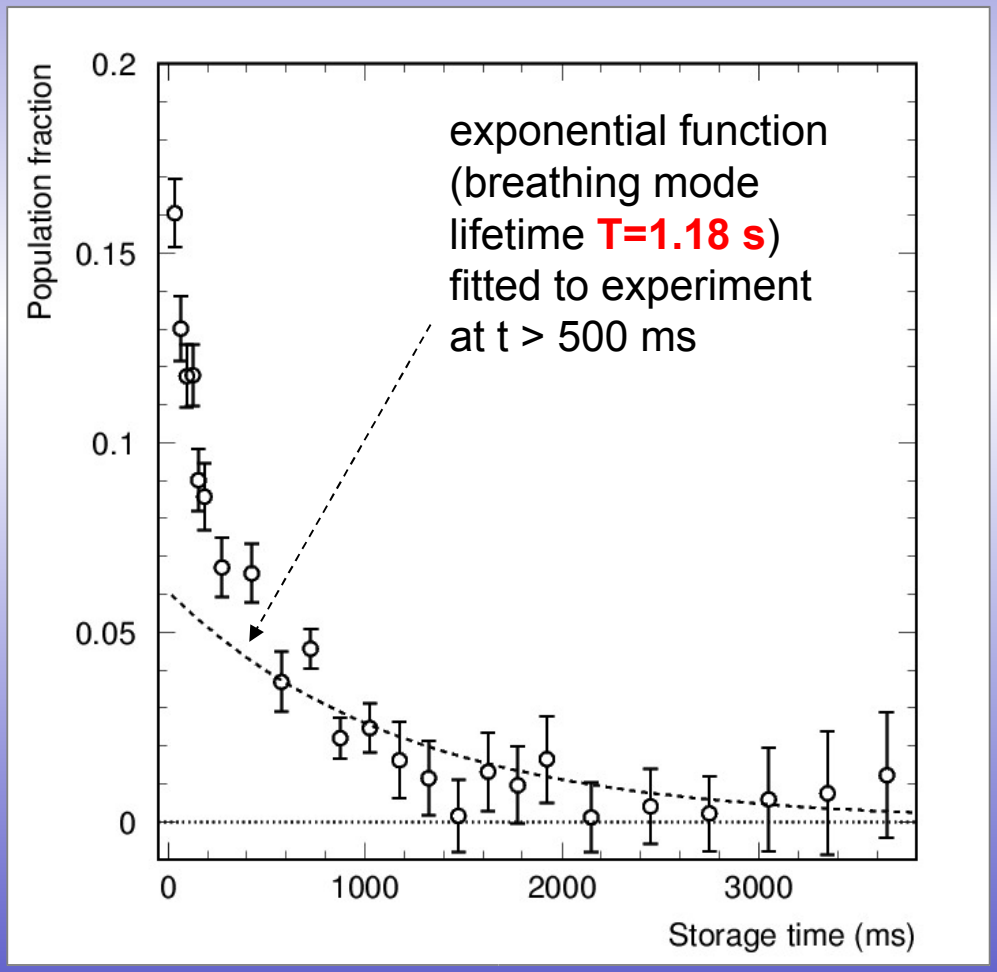
# Decay of the first breathing mode $(1,0^0)$ of $H_3^+$



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# DR fragment imaging

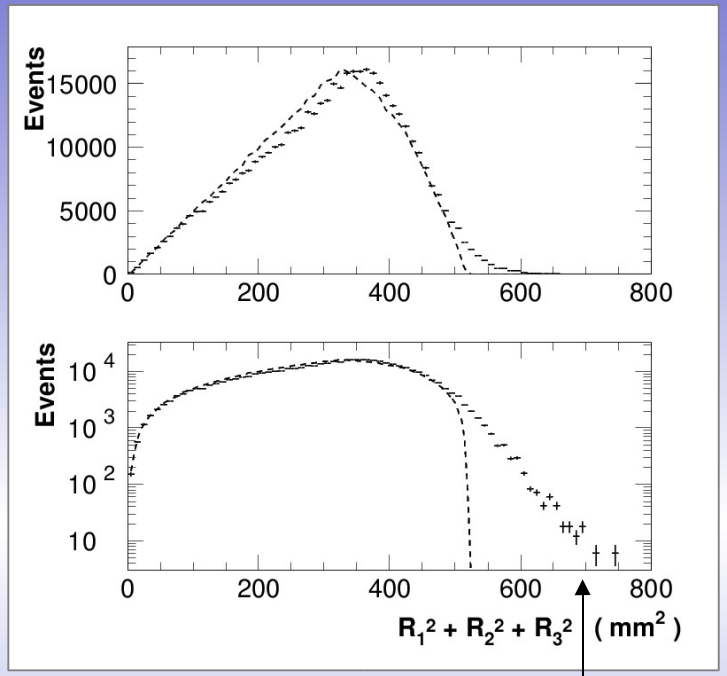
three-body breakup

**$H_3^+ + e^- \longrightarrow H + H + H$**

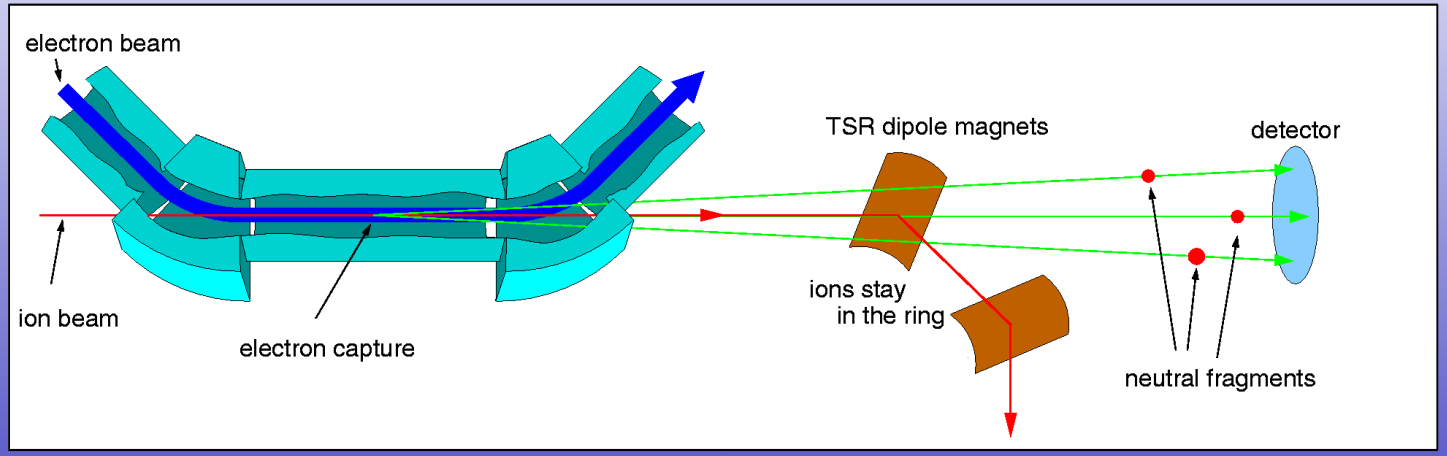
reveals substantial rotational excitation

**$T_{rot}$ ~ 2700K** for storage times up to 60 s

D. Strasser et al., PRL **86**, 779 (2001)




signature of excess energy up to 1 eV



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# The UCL line list for $H_3^+$

| $J_i$ | $E_i$ (cm$^{-1}$) | $J_f$ | $E_f$ (cm$^{-1}$) | $\tilde{\nu}_{if}$ (cm$^{-1}$) | $A_{if}$ (s$^{-1}$) | $g_i$ |
|---|---|---|---|---|---|---|
| 10 | 5559.156 | 9 | 2702.08 | 2857.0759 | 0.1864E + 01 | 2 |
| 8 | 7425.172 | 8 | 4567.275 | 2857.8973 | 0.1001E − 01 | 2 |
| 6 | 6650.963 | 5 | 3793.033 | 2857.9299 | 0.2614E + 02 | 2 |
| 11 | 7592.384 | 11 | 4734.082 | 2858.3022 | 0.4208E − 06 | 8/3 |
| 5 | 6679.233 | 4 | 3820.803 | 2858.4294 | 0.7224E + 02 | 4 |
| 9 | 7074.147 | 10 | 4215.239 | 2858.9074 | 0.1016E − 06 | 8/3 |
| 7 | 6736.544 | 7 | 3877.035 | 2859.5084 | 0.1871E − 03 | 2 |
| 12 | 7494.607 | 12 | 4634.287 | 2860.3195 | 0.1253E − 04 | 8/3 |
| 7 | 7436.699 | 6 | 4575.975 | 2860.7237 | 0.3921E + 02 | 2 |
| 2 | 7703.346 | 1 | 4842.568 | 2860.7781 | 0.5750E − 02 | 2 |
| 7 | 7317.772 | 7 | 4456.901 | 2860.8705 | 0.2691E + 00 | 2 |
| 8 | 5257.293 | 9 | 2396.415 | 2860.8785 | 0.1084E − 01 | 2 |
| 11 | 7157.95 | 10 | 4296.621 | 2861.3287 | 0.2814E − 01 | 8/3 |
| 5 | 6529.265 | 4 | 3667.123 | 2862.1418 | 0.2532E + 02 | 2 |

L. Neale, S. Miller, J. Tennyson, Astroph. J., **464**, 516 (1996)

B. M. Dinelli, L. Neale, O.L. Polyansky, J. Tennyson, J. Mol. Spectrosc., **181**, 142 (1997)

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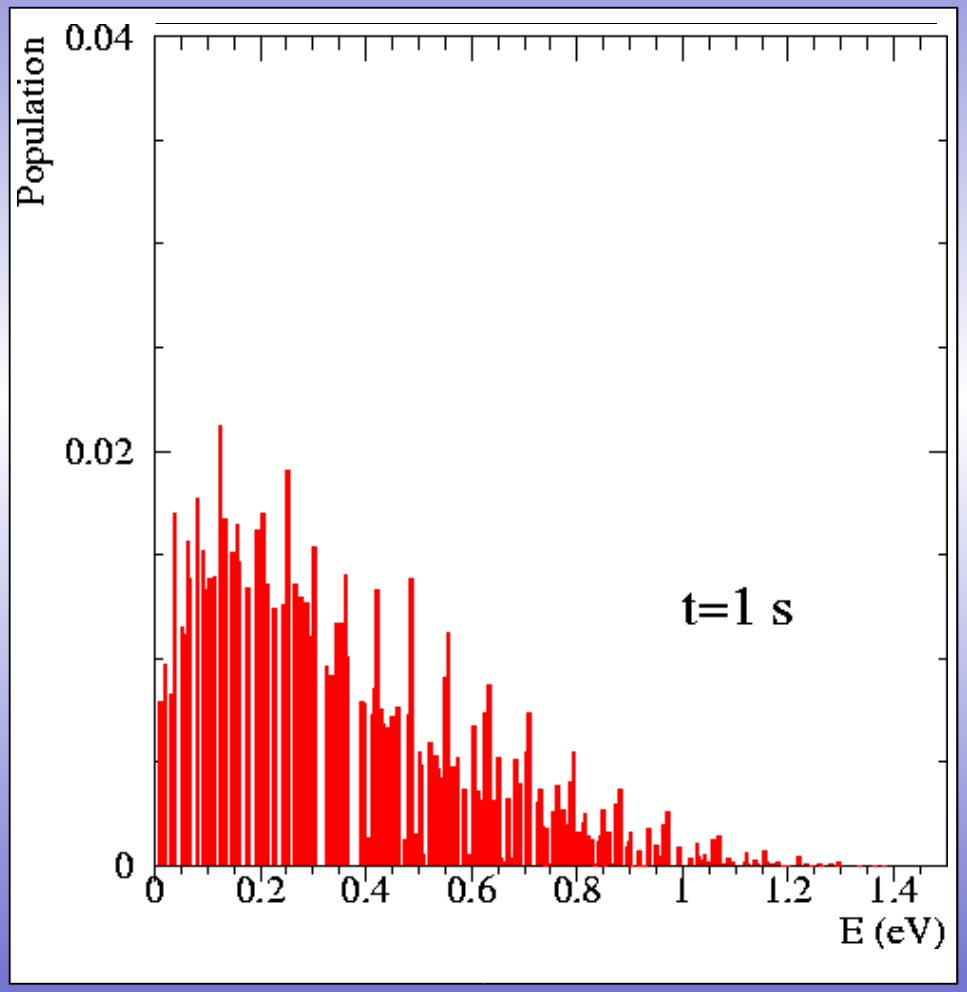
# Rovibrational relaxation model for $H_3^+$




H. Kreckel et al., New J. Phys. **6**, 151 (2004)

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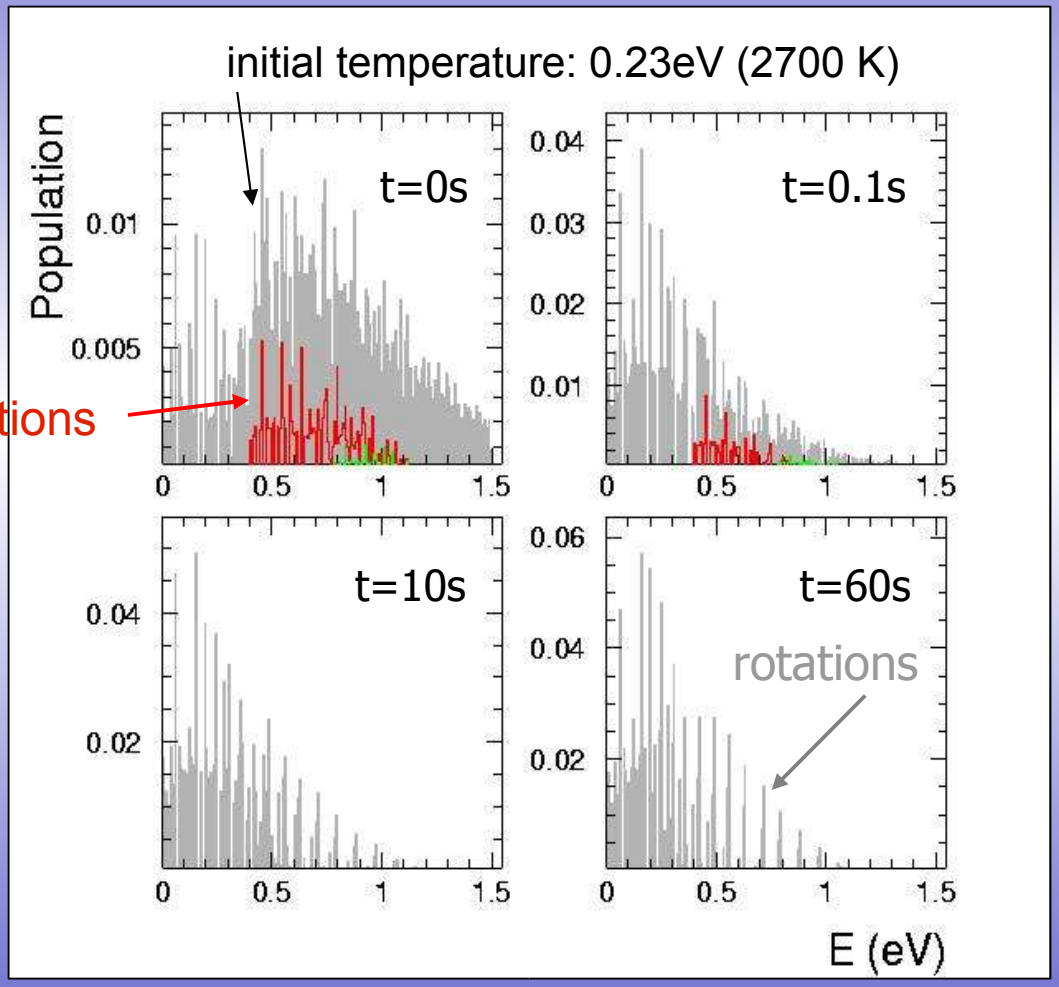
# Rovibrational relaxation model for $H_3^+$



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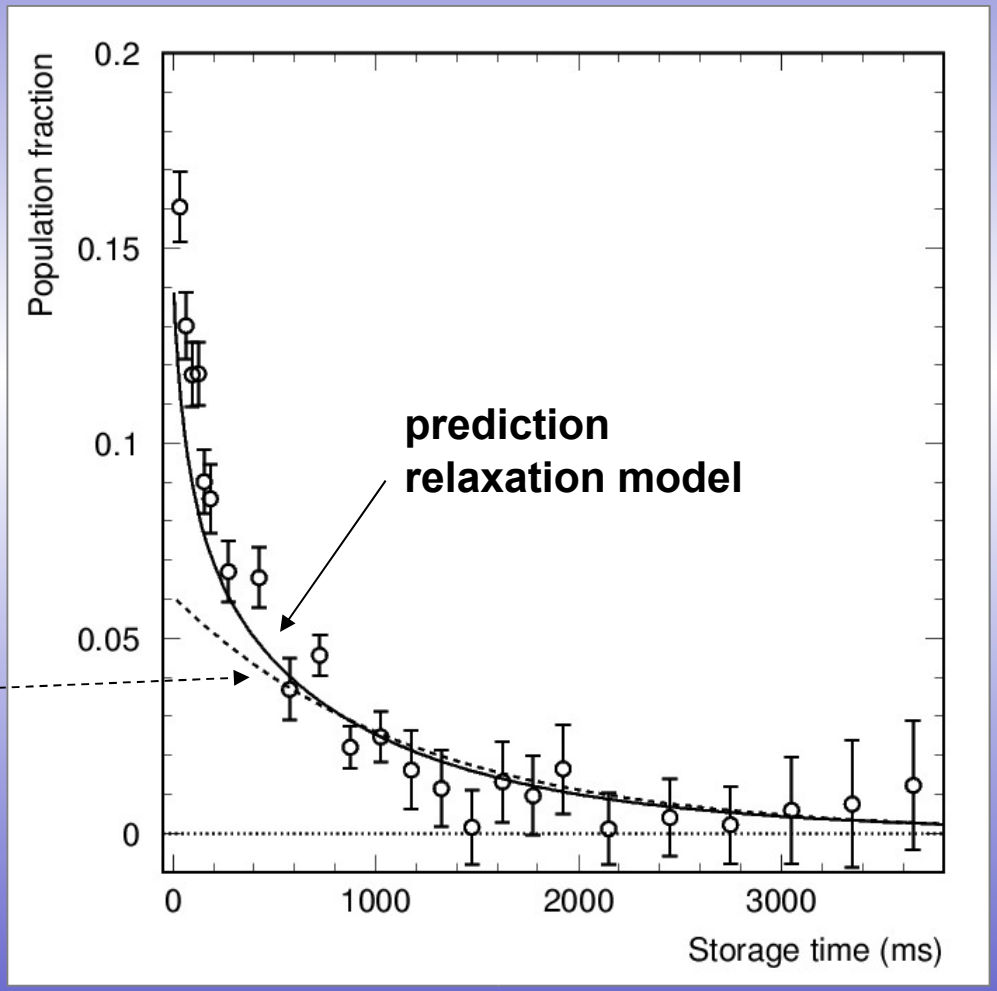
# Decay of the first breathing mode $(1,0^0)$ of $H_3^+$

exponential function (breathing mode lifetime **T=1.18 s**) fitted to experiment at t > 500 ms



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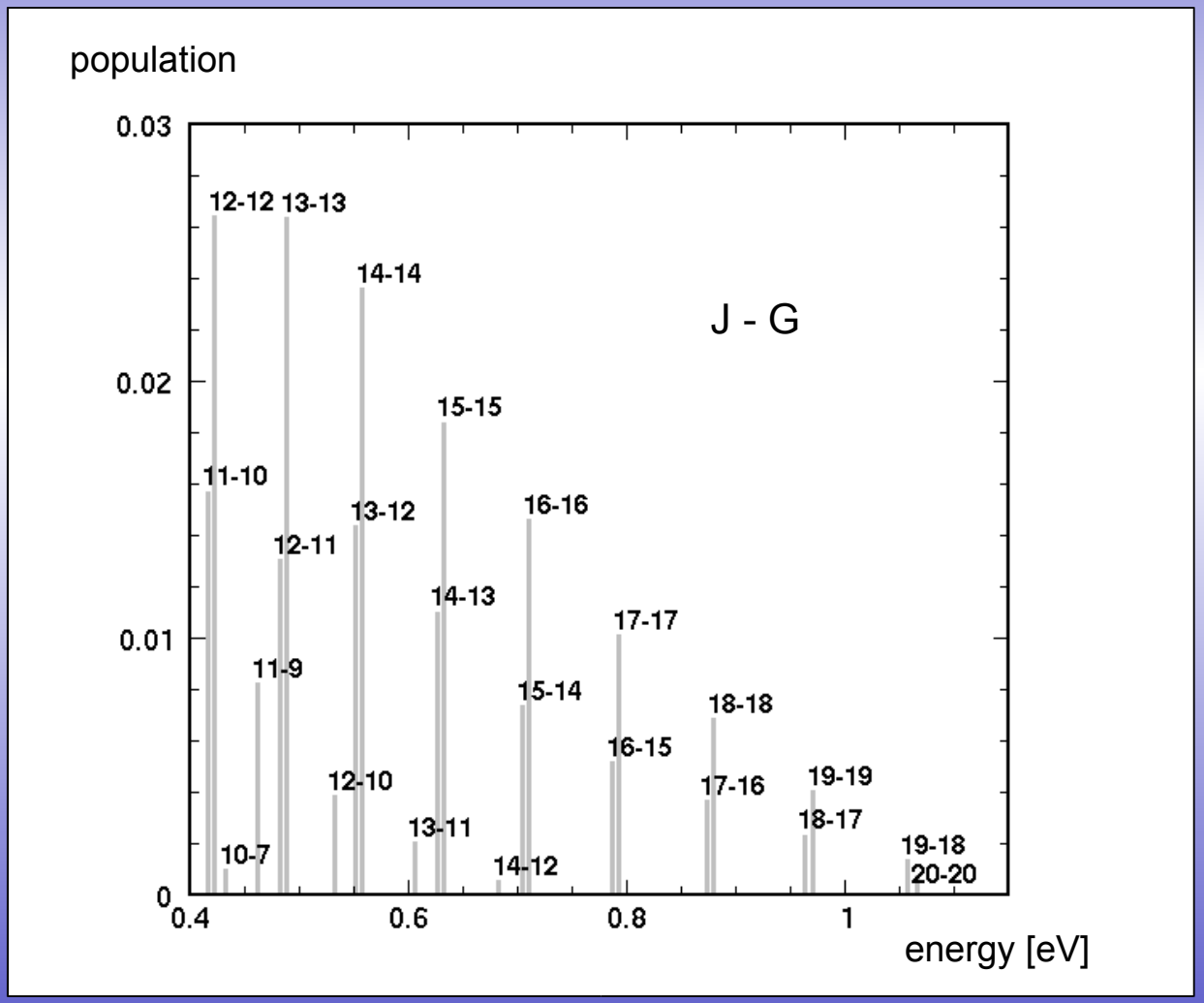
# Metastable rotational states (t=60 s)



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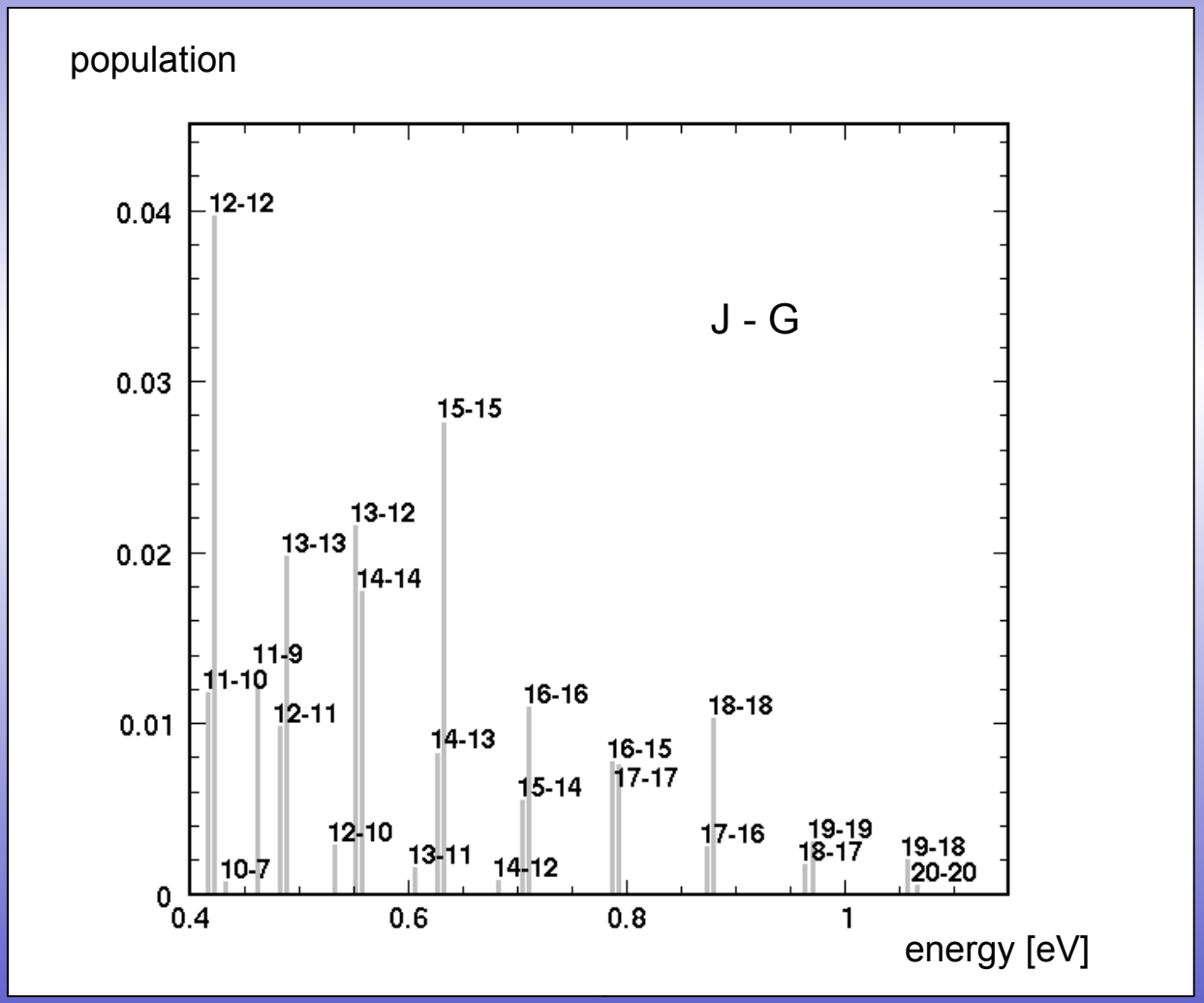
# Metastable rotational states (t=60 s)

**ortho/para corrected**



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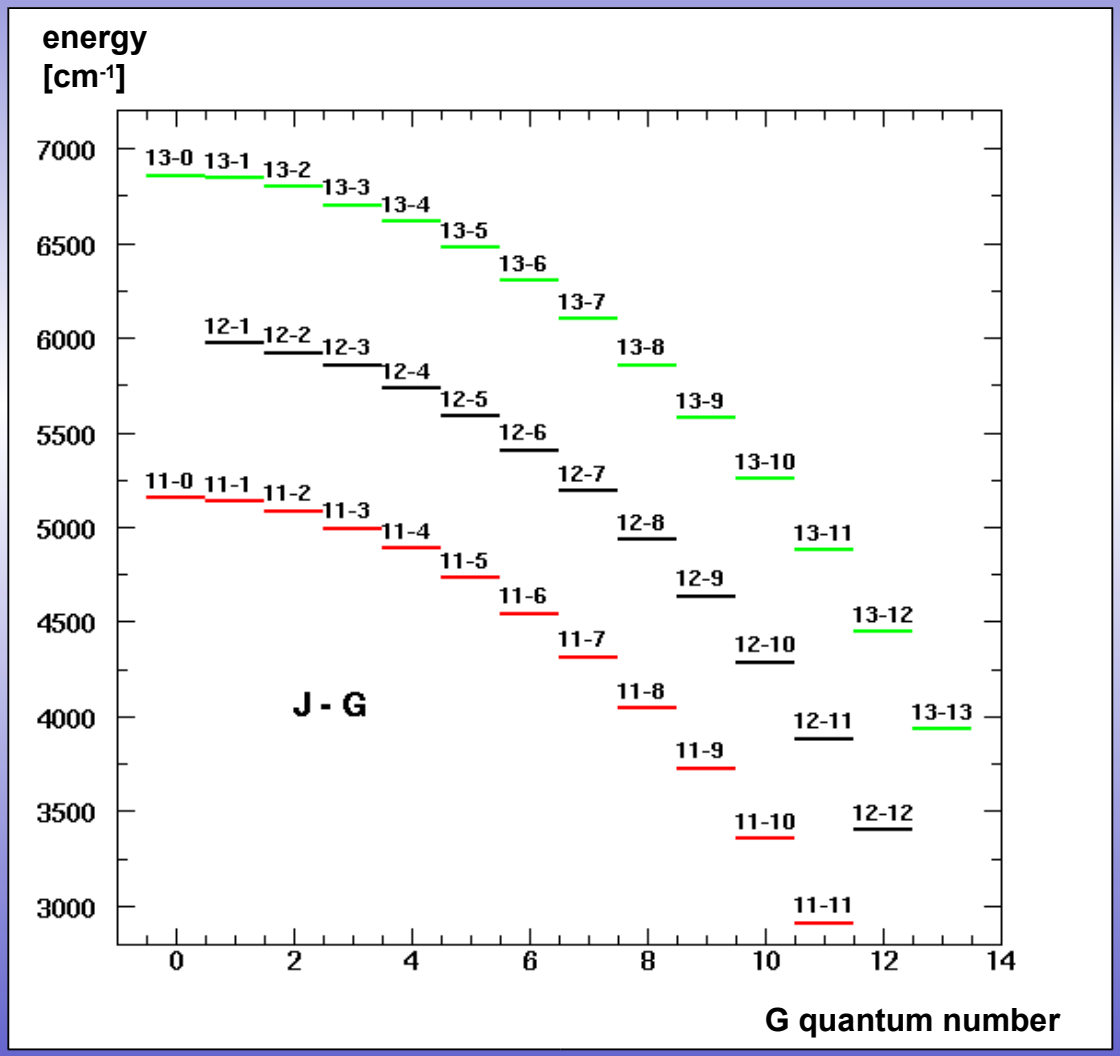
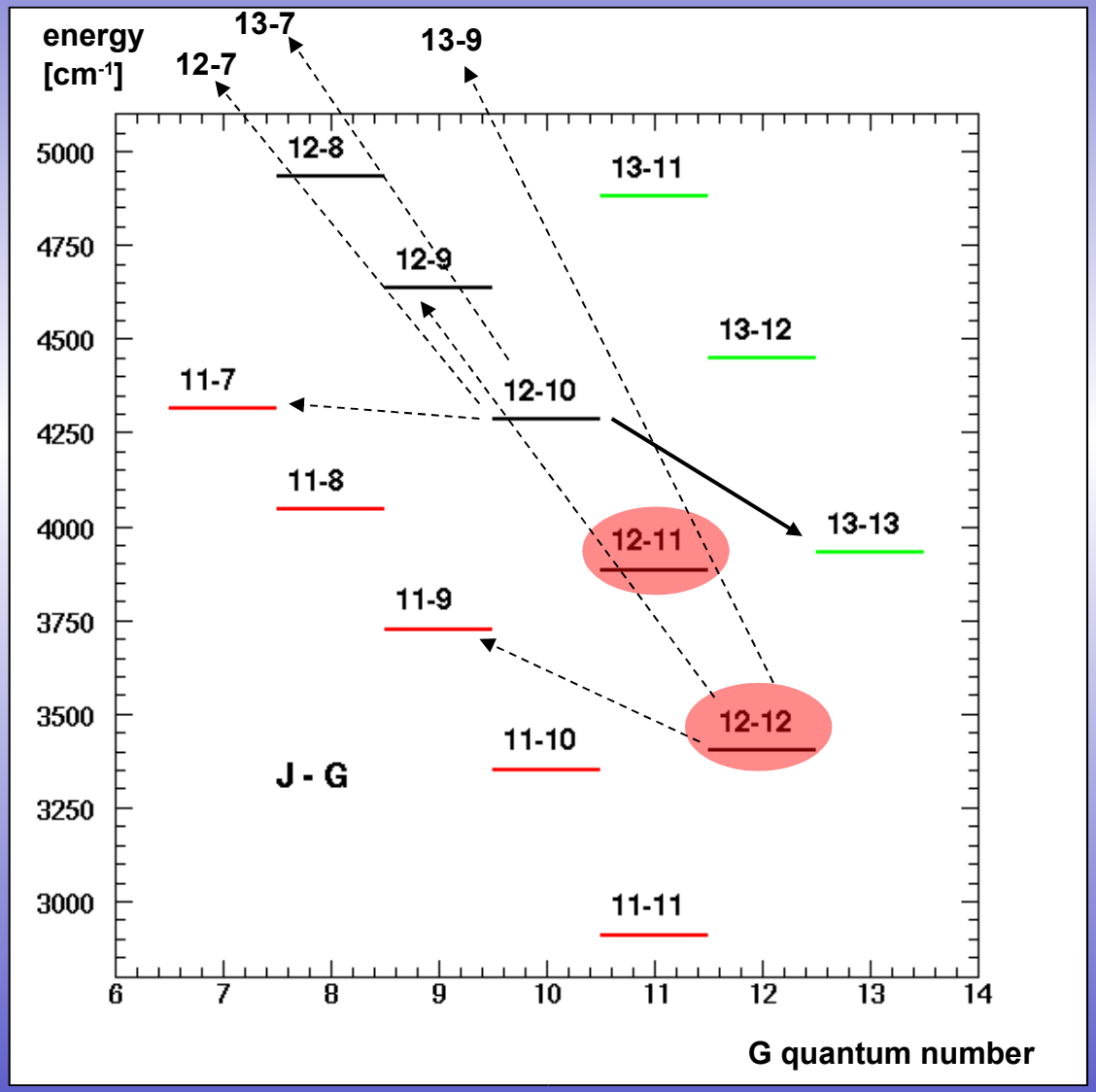
# Rotational levels






Selection rules

$\Delta J = -1, 0, +1$
$\Delta K = 2n + 1$
$\Delta G = 3n$

$\Delta J = -1, 0, +1$
$\Delta G = 3n, \; n \neq 0$

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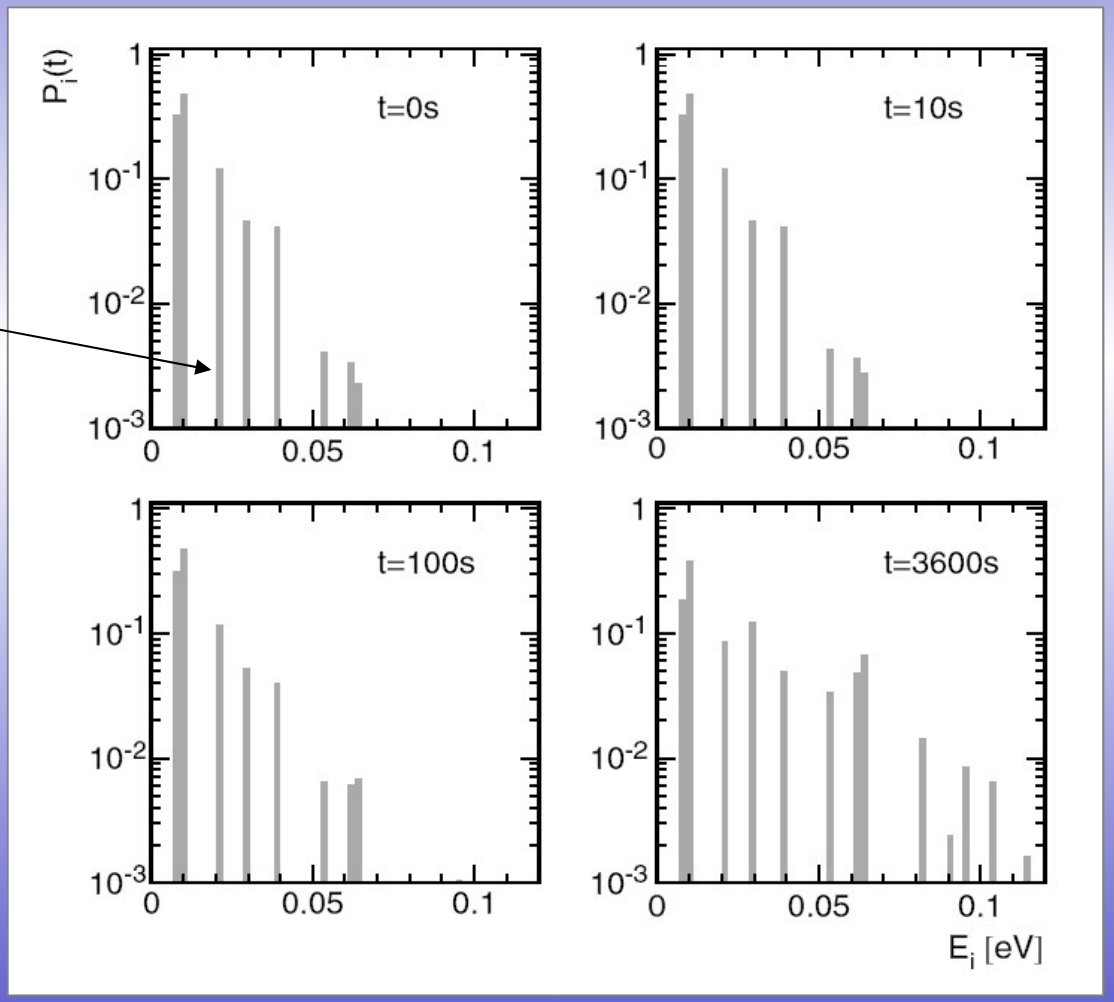
# Radiative heating by 300 K blackbody radiation

initial distribution:
100 K Boltzmann



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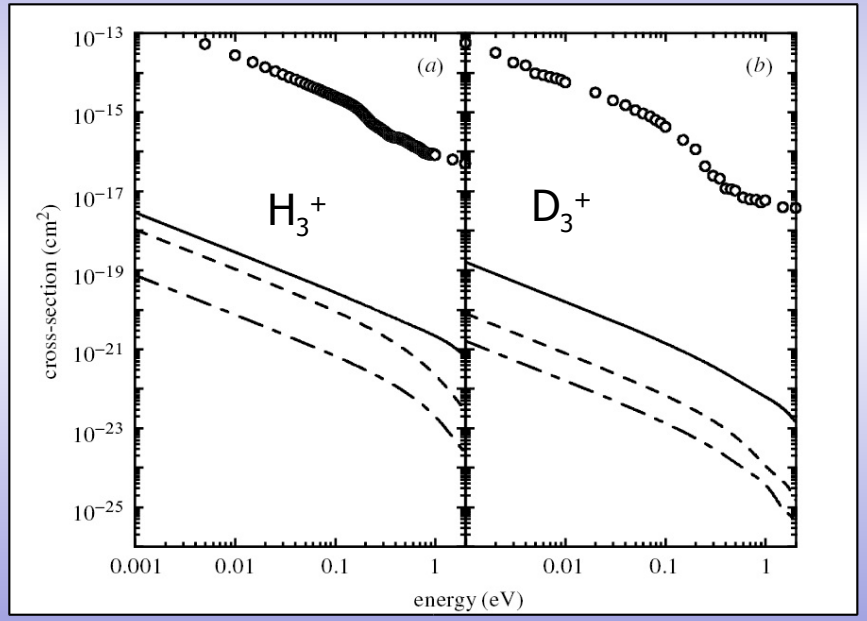
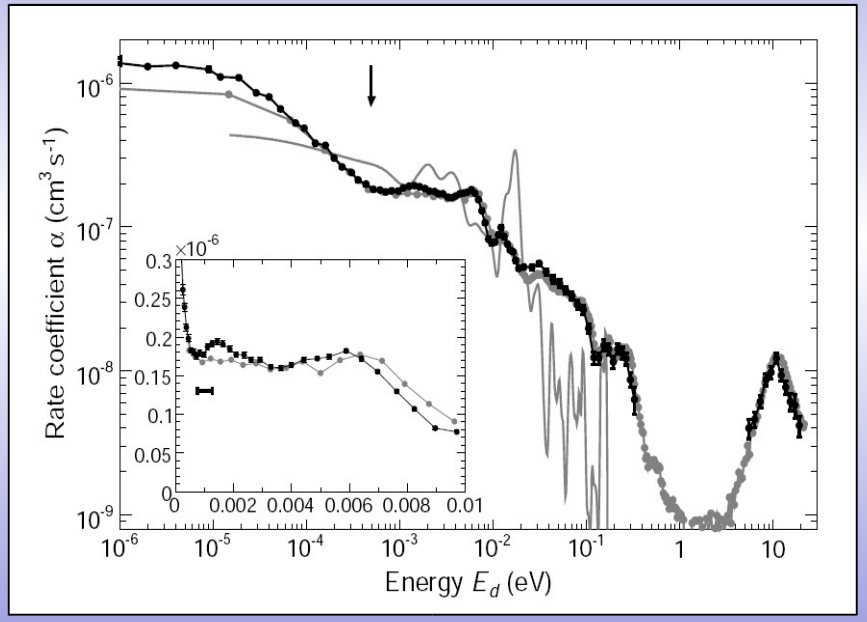
# Conclusion $H_3^+$ DR:




2000




2005