Rotationally cold (>99% J = 0) OH^- molecular ions in a cryogenic storage ring

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Cooling down molecular ions

- “Hot” ion production
- Cryogenic storage
- Rotational relaxation
- What happens to the temperature of the ions?
- Can we do something more?

Outline

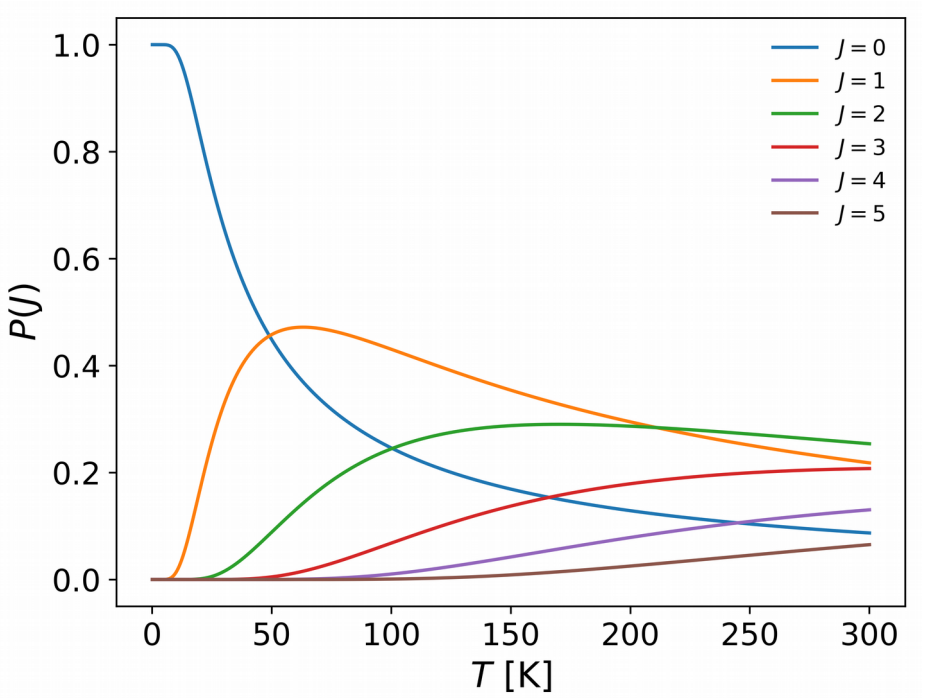
- Introduction
  - OH^-
  - Rotational states and temperature
  - Photodetachment thermometry
- Experiment
  - DESIREE
  - Measurements
  - Results
- Summary

The OH^- molecular ion

- Diatomic molecular ion
- Well studied
  - EA: 1.827 6488(11) eV
  - Rotational constant: 2.3228 meV
- Well separated rotational levels

$$E_J \approx BJ(J+1)$$

$$P(J) \propto (2J+1)e^{-E_J/k_BT}$$



Photodetachment thermometry

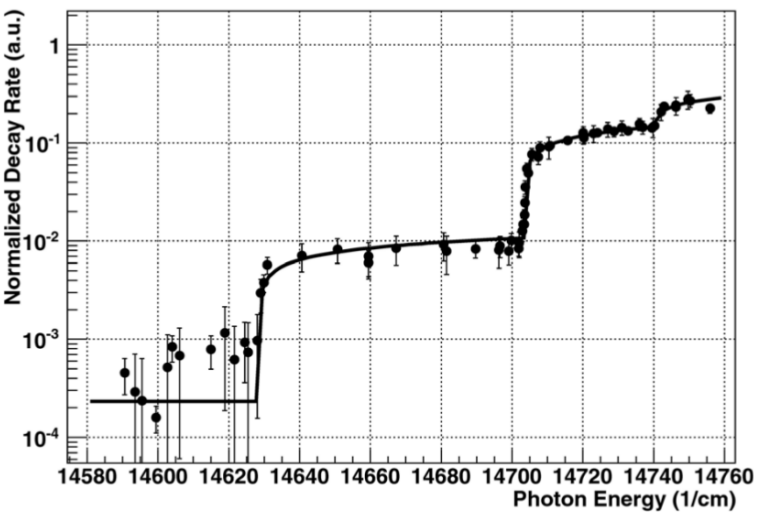
- Effective relative photodetachment cross section

$$\sigma_{\mathrm{eff}}^{\mathrm{pd}}(E) \propto \sum_J I(J)P(J)(E-\epsilon_J)^p$$

$I(J)$ – Intensity factor†
$P(J)$ – Population
ϵ_J – Transition threshold
$p = 0.28$ – Threshold exponent‡

†F. Goldfarb et al., J.Chem. Phys. 122, 014308 (2005).

‡P. Engelking, Phys. Rev. A 26, 740 (1982).



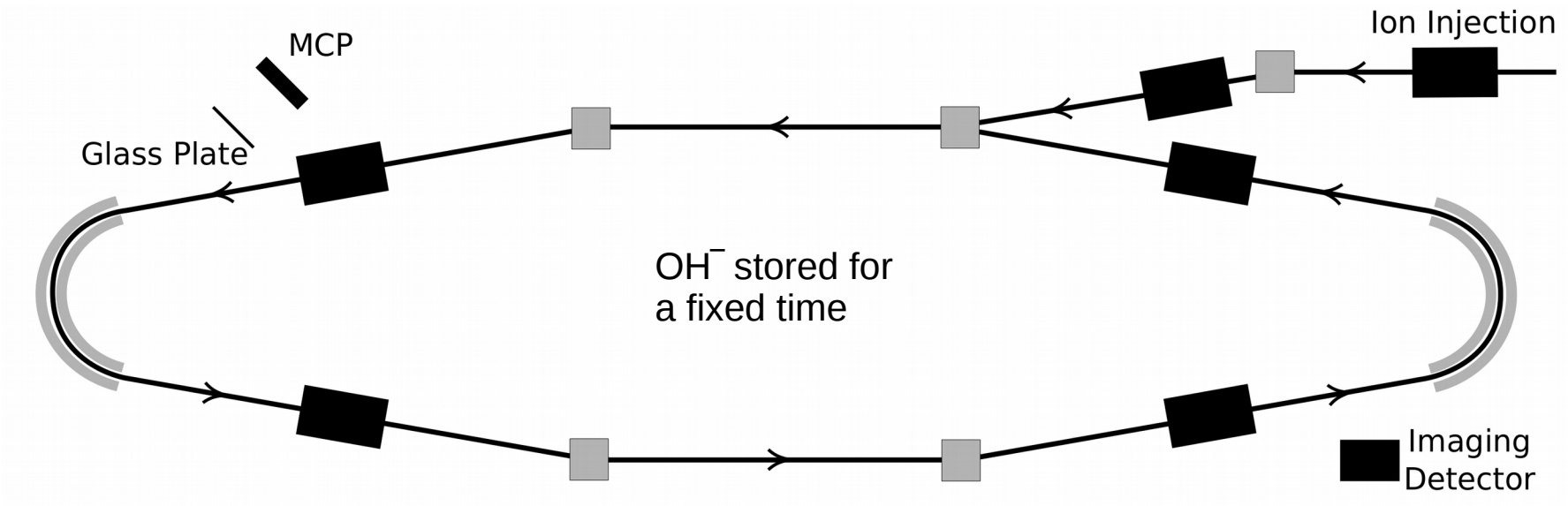
RF ion trap with He buffer gas at 50 K

R. Otto et al, Phys. Chem. Chem. Phys., 15, 612 (2013).

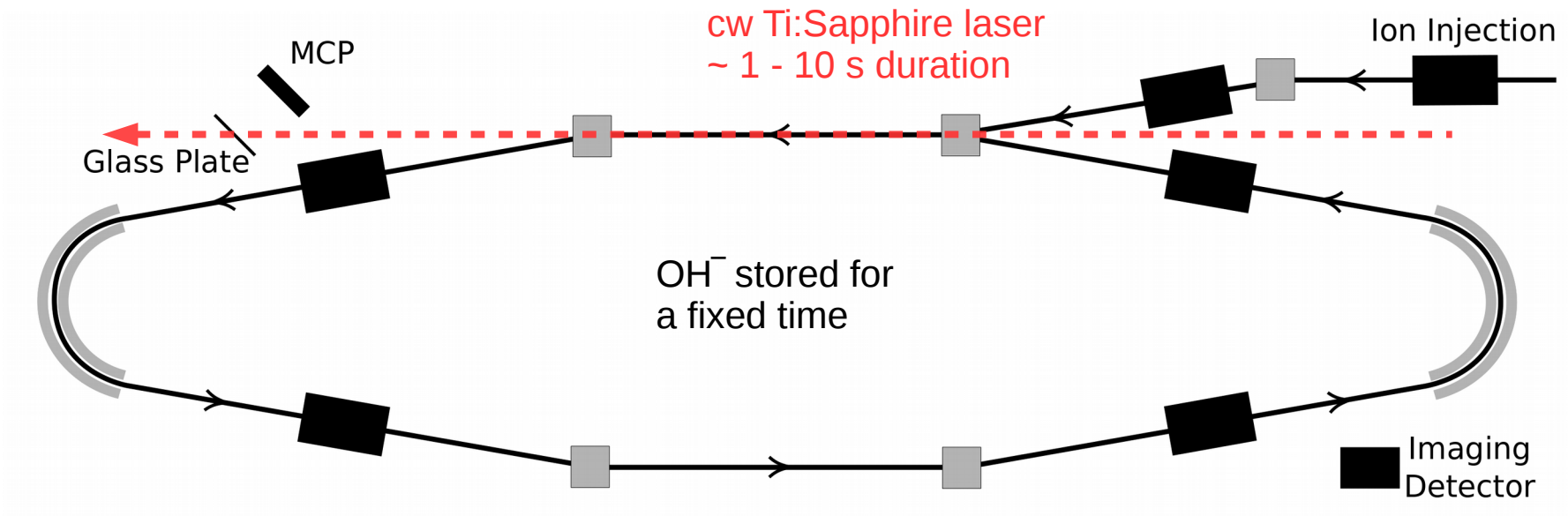
Double ElectroStatic Ion Ring ExpEriment - DESIREE

- Cryogenically cooled to 13.5 ± 0.5 K
- Residual-gas density of 10^4 hydrogen molecules per cm^3
- OH^- produced in cesium-sputter source
- Accelerated to 10 keV
- Mass selected by a bending magnet
- Bunch of ~ 1 – 10 million ions injected
- Beam storage lifetime ~ 10 minutes

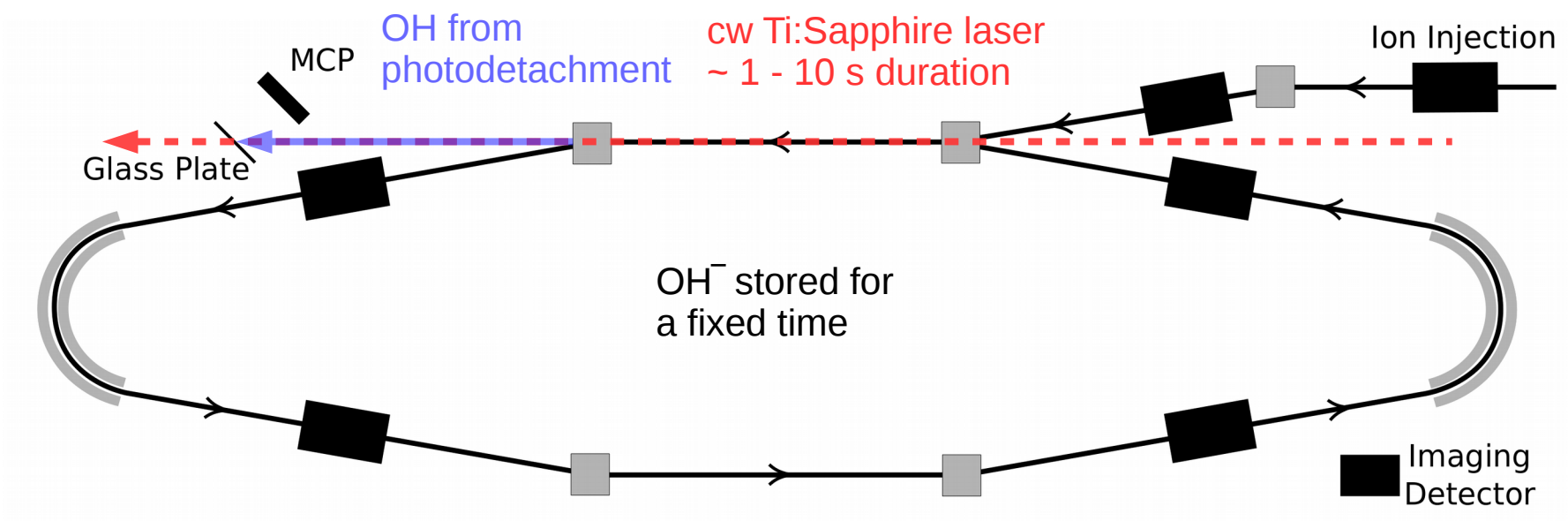
Experimental procedure
photodetachment thermometry



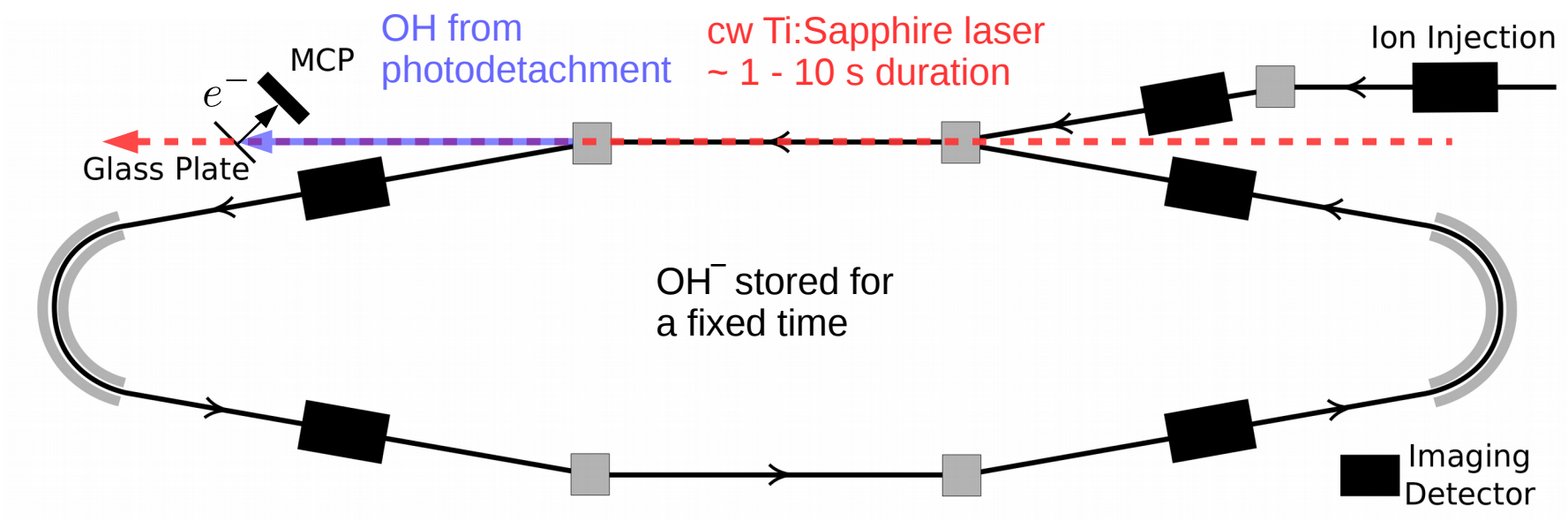
Experimental procedure
photodetachment thermometry



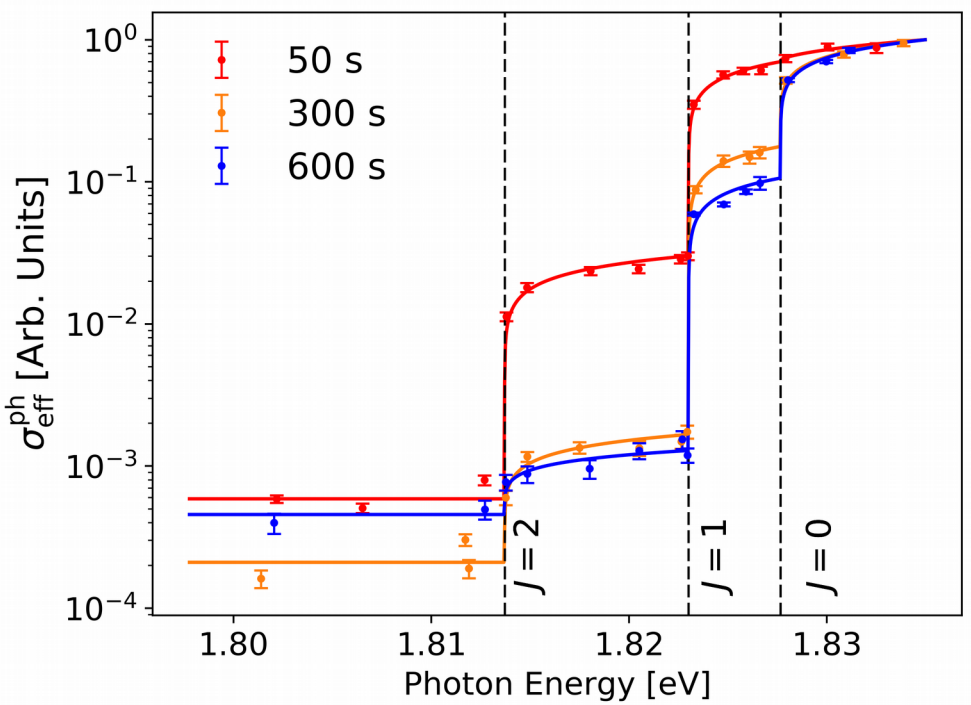
Experimental procedure
photodetachment thermometry

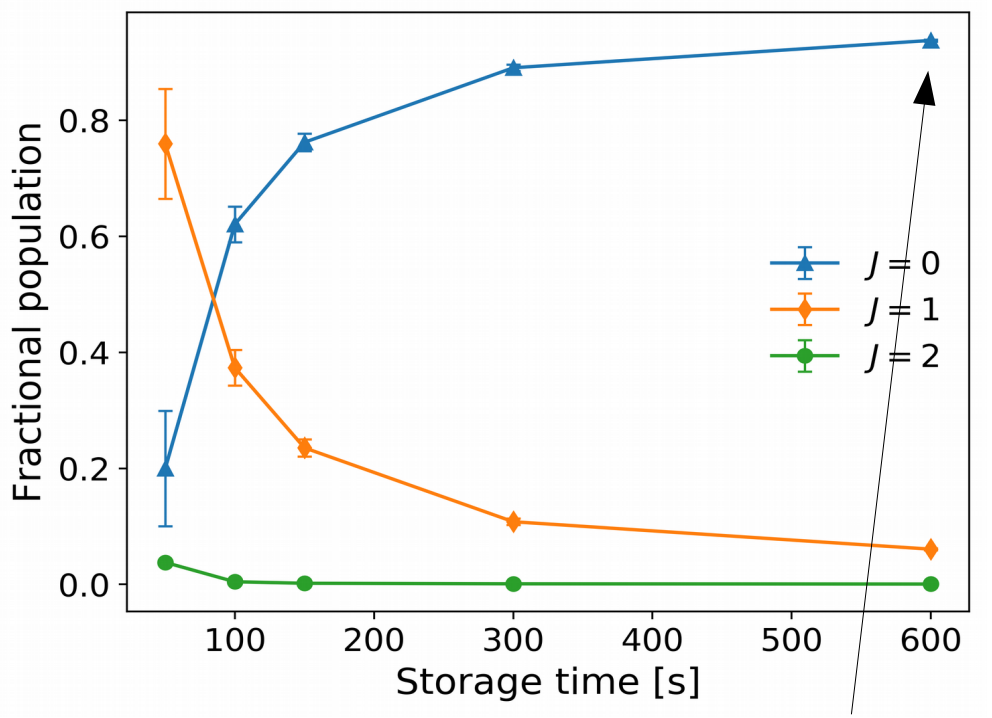


Experimental procedure
photodetachment thermometry



Photodetachment thermometry result





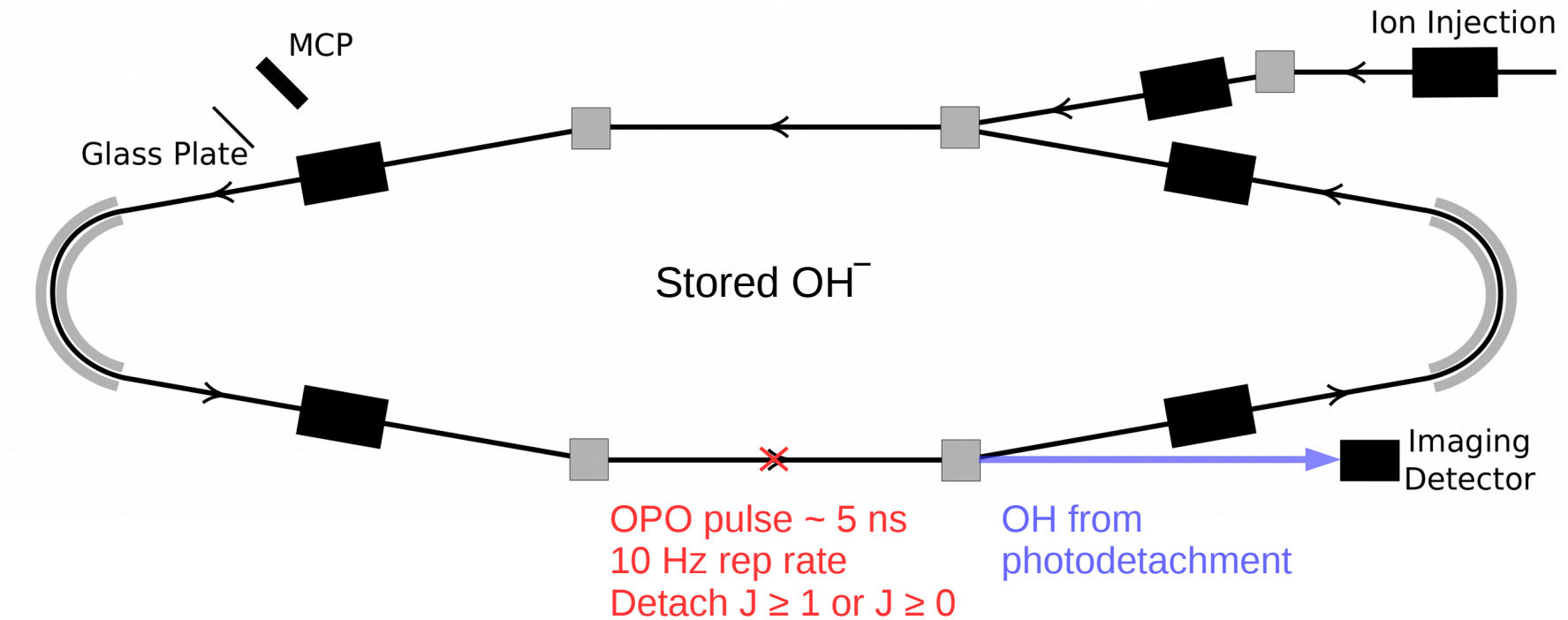
$$\sigma_{\mathrm{eff}}^{\mathrm{pd}}(E) = \sum_{J=0}^{2} K(J)(E - \epsilon_J)^p + C$$

$$K(J) \propto I(J)P(J)$$

14.1 ± 0.2 K

DESIREE temperature: 13.5 ± 0.5 K

Experimental procedure
continuous probing



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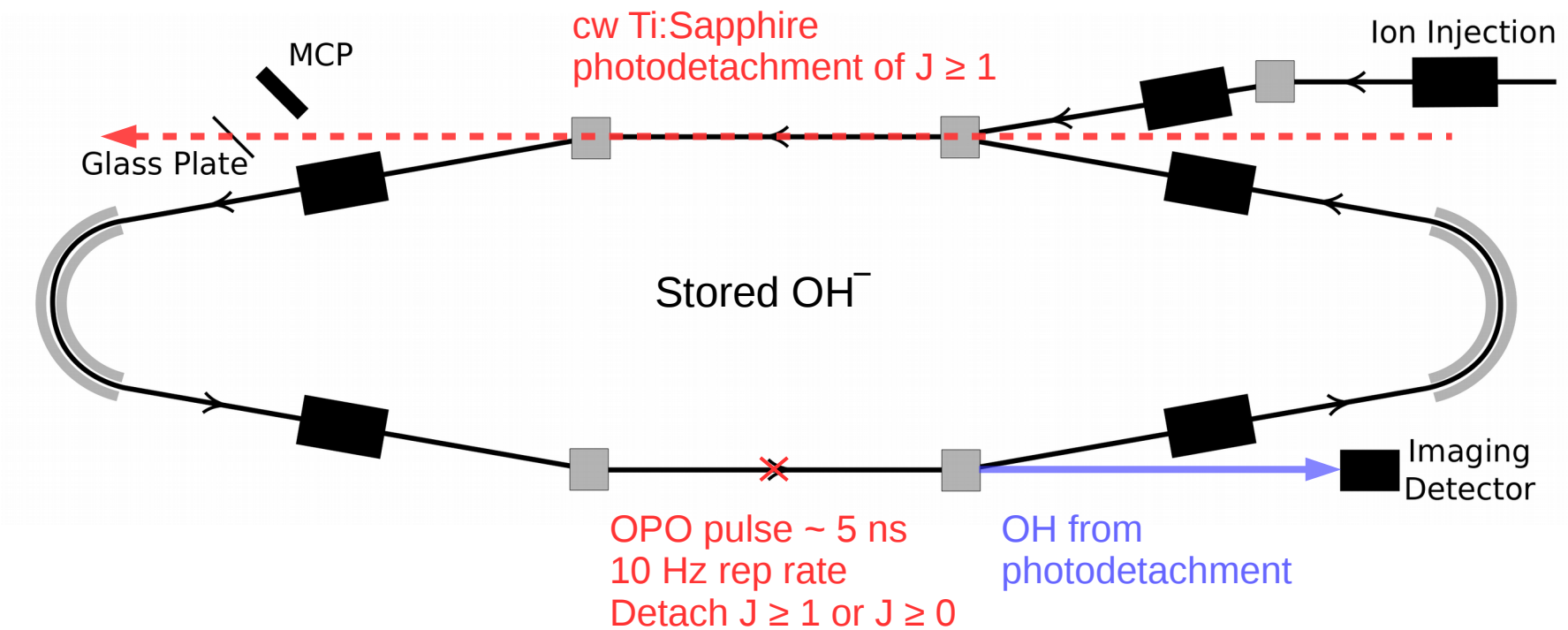

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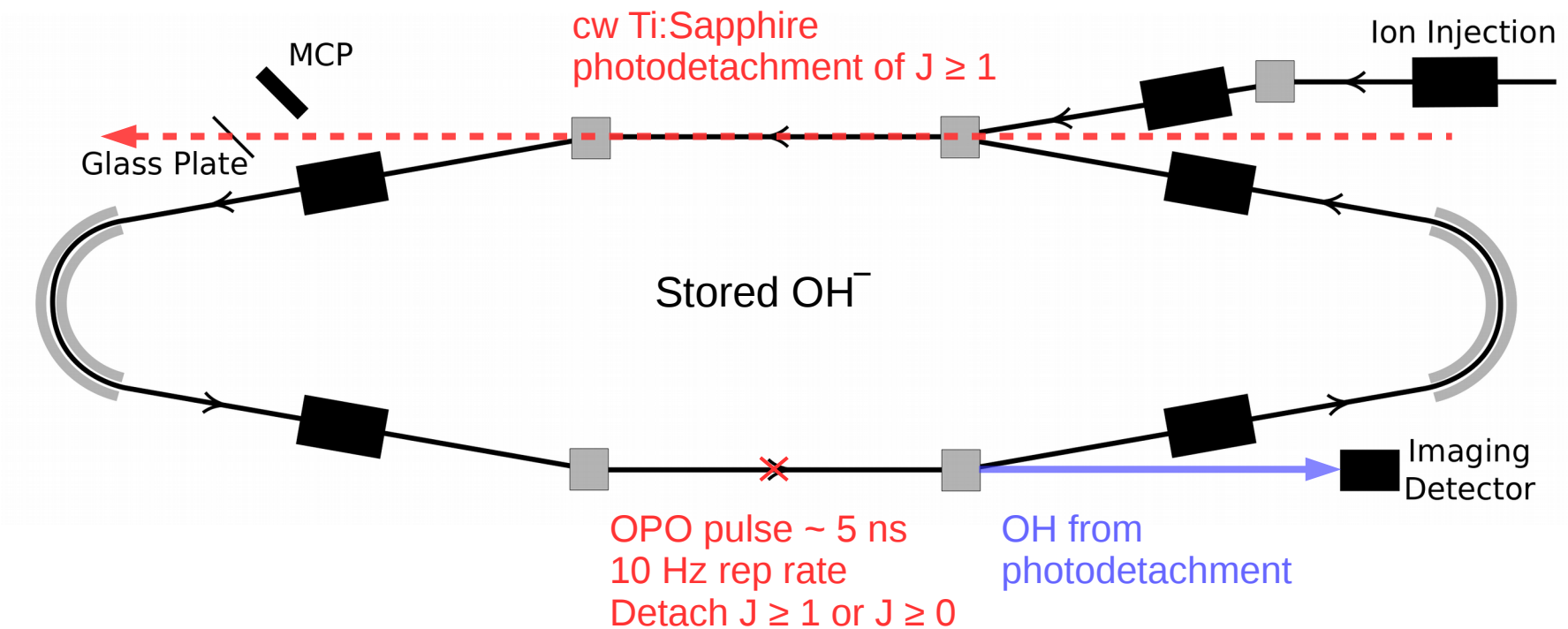
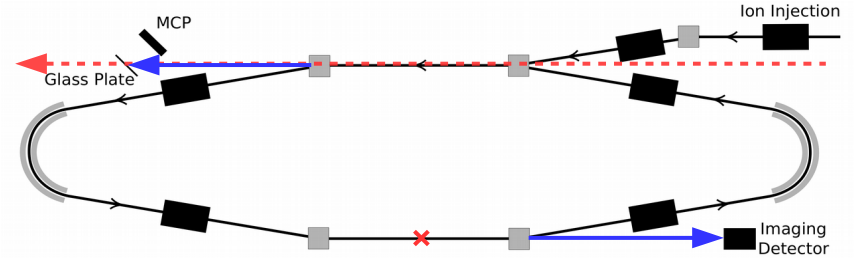
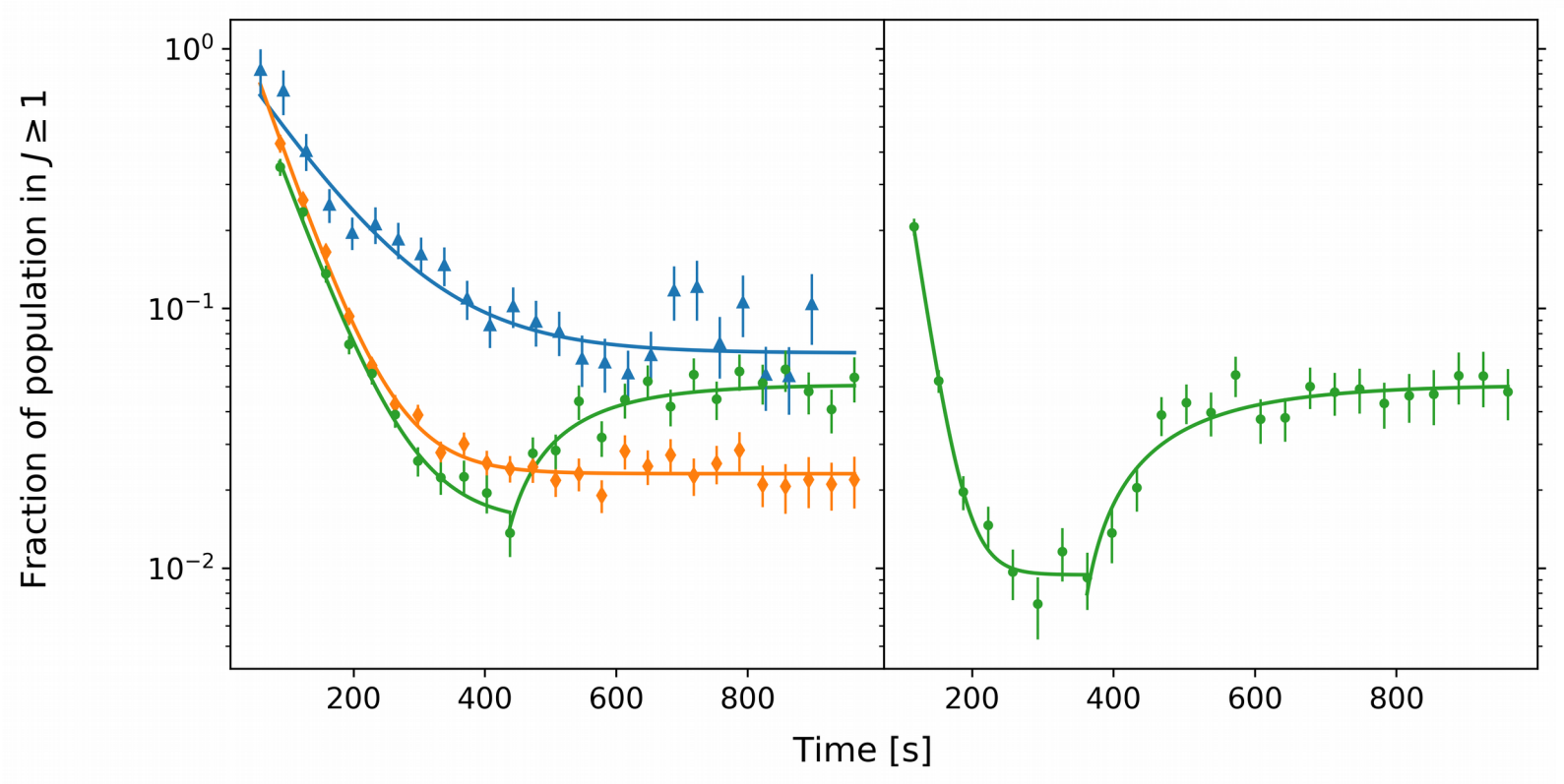
continuous probing



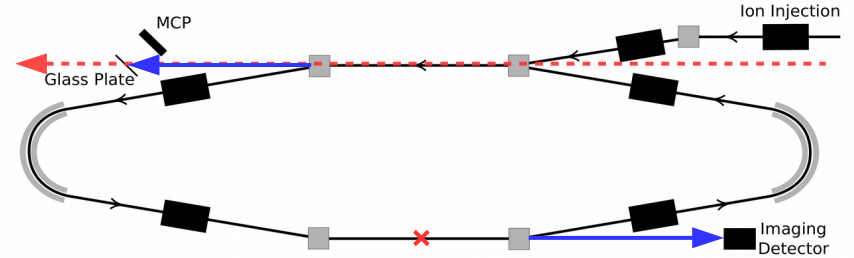
I. Probe spontaneous decay
II. Probe laser assisted decay

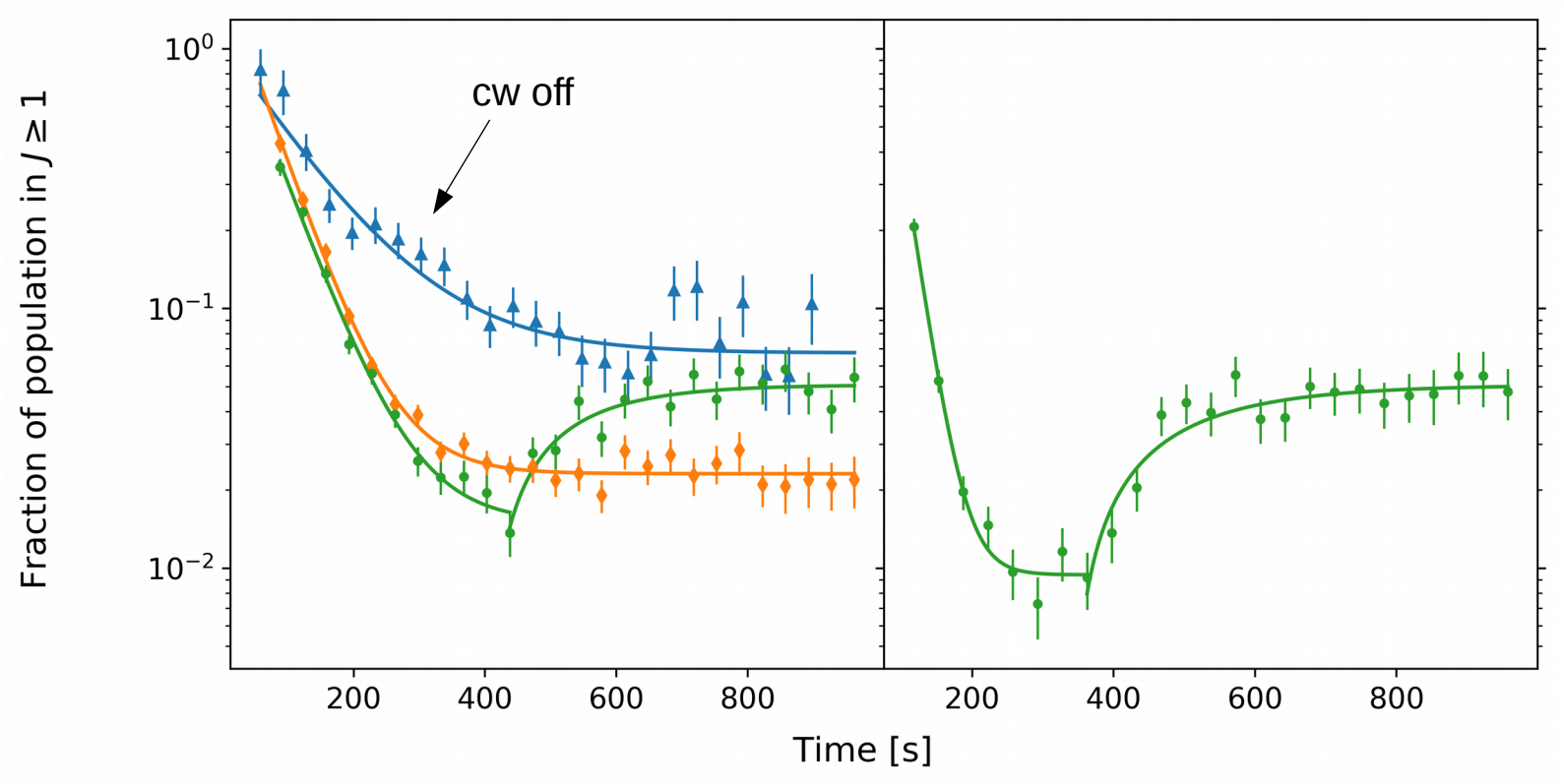
Fractional population





Fractional population





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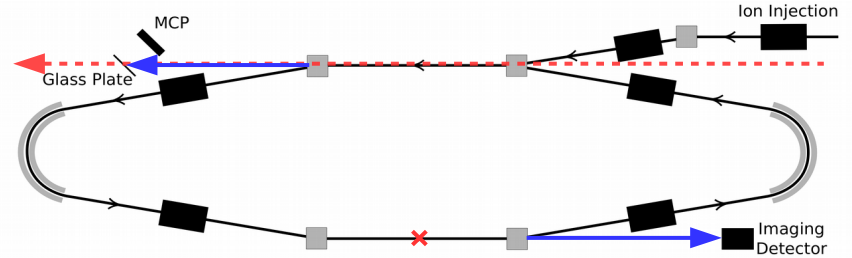

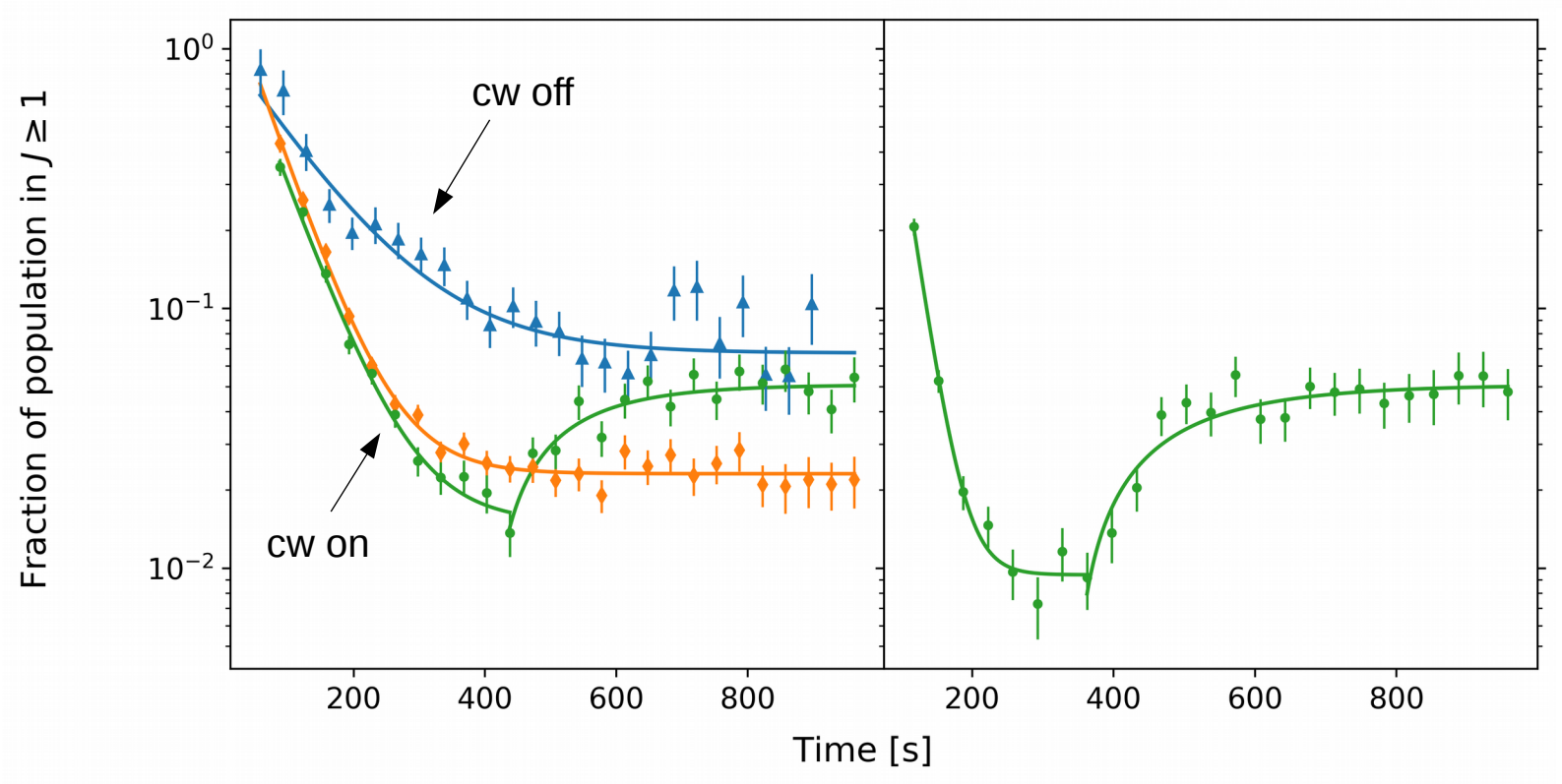

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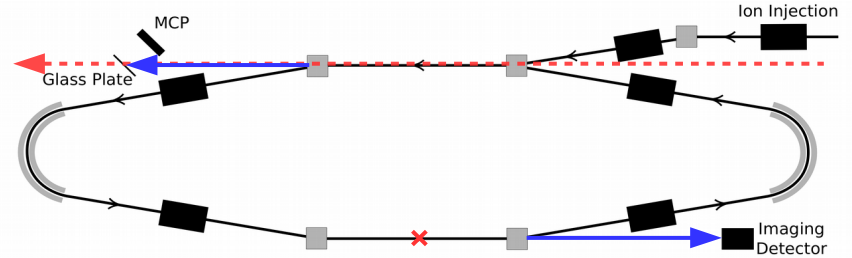

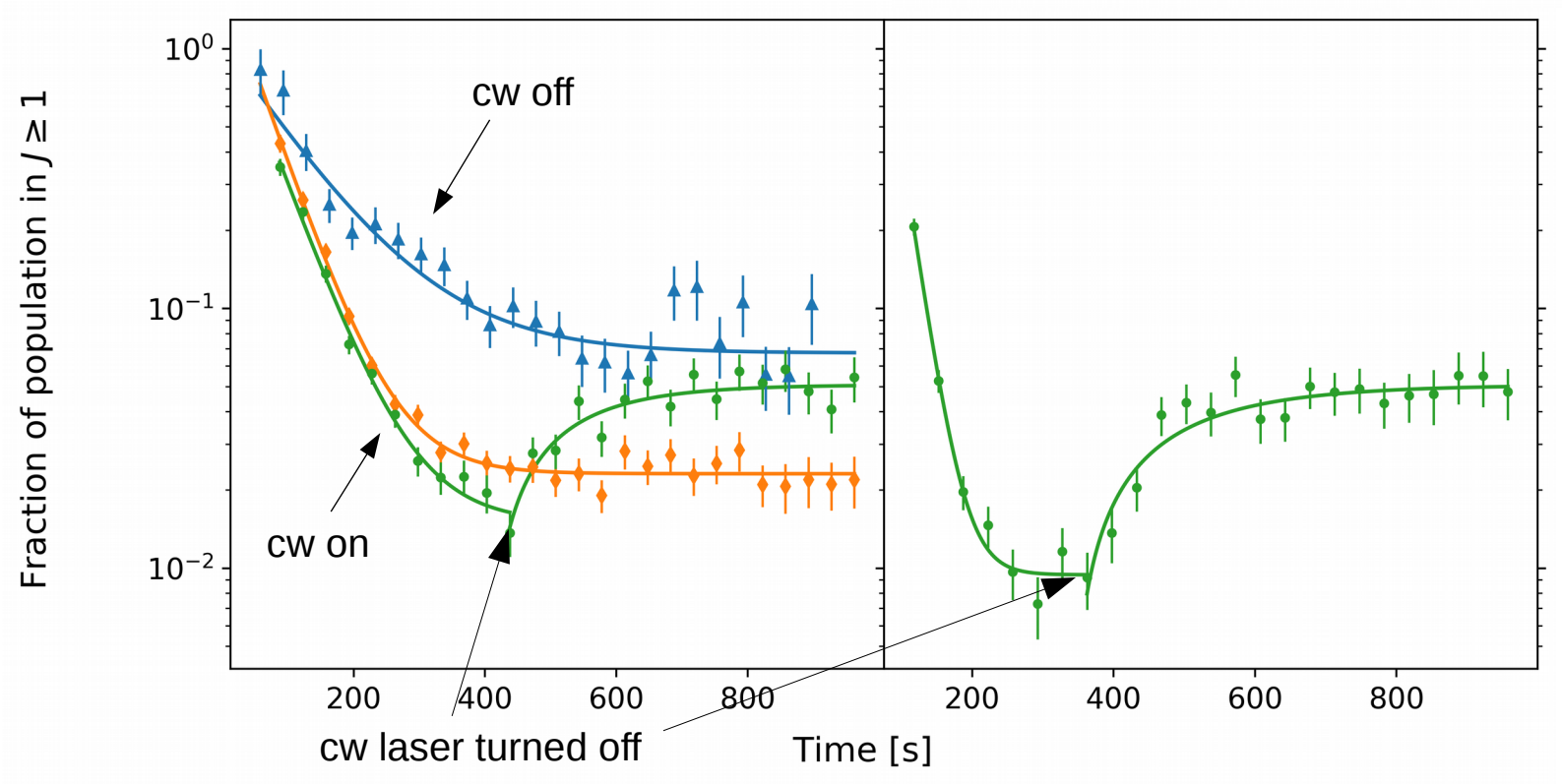

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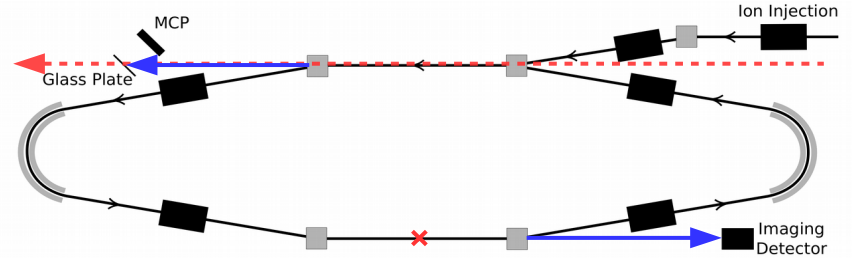

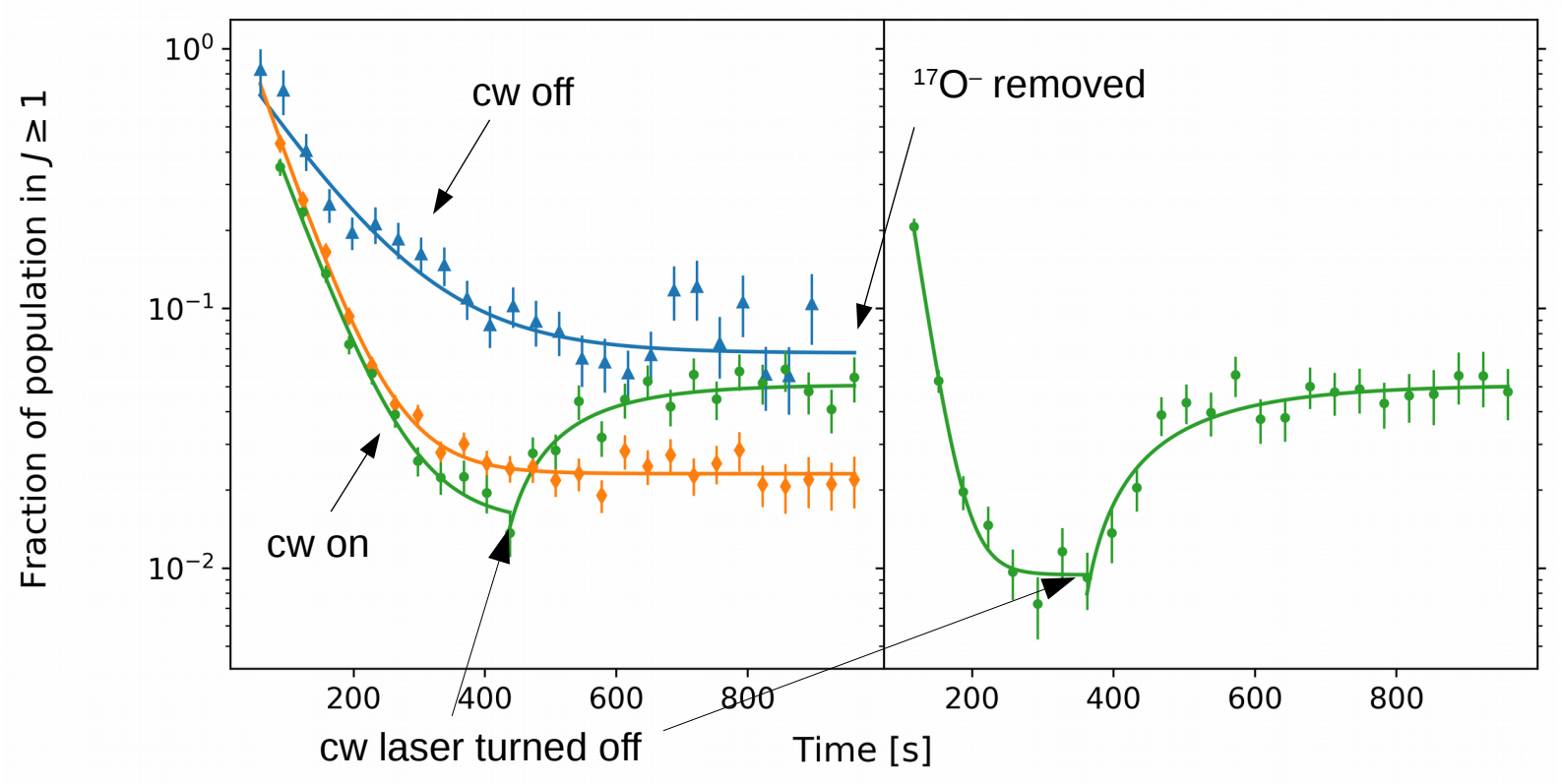

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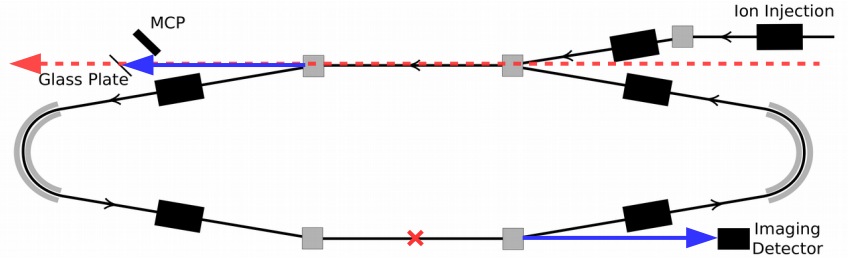
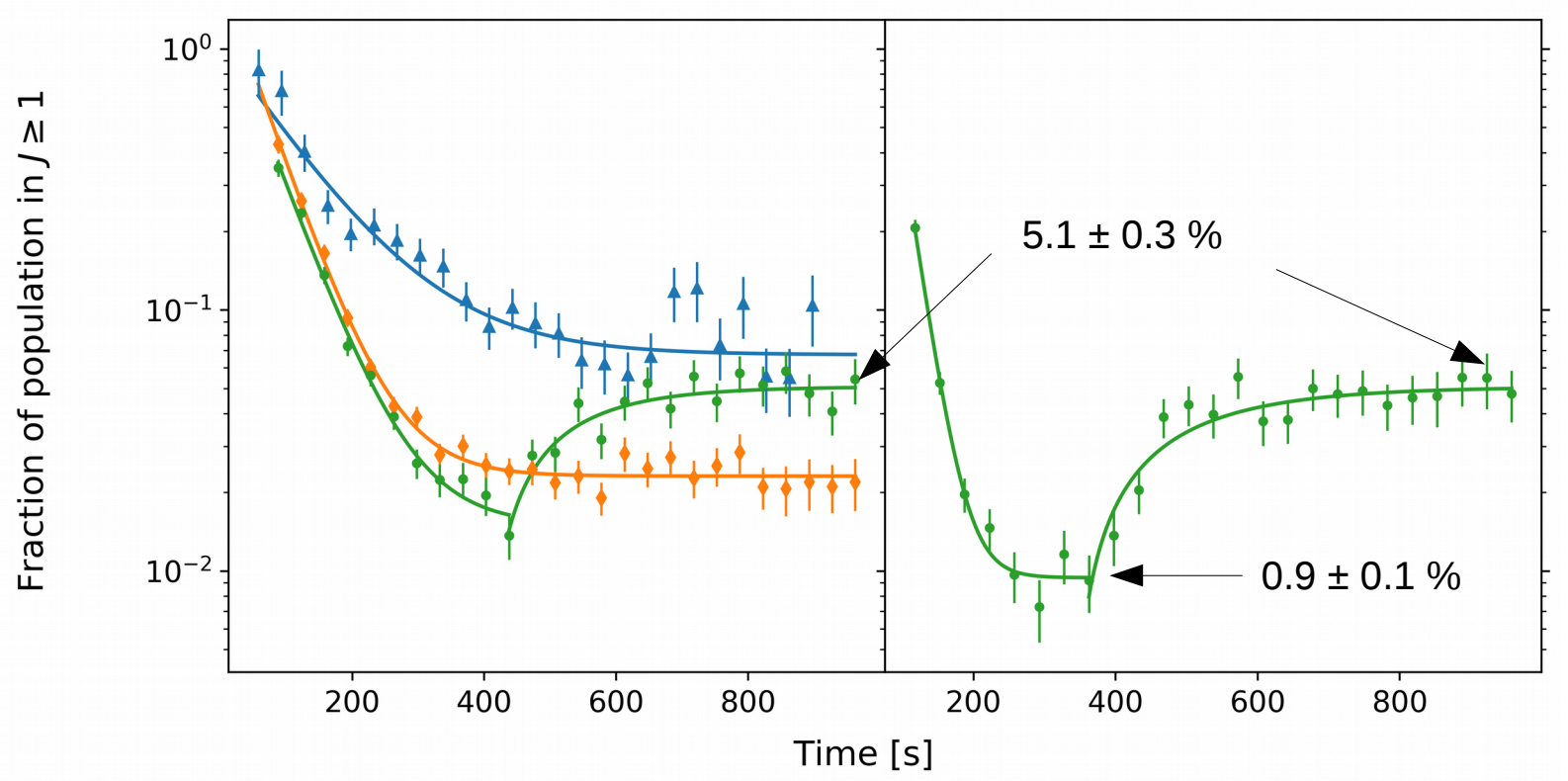
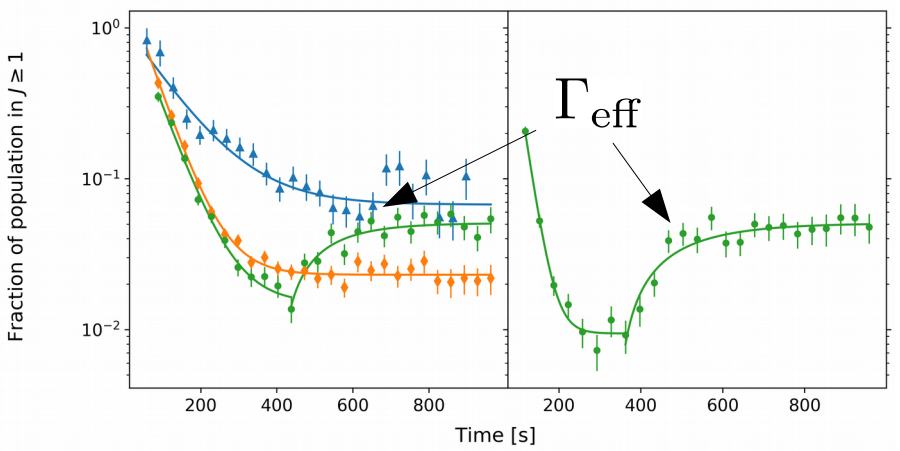




- Asymptotic temperature, T = 13.4 ± 0.2 K
- OH^- beam with > 99 % of ions in rotational ground state, T = 9.3 ± 0.2 K

The intrinsic lifetime A_{10}



- Fit gives effective decay rate

$$\Gamma_{\mathrm{eff}}^{-1} = 135 \pm 26 \text{ s}$$

- Two level system approximation at long times
- We find

$$A_{10}^{-1} = 145 \pm 28 \text{ s}$$

- Calculated dipole moment 1.10 D[†]

$$A_{10}^{-1} = 150 \text{ s}$$

- Recent measurement[††]

$$A_{10}^{-1} = 193 \pm 7 \text{ s}$$

[†]B. S. D. R. Vamhindi and M.Nsangou, Mol. Phys. 114, 2204 (2016).

[††]C. Meyer et al. Phys. Rev. Lett. 119, 023202 (2017)

Summary

- Using photodetachment thermometry we have found
  - Equilibrium distribution of rotational states
    - *P(1)* = 5.1 ± 0.3 %
    - *T* = 13.4 ± 0.2 K
    - Consistent with thermal equilibrium with surroundings, *T* = 13.5 ± 0.5 K
- Produced an ion beam with > 99 % of ions in rotational ground state
  - Photon, electron, ion and neutral interaction
  - Merged beam experiments
  - Action spectroscopy
  - Molecular ions with no permanent dipole moment
- Measured the intrinsic lifetime $A_{10}^{-1} = 145 \pm 28 \text{ s}$

H. T. Schmidt et al., Phys. Rev. Lett. Accepted 18 July 2017

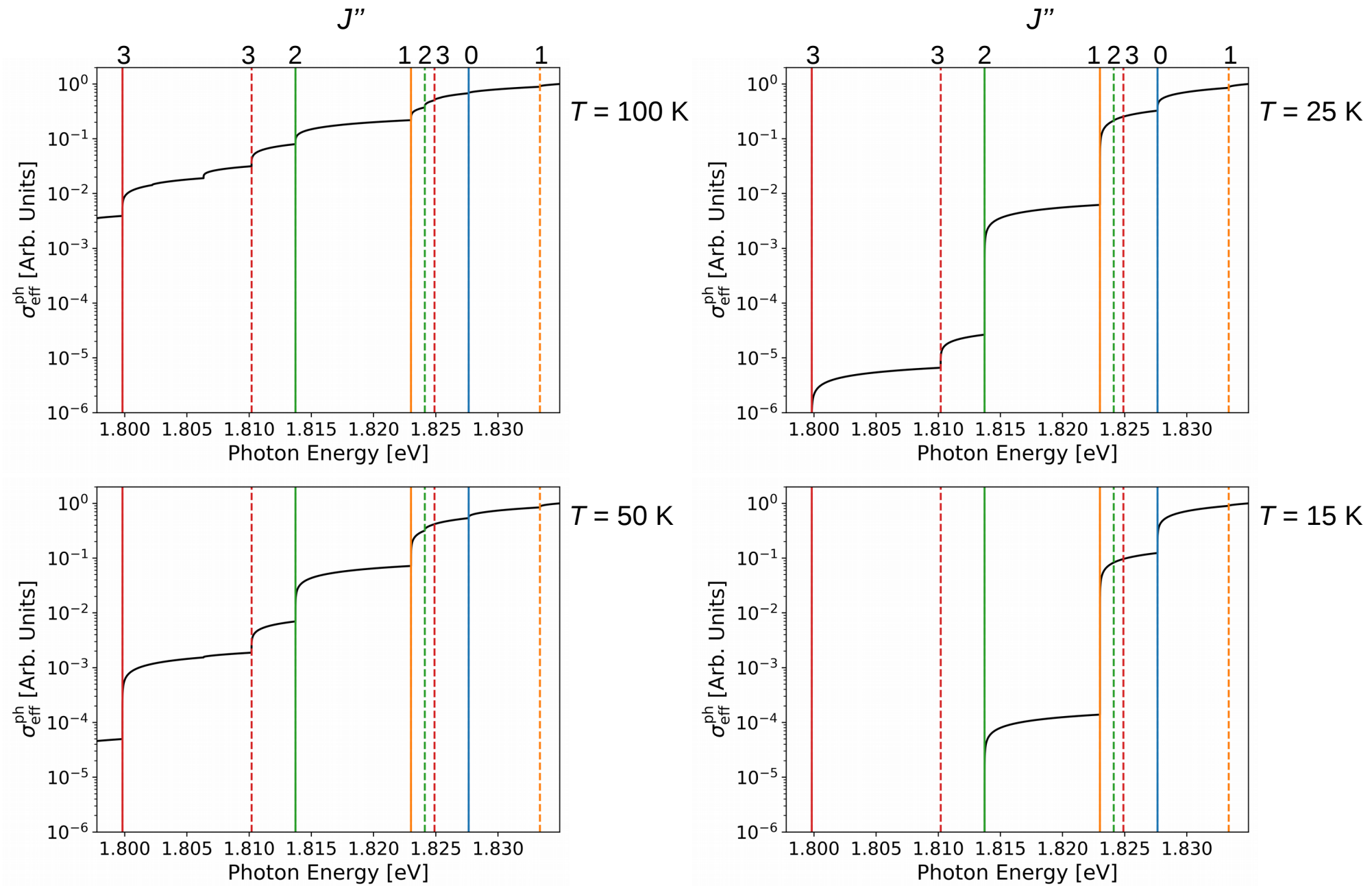
Mark Stockett
FR-117 - The role of angular momentum in the spontaneous decay of small copper cluster anions measured on long timescales at DESIREE

Gustav Eklund
TH-111 - Rotationally cold (>99% J = 0) OH^- molecular ions in a cryogenic storage ring

Kiattichart Chartkunchand
FR-15 - Lifetimes of bound excited states of Pt^-

Emma Anderson
MO-142 - Spontaneous decay of hot Ag_n^- clusters in a cryogenic environment

Thank you for your attention!


J”
3
3
2
1
2
3
0
1
T = 100 K
T = 25 K
T = 50 K
T = 15 K
σ^ph_eff [Arb. Units]
Photon Energy [eV]
1.800
1.805
1.810
1.815
1.820
1.825
1.830