LIF Spectroscopy on Rotational Distribution of HfF Photo-ions

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1 Motivation
   - Why Use HfF$^+$?

2 Auto-Ionization
   - Rotational Distribution
   - Orientation
HfF\(^+\) in \(^3\Delta_1\) is Sensitive to electron EDM.

\[ E_{\text{eff}} T \sqrt{N} \]

- Measuring the electron EDM is a sensitive probe of CP violation, and exotic new physics.
- EDM sensitivity is proportional to \(E_{\text{eff}} T\).
- Diatomic molecules have large effective electric field.
- Trapped ions can have long measurement times.
Motivation

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Auto-Ionization

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HfF⁺ in $^3\Delta_1$ is Sensitive to electron EDM.

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Creating HfF⁺ In a Single Quantum State

- Perform electron spin resonance on $J = 1, ^3\Delta_1$.
- We want to create a large fraction of ions in this state.
  - More signal
  - Better contrast.
  - Less collisions (better $\tau$).
- Produce ions in this state via Auto-Ionization.

$J = 1, ^3\Delta_1$

Motivation
Auto-Ionization

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$m = -1 \quad m = 0 \quad m = +1$

$J = 1 \quad ^3\Delta_1$
Outline

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2. Auto-Ionization
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Motivation
Auto-Ionization
Rotational Distribution
Orientation

Ionization Setup.

Ablation

Skimmers

Ionization Lasers

Hf

F

Hf+

MCP

PMT

Ar(99%)+

SF6(1%)

Ionization Lasers
Optical-Optical Double Resonance Auto-ionization.

1. Intermediate selects isotope, parity, and J.
2. Ionization spectrum shows structure on all scales.
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Circular Dichroism.

Polarization tricks used to enhance or suppress different $J$. 

(a) Ions

(b) P(3/2)
Perturbation of Rydberg State Rotational Band.

\[ y = y_0 + B J(J+1) \]

\[ B = 0.2911(6) \text{ cm}^{-1} \]

\[ y_0 = 5.58(2) \text{ cm}^{-1} \]
Perturbation of Rydberg State Rotational Band.

Motivation
Auto-Ionization
Rotation Distribution
Orientation

\begin{align*}
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\end{align*}

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Ablation

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PMT

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Ar(99%) + SF₆(1%)

Hf

F

Hf⁺

LIF Spectroscopy on Rotational Distribution of HfF Photo-ions

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LIF Setup.

Motivation
Auto-Ionization
Rotation Distribution
Orientation

LIF Spectroscopy on Rotational Distribution of HfF Photo-ions
Rotational Distribution of Decay Products.

LIF intensities

- Measure LIF photons from $^1\Pi \rightarrow X^1\Sigma$ of HfF$^+$.  
- A simple model where the Rydberg molecule wavefunction is projected onto decay products.  
- Good agreement, does not assume rotational dynamics.

67.5%$p_{3/2}$, 9.8%$d_{3/2}$, 22.7%$d_{5/2}$

J. Wang, C. Greene, JILA

JILA
Rotational Distribution of Decay Products.

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LIF Setup.

Ar(99%)+SF₆(1%) → Hf

Ablation

Skimmers

Hf F

MCP

PMT

Ionization Lasers + LIF

Hf F

Hf+

PMT

MCP

LIF Spectroscopy on Rotational Distribution of HfF Photo-ions
LIF Setup.

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LIF Spectroscopy on Rotational Distribution of HfF Photo-ions
Orient Molecule With Circularly Polarized Light.

By using circularly polarized for the ionization photons, certain transitions are forbidden.

As a result, we can create a Rydberg molecule with polarized Zeeman levels.
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Orientation results.

- The orientation of the Rydberg molecule is preserved during auto-ionization.
- Simple projection model does not do as well.

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- Rotational Distribution
- Orientation

**Orientation results.**

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Progress Towards State Preparation.

60% of ions in $J = 1$.

50% of ions in $m_J = -1$.

Create 1000 ions per shot, 30% are in the $J = 1$, $m_J = -1$. 
Summary

- We create 300 HfF$^+$ in $X^1\Sigma_0$, $J = 1, m_J = -1$.

Outlook
- Still need to create HfF$^+$ in $^3\Delta_1$ science state.
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Electron Spin Resonance Measurement.