Laboratory observation of forbidden transitions following charge exchange collisions between solar wind ions and neutrals

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Outline

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   - **CX**
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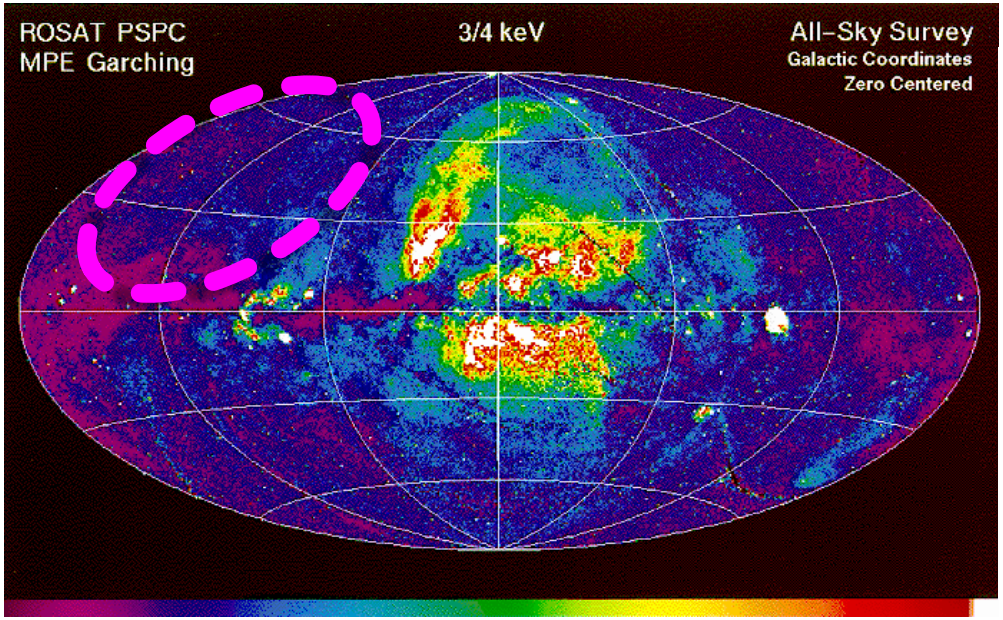
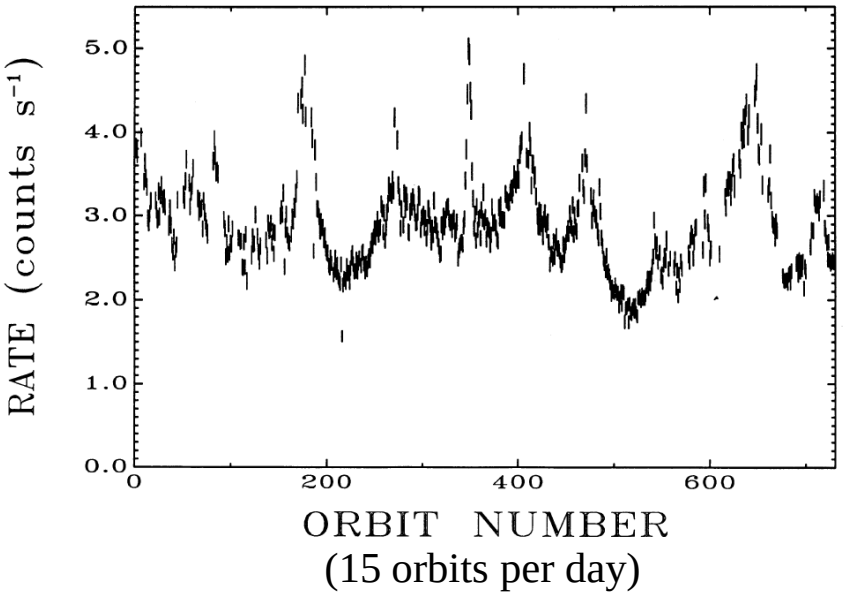
Introduction

Mysterious soft X-ray emission with a varying intensity, repeating in cycles of a few days, was observed.





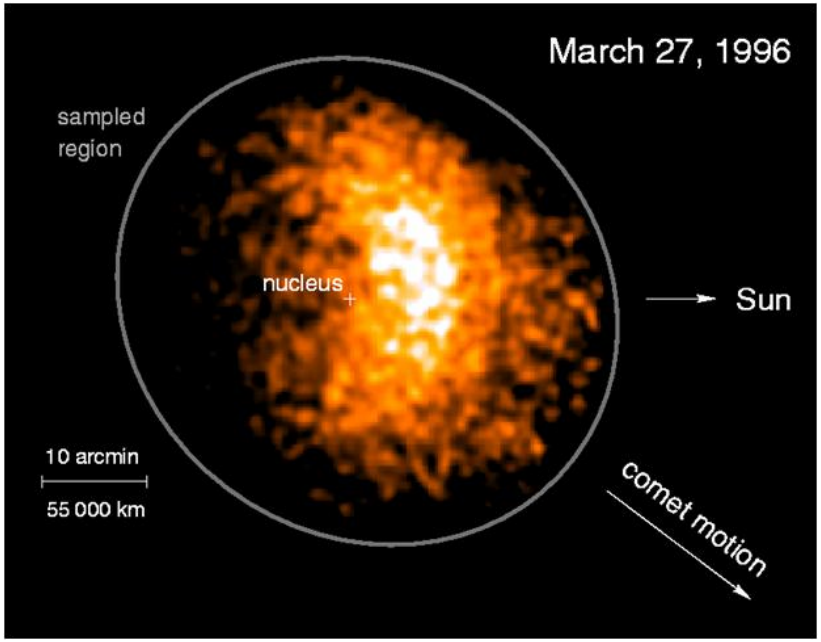
All-sky-map observed by ROSAT

Average all-sky-survey count rate

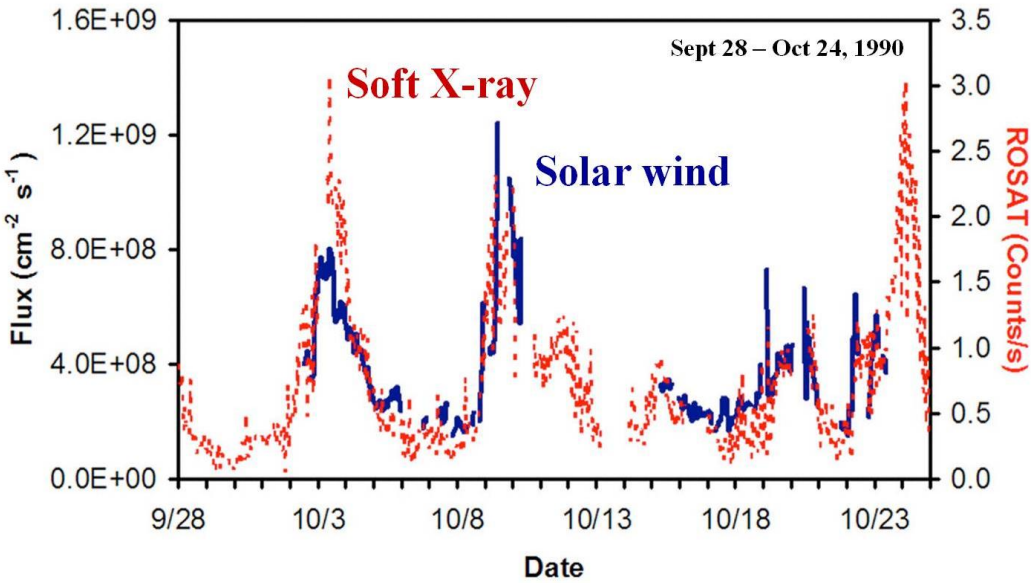
S. L. Snowden *et al*. 1994, 1995

Introduction

Soft X-ray emission from a comet was observed and the intensity fluctuation corresponded to the solar activity.



Emission from the comet Hyakutake
C. M. Lisse *et al*. 1996



Comparison between the X-ray fluctuation and the solar wind proton flux
T. E. Cravens *et al*. 2001

Solar Wind Charge eXchange (SWCX)

Introduction

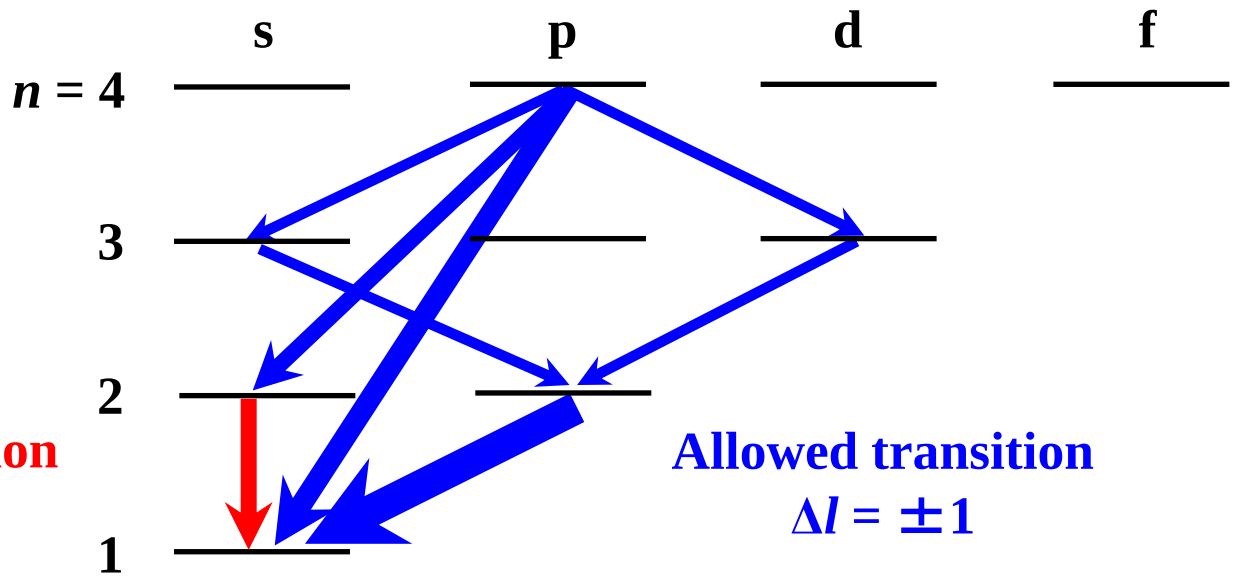
Charge exchange

$$A^{q+} + B \longrightarrow A^{(q-1)+*} + B^{+}$$
$$\downarrow$$
$$A^{(q-1)+} + B^{+} + h\nu$$

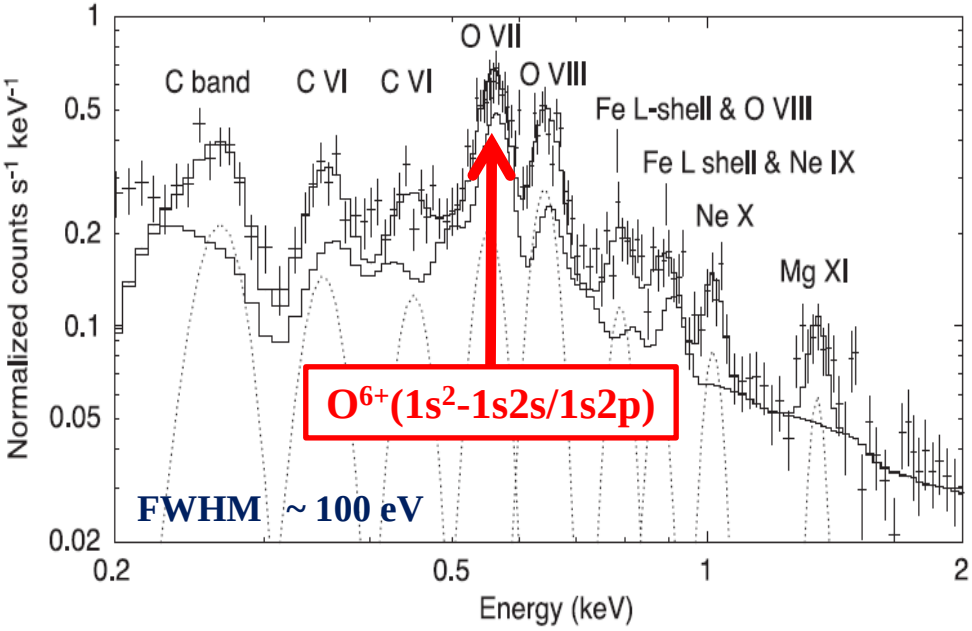
A^{q+} : Ion

B : Neutral

Cascades of transitions

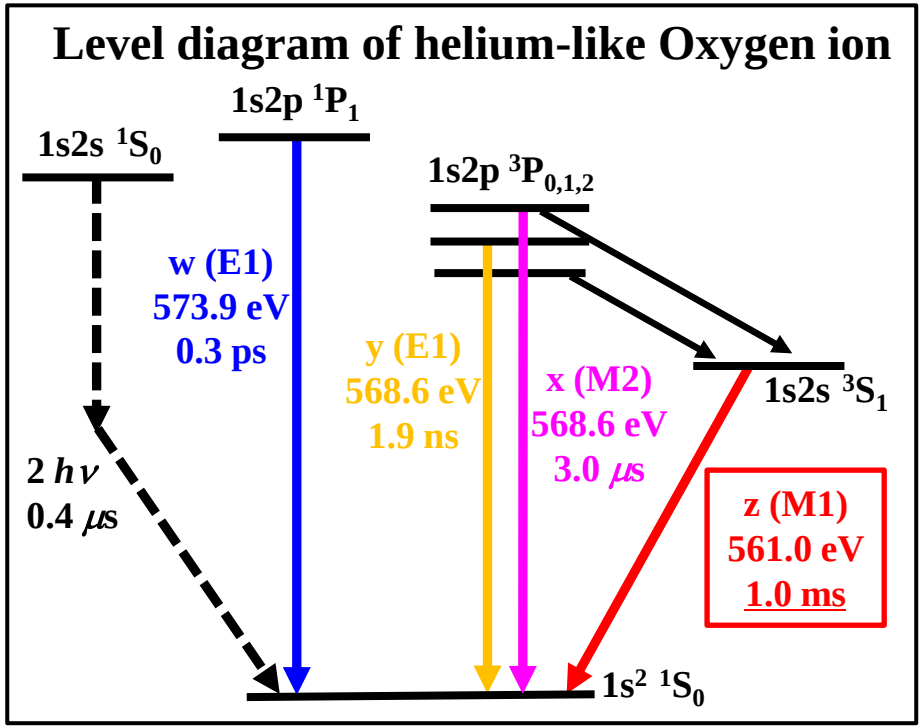


Introduction



Soft X-ray spectrum observed by Suzaku satellite

R. Fujimoto *et al.*, 2007



The long-lived, forbidden transitions in the SWCX had not yet been observed by beam-based experiments in the laboratory.

The ASTRO-H (to be launched on 12 Feb. 2016) can separate the resonance, inter-combination and forbidden lines.

Purpose

- **Reproduction of the observed solar wind charge-exchange with collision energy of 0.2 - 4.2 keV/u in the laboratory**
- **Observation of the long-lived, forbidden transitions following charge exchange collisions with an ion trap**

Collision system in our experiment:

$$O^{7+}(1s) + He \rightarrow O^{6+}(1snl) + He^{+}$$

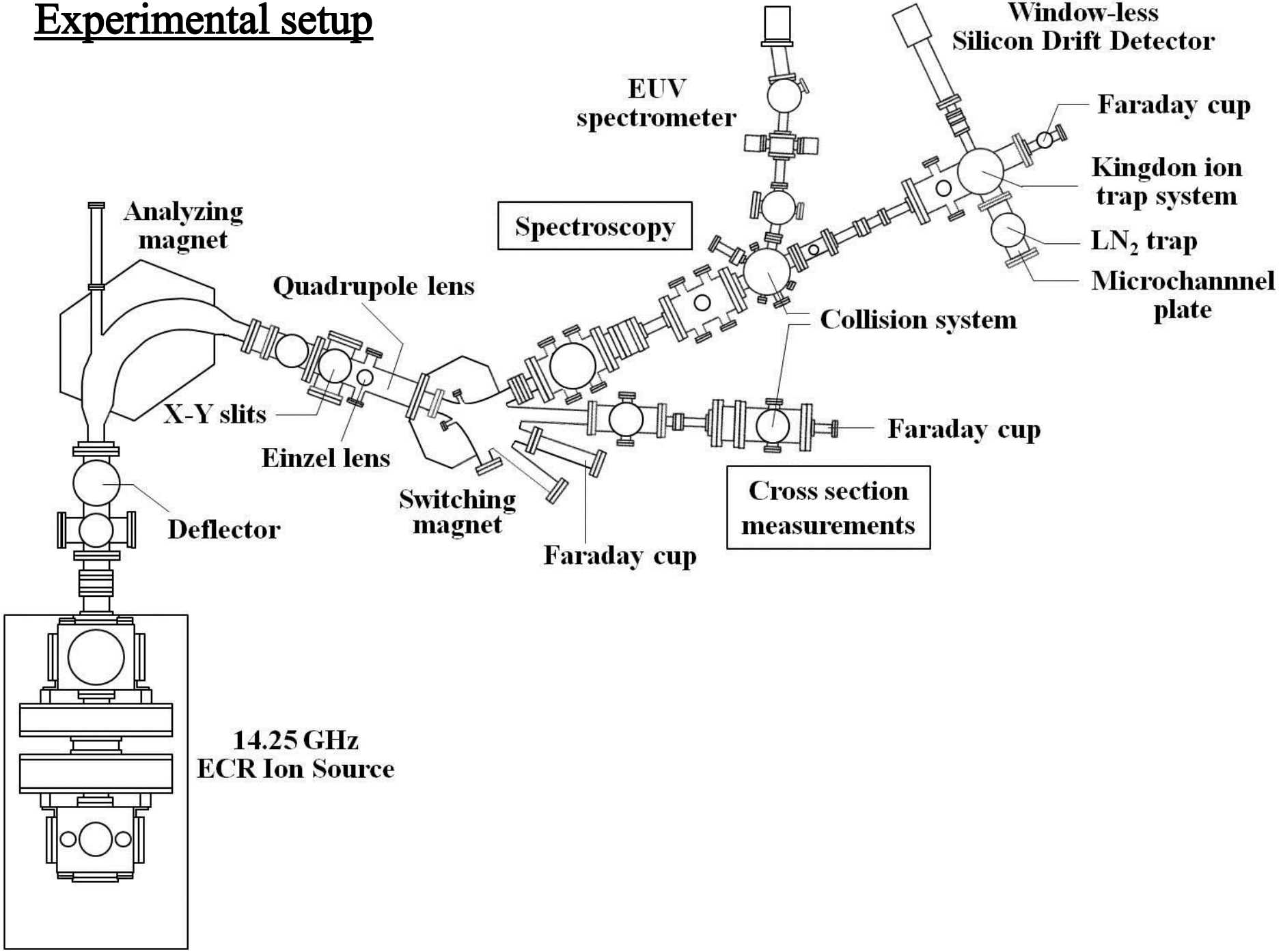
$$\downarrow$$

Ion trapping $O^{6+}(1s2s)$

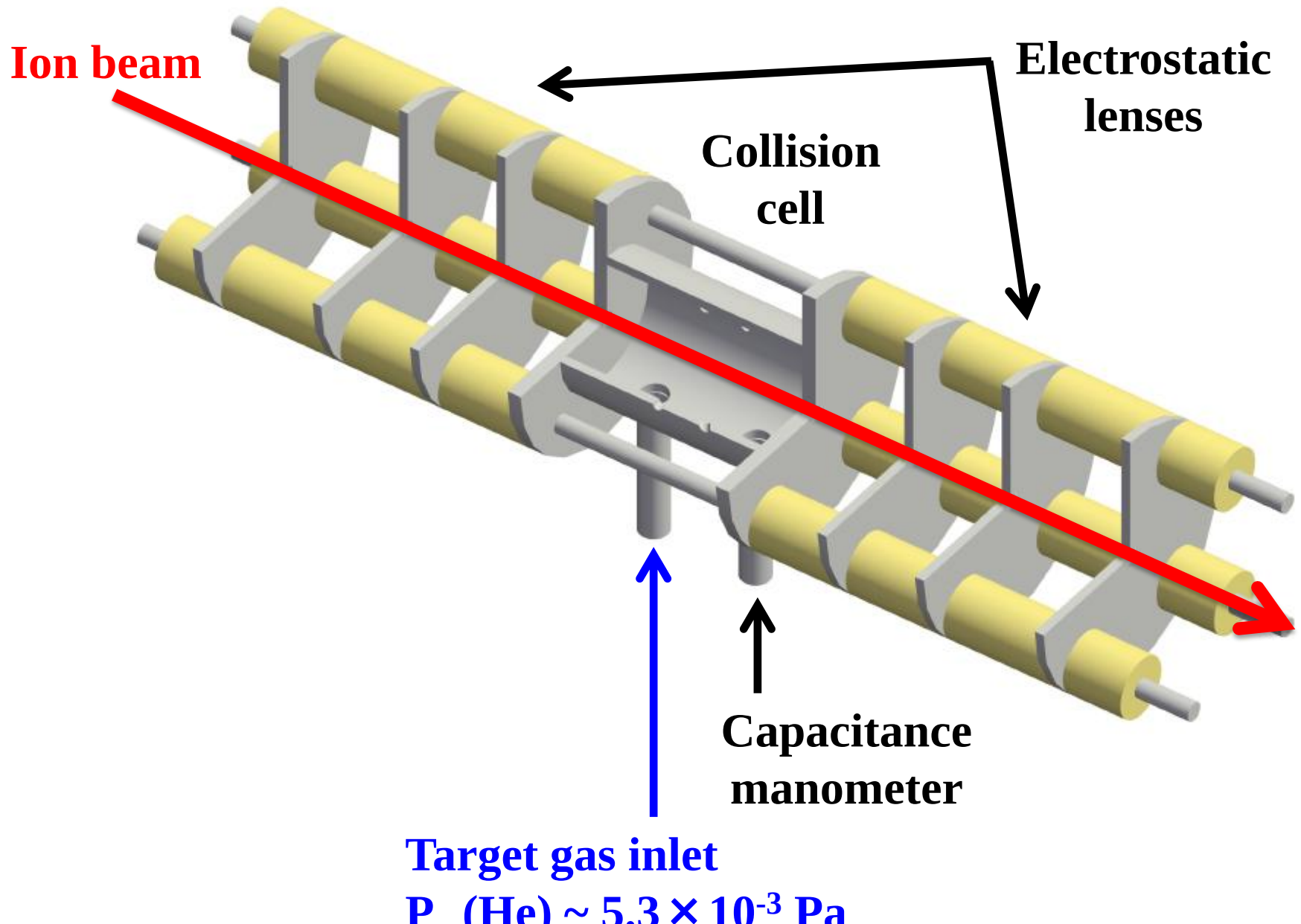
$$\downarrow$$

Soft X-ray observation $O^{6+}(1s^2) + h\nu$

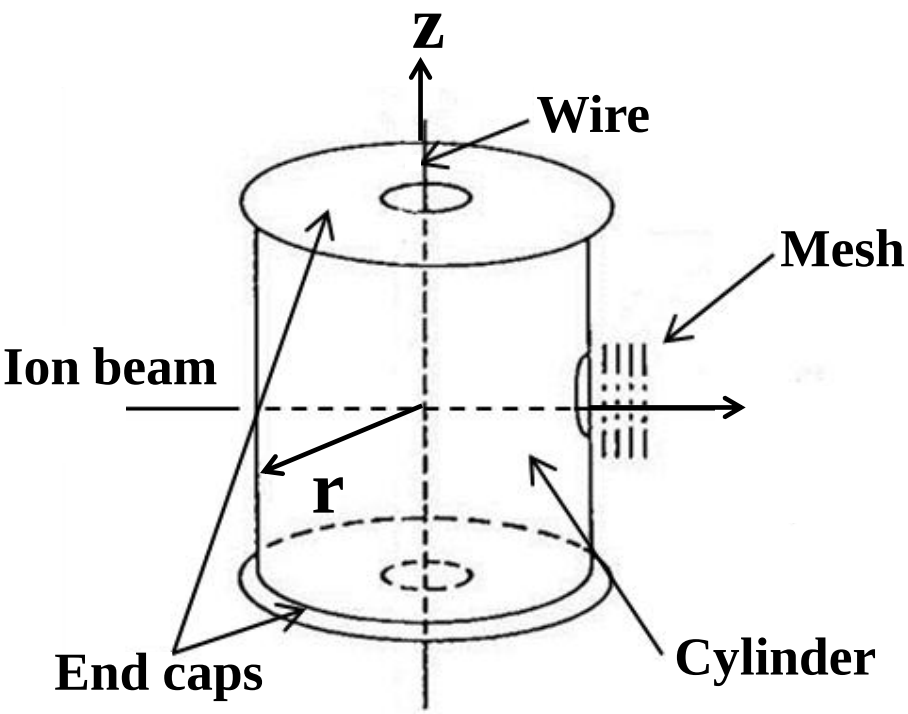
Experimental setup

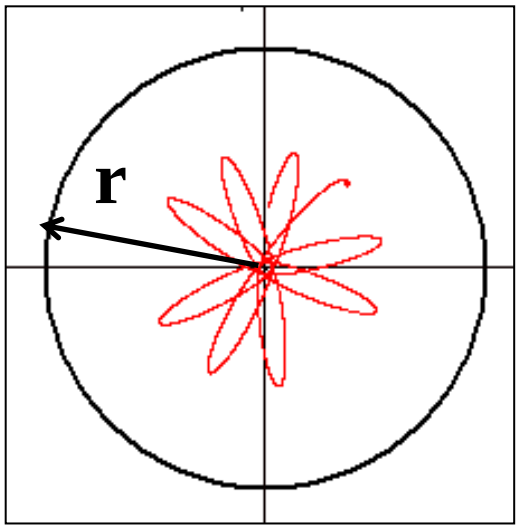


Collision system for spectroscopy



Kingdon ion trap





Motion equation of trapped ion

- **Radial (r direction)**

$$m\frac{d^2r}{dt^2} - \frac{m\dot{\theta}^2}{r} = -qe\frac{dV(r)}{dr}$$

→Logarithmic potential V(r)

- **Axial (z direction)**

$$m\frac{d^2z}{dt^2} = -qe\frac{dV(z)}{dz}$$

→Harmonic potential V(z)

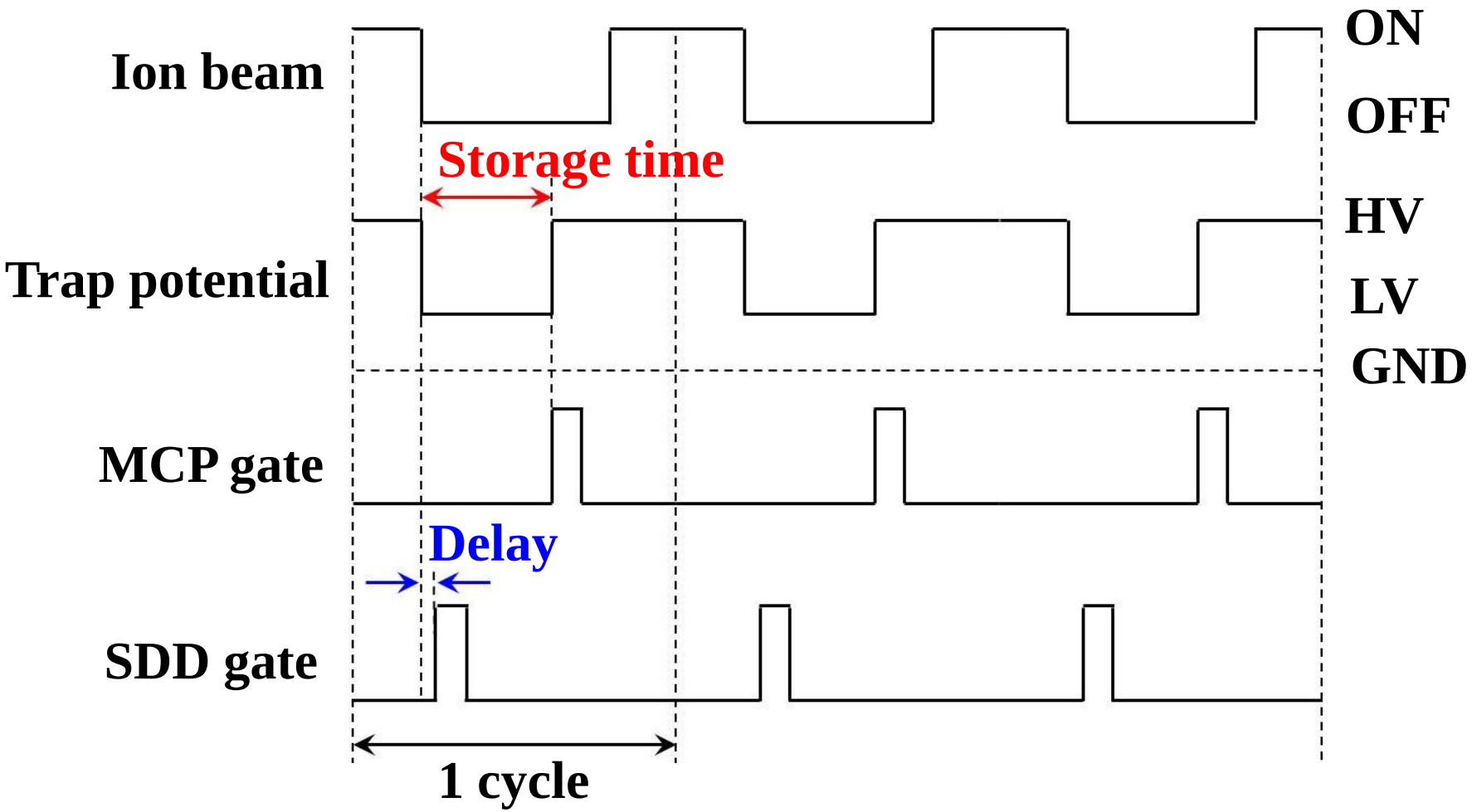
- **Trajectory simulation of trapped ion (view from above the trap)**

Soft X-ray detector

Window-less Silicon Drift Detector (SDD)

- **Detection efficiency: ~ 100 %**
- **FWHM: ~ 80 eV @ ~ 600 eV**
- **Detection area: 10 mm × 10 mm**
- **Peltier cooling**

Timing chart of the ion trapping and the soft X-ray measurements



Results

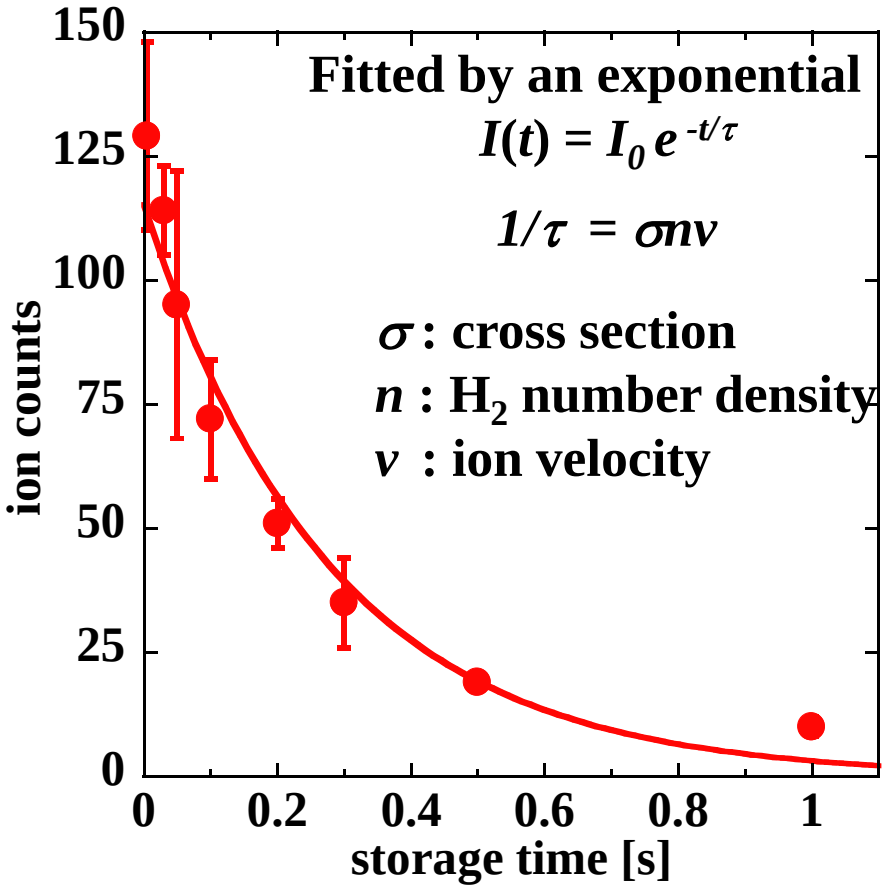
1. Trapping lifetime measurements

2. Observation of the forbidden line

Results of lifetime measurements

Lifetime measurement of O^{6+} ions

H_2 pressure in the trap : 4.4×10^{-7} Pa



$\tau \sim 270$ ms

$v = 4.0(0.4) \times 10^4$ m/s

$E_{cm} = 13.7$ eV

$\sigma = 1.2(0.8) \times 10^{-14}$ cm^2

Reasons for the ion decay in the trap

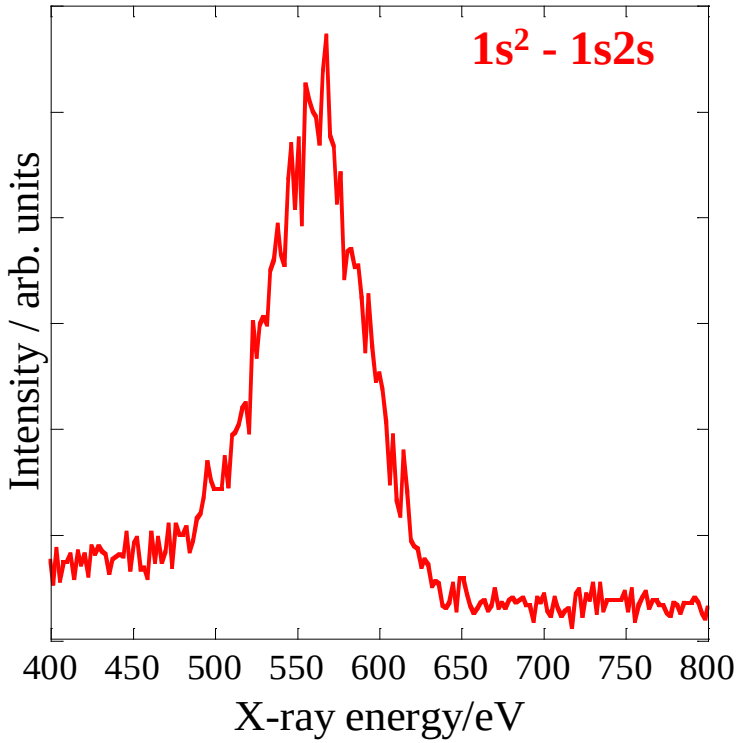
- Charge exchange
- Elastic scattering

Trapping lifetime was long enough to observe the forbidden transition.

$\tau \sim 270$ ms >> 1 ms

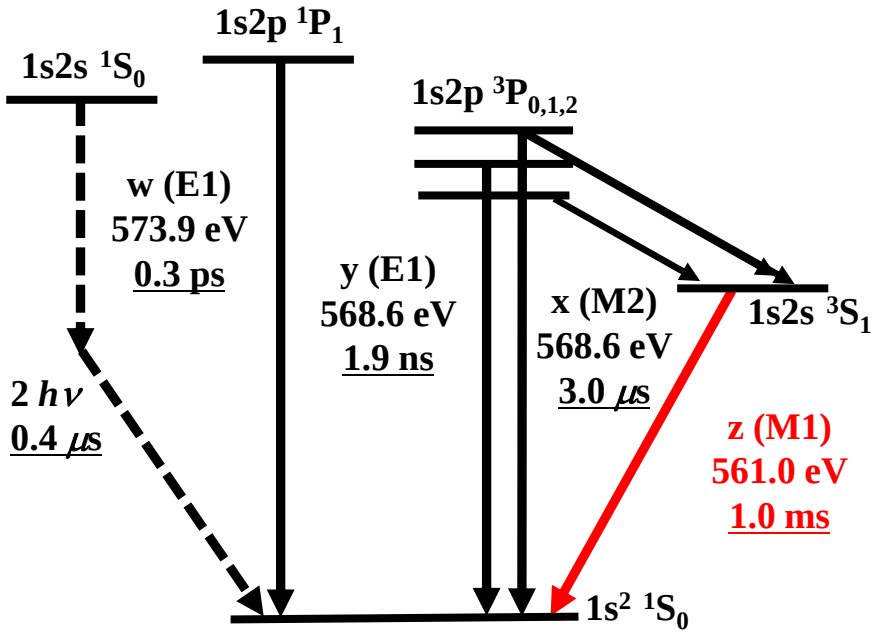
Results of emission measurements

Forbidden line from O^{6+} ions produced by charge exchange of O^{7+} - He system



Collision energy : 2.6 keV/u

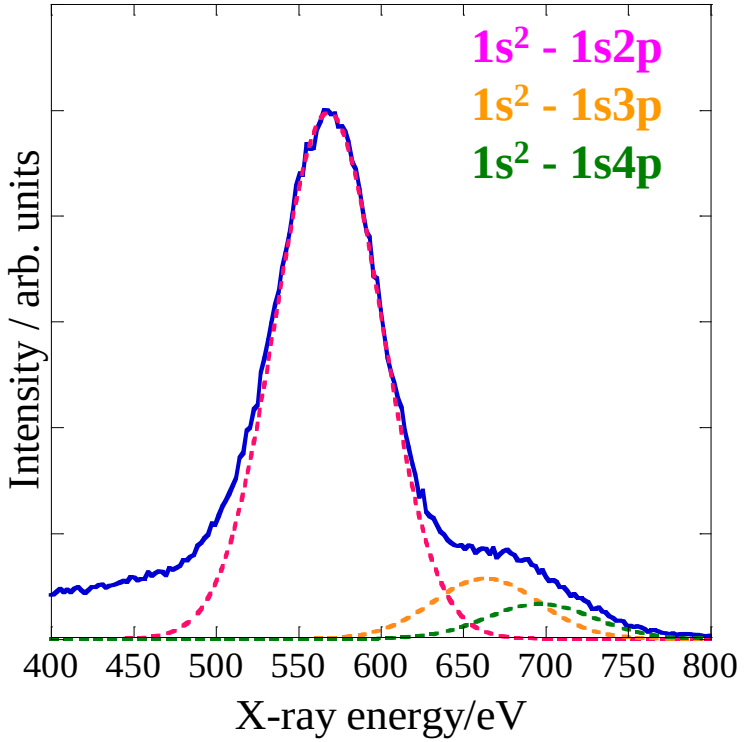
Level diagram of He-like Oxygen ion



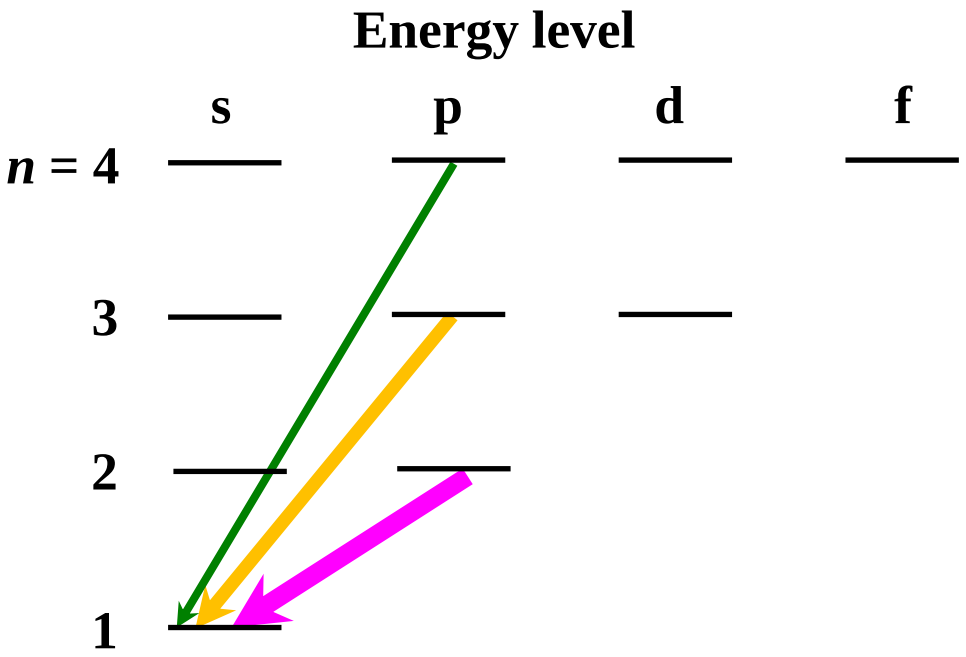
- **Forbidden line from the metastable O^{6+} ions**

Results of emission measurements

Resonance line from O^{6+} ions produced by charge exchange of O^{7+} - H_2 system



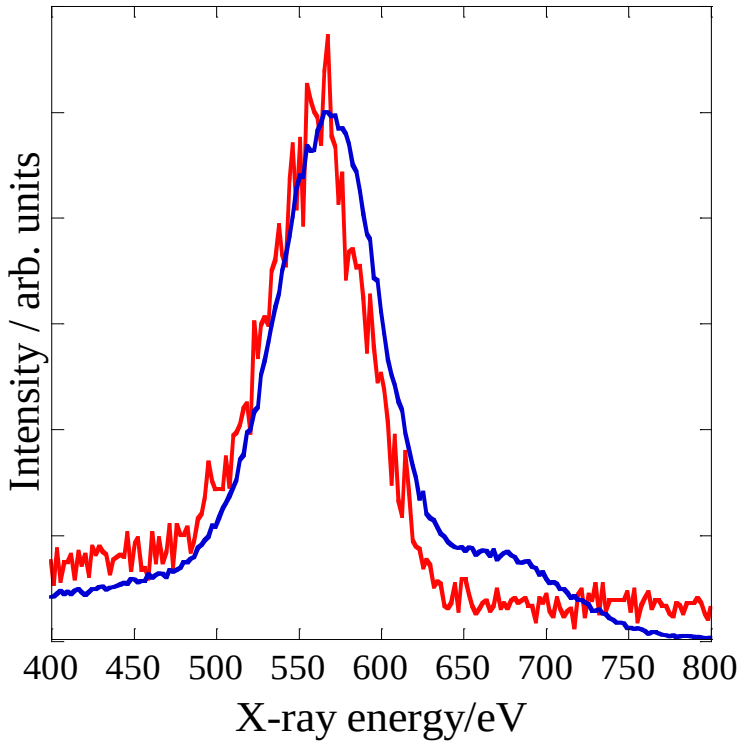
Collision energy : 2.6 keV/u



- **Resonance line from O^{6+} ions**
- **Deconvolution using Gaussian functions**

Results of emission measurements

Comparison of the forbidden and the resonance lines from O^{6+} ions



Forbidden line: $1s^2$ – 1s2s

Resonance lines: $1s^2$ – 1s*n*p (*n* = 1 - 3)

- **Peak positions**

Forbidden line measurement: 560 eV

Resonance line measurement: 570 eV

FWHM: ~ 85 eV

There was a significant difference between their peak positions.

We succeeded in the observation of the forbidden lines in the lab.

Summary

- **We developed the Kingdon ion trap system and achieved much longer trapping lifetime than the forbidden transition lifetime of O^{6+}.**
- **We succeeded in the laboratory observation of the forbidden transition following the SWCX.**

Future plans

- **Observation of other forbidden transitions in C^{4+}, N^{5+} etc.**
- **Perform measurements using a hydrogen atom target**
- **Precise spectroscopy with a soft X-ray spectrometer**
- **Measurements of the absolute values of forbidden emission cross sections**

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IAPCM (Beijing):

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